Market Mechanisms and Incentives: Applications to Environmental Policy

PROCEEDINGS
SESSION ONE

WATER TRADING

A WORKSHOP SPONSORED BY THE US ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS AND NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH

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DISCLAIMER

These proceedings are being distributed in the interest of increasing public understanding and knowledge of the issues at the Workshop and have been prepared independently of the Workshop. Although the proceedings have been funded in part by the United States Environmental Protection Agency under Contract Number 68-W-01-055 to Alpha-Gamma Technologies, Inc., it may not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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Market Methods and Incentives: Applications to Environmental Policy
May 1 and 2, 2003
Wyndham Washington
1400 M Street

Welcome to Market Methods and Incentives: Applications to Environmental Policy.

Five years ago, the National Center for Environmental Economics at EPA joined forces with ORD's National Center for Environmental Research to create the Environmental Policy and Economics Workshop Series. Originally, these workshops were started as a way to show case STAR Grant research to interested EPA and other economists.

Along the way, we realized that these workshops also presented an opportunity to provide policy perspectives to the research community. This model of give and take has proven extremely successful.

Jointly, we have hosted seven workshops on topics ranging from valuing health risks to children and water use and watershed management.

This, the eighth workshop, may prove to be the most exciting and informative one yet. During the next two days, we'll be learning a lot about market methods and incentives, a suite of policy tools that are enjoying renewed interest at EPA.

Market incentives has come a long way since Dales and Pigou first proposed permits and environmental taxes as promising policy instruments. Since the success of the Acid Rain Trading Program, market incentives have enjoyed support from a variety of disciplines and interest groups.

Occasionally, instead of pushing economic instruments, economists now find ourselves pointing out potential down sides and pitfals of incentive systems, particularly poorly designed systems. Transaction and search costs, the tax-interaction effect, spatial issues, so called "second best" conditions, and enforcement concerns all must be considered during their design.

And, we will hear about these issues today.

We'll begin with a session on water quality in which we'll learn about how trading markets have been designed to address water quality in Idaho and stormwater runoff in Ohio, along with an internet tool to bring traders together. Incorporating nonpoint sources into any market is challenging and we will hear about how voluntary incentives such as performance-based contracts may used to address agricultural pollution.

We're fortunate to be able to include Governor Whitman and two Assistant Administrators on our agenda and we'll be hearing from them after the lunch break. Governor Whitman will give a keynote address and Tracy Mehan, and Jeffery Holmstead will participate in a panel discussion on market mechanisms in environmental policy. Governor Whitman will provide her own views about market incentives and specific policy changes she is proposing in this area.

We'll end the day with an exciting session on environmental taxes and the double dividend hypothesis.

Tomorrow we'll start with a session on NOx and SOx. During lunch, Vernon Smith, the most recent recipient of the Nobel Memorial Prize in Economics will discuss Experimental Economics as a Tool for Developing Market-Oriented Environmental Management Programs.

Professor Smith received the Prize from his Majesty Carl 16th Gustaf for "having established laboratory experiments as a tool in empirical economic analysis, especially in the study of alternative market mechanisms."

This will be followed by a session on experimental economics that will present research on auction for reducing nonpoint source pollution and experiments to address compliance in emissions.

The workshop will conclude with a discussion of recently proposed multi-pollutant trading bills.

EPA will be sending you an email when we have posted the papers presented today on the web.

Finally, it takes a great deal of planning, foresight, and collaboration to design and implement a successful workshop like this. I'd like to take this opportunity to specifically thank Peter Pruess, Matt Clark and Will Wheeler of ORD's NCER and Nicole Owens, Kelly Maguire, and Cynthia Morgan from NCEE doing just that.

I'd like to thank you all for coming.

Water Quality Trading: Reinvigorating EPA Policy and Support

Presented to Workshop on

Market Mechanisms and Incentives:

Applications to Environmental Policy

May 1, 2003

Lynda Hall Wynn

EPA Office of Water

Water Quality Trading Policy: Purpose

- Guidance to states and tribes implementing trading programs
- Express clear policy support for trading programs that align with Clean Water Act
- Signal EPA belief that trading can legally occur under CWA
- Provide guidance on *how* trading can occur consistent with CWA
- Identify mechanisms to ease transactions

Water Quality Trading Policy: Contents

- Trading objectives and potential benefits
    - Nonpoint source improvements
- Trading areas –within a watershed
- Pollutants and parameters traded
    - Emphasis on nutrients and sediments, trading of persistent toxics not supported
- When trading may occur
    - With/without TMDL – progress towards or meet WQS
    - High quality waters – preserve water quality

Water Quality Trading Policy: Contents, cont'd

- Alignment of trading with Clean Water Act
  - ➢Consistency with water quality standards including antidegradation; protection of source water
  - ➢Permitting approaches that provide flexibility, preserve enforceability
  - ➢Antibacksliding
- Elements of credible trading programs
  - ➢Units of trade, public access and participation
- EPA role and oversight

Water Quality Trading: Observations

- Trading is powerful where circumstances favor – not a silver bullet for all water quality problems
  - ➢Need to help states, watersheds assess trading potential
- Program design will affect environmental outcomes and economic viability
  - ➢e.g., accounting for uncertainty in performance of nonpoint best management practices

Water Quality Trading: Observations

- Expect variety in types of water quality trading markets
  - ‘Dynamic’ seller-to-buyer, clearinghouses, basin associations with group permits, etc.
  - Models abound; what works in one watershed may or may not work in another
- Trading highly dependent on partnerships at state and local levels

Water Trading: Next Steps for EPA

- Assessment tool for states, watersheds to determine trading potential
- Collaborative work with USDA to improve nonpoint source load estimates
- Make information available on trading program designs
- National Forum on Water Quality Trading

National Forum on Water Quality Trading

- July 22-23, 2003
- Downtown Chicago
- Gain deeper understanding of trading program goals, designs, and on-the-ground implementation
- For info, send email to wynn.lynda@epa.gov

AN INVESTIGATION INTO THE POTENTIAL TO LINK VOLUNTARY INCENTIVE PAYMENTS TO WATER QUALITY PERFORMANCE

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AN INVESTIGATION INTO THE POTENTIAL TO LINK VOLUNTARY INCENTIVE PAYMENTS TO WATER QUALITY PERFORMANCE

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INTRODUCTION

Currently, federal and state agencies use a wide variety of voluntary incentive programs (Conservation Reserve Program, Environmental Quality Incentive Program, Wetland Reserve Program, EPA Section 319, etc.) to attempt to improve water quality by changing farming practices. Since 1996, federal programs have provided over $XXX million per year in cost-share payments for a variety of agricultural pollution abatement programs. That amounts to $X.XX per acre for all farmland in the United States. Funding for these programs over the next 6 years will increase as the 2002 Farm Bill is implemented. Despite the large payments that have already been made, water quality problems persist in agricultural watersheds throughout the United States, and there have been few, if any, documented cases of water quality improvements arising from federal voluntary incentive programs.

Many factors may contribute to the failure of voluntary conservation programs to have measurable impacts on water quality. First, the water quality data used to determine the causes of stream impairments might be incorrect, suggesting that no amount of agricultural pollution abatement will improve quality. Second, despite the relatively large quantity of money spent on water quality, there simply may not be enough money available to have an impact in most watersheds. Third, the funds may not be properly targeted. While aggregate funds may be large enough to solve many water quality problems, institutional pressures to spread the funds out, potentially to high cost-low benefit projects, may limit the effectiveness of programs. Currently only about 20-23% of farmers participate in federal conservation programs. It is entirely possible that the farmers entering the programs are the ones doing the least amount of damage to the water, either because they are already "conservation oriented" or because the funds are directed towards farmers that have small impacts on water quality.

Finally, the structure of current federal programs (and many state programs) may provide little, if any, incentive for individual farmers to carefully select, implement and management best management practices on their farms. There are many economic problems with existing incentives. For example, once a farmer has agreed to enter a program, the program guidelines might encourage the wrong practices for the downstream water quality problem, or the practices might be installed on the wrong farm fields. Often, agencies in charge of implementing programs push for specific types of best management practices, and then simply attempt to recruit whichever farmers they can find to implement them. Lower cost options, however, may be available to farmers to reduce the same pollution outputs from their farms. Alternatively, the contracts rarely, if ever, provide incentives for performance. Most contracts for voluntary agricultural pollution abatement programs pay for technology, but ignore the operation and maintenance of that technology. Without incentives to operate the new technology efficiently, or in a way that reduces pollution, the new technology may have surprisingly small impact on stream quality. Nutrient management plans can certainly help farmers understand their use of nutrients, but providing incentives simply to plan may actually have little impact on the farm operation.

This paper addresses the last issue above by focusing on contracting issues associated with voluntary incentive programs. Currently, incentive payments in most voluntary programs are disconnected from the ultimate goal of the payments – reducing impacts in the water. To address this issue, this paper explores the potential to introduce payments that value performance in terms of water quality improvements in voluntary incentive agreements with farmers. Because performance on individual farms is costly to measure and unlikely in practice, we explore group contracts where individuals in small sub-basins are paid according to outcomes at a single outlet point downstream. Payments are tied to ex post measurements of improvements in water quality, thus giving farmers an incentive to optimize farming practices to reduce pollution outputs and improve stream quality.

Group contracts have been suggested in several different settings for nonpoint source pollution. Segerson (1988), for example, shows how taxes and subsidies can be used to provide nonpoint sources with sufficiently strong subsidies to abate their optimal levels of pollution. Alternatively, tournament contracts have been suggested (i.e., Govindasamy et al., 1994), where pay-offs depend on the relative ranking of one individual's results compared to others on the team (Lazear and Rosen, 1981; Green and Stokey, 1983; and Malcomson, 1986). Both these contracts have seen little application in the regulatory system due in part to potential inequities or inefficiencies. It is also unclear how such contracts may be applied in a voluntary setting where landowners are not obligated to enter into the program. In the voluntary realm, any contracts ultimately used must clear a higher participation constraint than other regulatory approaches.

A recent study by Pushkarskaya (2002) suggests that if farmers have perfect knowledge about each others land quality or production technology, it is possible to design a contract with the proper incentives to reduce pollution for a given subsidy payment. The contract relies on farmer knowledge about nearby farmer's production costs and costs of abatement. In relatively small groups, such knowledge may be entirely possible. Payments for pollution abatement involve two parts, a base payment for the stated abatement, and a payment or loss of payment that depends on relative performance. Farmers who abate more pollution get larger payments, and farmers who abate less pollution get smaller payments.

Passing the hurdle of perfect knowledge about one's neighbor, as suggested in Pushkarskaya (2002) is a strong test to pass. Potentially, however, peer pressure and peer monitoring with less than perfect information could provide enough incentive for individual farmers to meet voluntary, but contractual, obligations to reduce pollution. Take for example the group performance contracts suggested by development economists for individuals who are unable to obtain credit due to risk. To provide collateral, individuals can form groups whose members are willing to share the risk of failure. If any member of the group defaults, other members have to repay that individual's share of the debt, or the entire group loses access to future refinancing. As shown by Stiglitz (1990) and Varian (1990), the key issue for such contracts is peer monitoring, which provides incentives for individuals to repay loans even if they do not have collateral.

Peer monitoring and peer pressure may be strong allies in voluntary incentive agreements with farmers when farmers have some, but not all, information about their neighbor's production practices. Armendariz de Aghion (1999) demonstrates that collective credit agreements can induce peer monitoring, reduce the incidence of strategic default, and enhance the lender's ability to have debts repaid. Prescott (1997) further suggests that borrowers who know a lot about each other, such as those who live in close proximity or socialize in the same circles, are the most promising candidates for group lending, and are better able to apply social pressure on potential defaulters. This seems a promising avenue for nonpoint source pollution, where groups of farmers within a small drainage area or linked to a common tile drainage main, could pledge to work together to reduce pollution at their common outlet in exchange for payments.

Shifting towards performance based contracts with groups of farmers would involve substantially new incentive structures compared to the existing voluntary programs. To engage farmers in contracts that tie their payments to ex post observations of improvements in water quality, where the improvements depend on their neighbors output is a non-trivial change. First, it is unclear whether farmers have enough knowledge about the pollution production process, i.e. how farm practices relate to water quality in streams, to make informed decisions about changes in management that would reduce pollution at the common outlet point. Second, it is unclear if farmers believe they have sufficient information to monitor each other effectively. Finally, it is unclear if they would be willing to do it. For this paper, we present the results of a series of focus groups that address these questions.

This paper is organized as follows. The second section discusses the design of the focus groups and the specific group contract that was proposed to farmers in the focus groups. The third section then describes the results obtained from analyzing the responses of farmers to specific focus group questions. Within the focus groups, farmers were engaged in a simulated bidding game to assess their willingness to enter into the group contracts. Although we do not have enough data points to entirely assess the different components of the contract, several interesting insights emerged from the bidding results, and from the subsequent discussion. The final section is our discussion and conclusion.

FOCUS GROUP CONDUCT

The focus groups explored the three general questions discussed in the introduction: (1) Can farmers determine the practices that could be used to reduce run-off and the costs of these practices? (2) Do farmers know enough about the other farmers in their watershed to engage in peer monitoring within small sub-watersheds? (3) Would they participate in voluntary agreements that include performance criteria based on ex post observations of water quality at a common outlet point downstream? The focus groups were all conducted by a moderator external to the researchers. A series of specific questions designed to elicit responses in the three areas described above were provided to the moderator, who lead the group through a discussion that was captured on video- and audio-tape, and subsequently transcribed.

The general flow in each of the focus groups included an introductory section to familiarize participants with terminology, and to engage them in a discussion about water quality in their region. Participants were then introduced to a scenario that asked them to treat nitrogen run-off as a commodity. The scenario allowed us to engage the participants in a discussion of the types of practices they may use to reduce nitrogen run-off and whether they could estimate the costs of these reductions. The final section of the focus group introduced a simulated group contract that allowed the participants to voluntarily bid on their pollution abatement, to observe the outcome, and in two focus groups, to make the same decisions a second time. A very specific contract was proposed for the participants and their responses to the contract were recorded.

For the simulation, participating farmers were shown a hypothetical watershed with 10 farms draining to a common point downstream. They were told that the town downstream was experiencing water quality problems that affected their drinking water, and the town was willing to pay farmers to reduce nitrogen loadings at the intake point (downstream from all of the farmers). Since the loadings could only be observed in aggregate at intake point, the town proposed a contract that paid farmers only if they performed on the contract. The following bidding procedure was used to determine if farmers were willing to enter the contract (Taylor, 2003).

Each participant in the focus group was given a card with private information about their own hypothetical farming operation. The card showed the costs per ton for installing specific practices to abate nutrient loadings downstream and the total tons they could reduce. They were told these costs included all direct expenditures and/or reductions in profits that would arise from abating specific levels of nutrients. The abatement practices used in the simulation were drawn from those commonly adopted by Ohio farmers, and the marginal costs of abatement were based on actual implementation costs for Ohio farmers. The practices included, forested buffer strips, grass buffer strips, and reductions in nitrogen applications. While the costs that each farmer observed on their individual cost cards was a constant marginal cost function, marginal costs varied across individual farmers, ranging from \$500 to \$1,2500 per ton of nitrogen reduced.

Participants were then instructed to submit bids to the town for nutrient reductions. The bids were to be for an individual quantity of nitrogen abatement and a corresponding cost to be reimbursed for the abatement. While the participants were given costs for their potential abatement activities, they were told they could submit bids that would allow for profits. Farmers were further instructed not to share their cost or bid information with their neighbors (i.e. others in the room). Upon receiving the bids, the town would contract with the lowest-cost bidders to produce a given level of nitrogen reduction as a group. In each case, a specific level of total abatement was mentioned as the target the town hoped to attain. The contract specified that if the *actual*, monitored level of reductions in nitrogen loadings at the end of the season is greater than or equal to the amount bid by the group, each farmer is paid his/her own bid price. If the monitored level is less than the group bid level, all farmers will receive zero payment.

To determine the actual level of loading reductions, farmers were asked to submit a sheet of paper describing the amount they would actually abate. These amounts were submitted privately, and collected in a way that did not allow farmers to know who, if anyone, had cheated. Farmers could thus “profit” if they submitted levels lower than they initially bid. Random weather shocks were introduced by using a roll of a six-sided die. A roll of one or two resulted in a 20% decrease in the sum of individual abatement levels. A roll of three or four had no effect on the sum of individual abatement levels. A roll of five or six resulted in a 20% increase in the sum of individual abatement levels. In this way, there was an equal probability of bad, average, and good weather, respectively, in terms of abatement performance.

The entire simulation was described to participants in advance, while they had their cost cards handy. Once the simulation was described, participants were asked to decide if they would like to bid into the system. All bids were collected and tallied for the participants. Any bids that include prices that exceed the town's maximum willingness to pay were rejected. The bids were ranked by cost per ton, and the lowest cost bidders willing to provide the target (which depended on the size of the focus group). Any bidders not included in this group were left out of the contract. If the targeted reduction was not bid into the game, all bids below the town's maximum cost were accepted, and the new target was set equal to the sum of the quantity of individual nitrogen reductions bid.

The farmers included in the contract were then asked to commit to their nitrogen reduction levels by recording the amount of abatement they would actually do on a blank slip of paper and dropping that in a hat. The sum of each individual's effort constitutes the group reduction of nitrogen without weather effects. The dice was rolled to determine weather effects, and abatement levels bid by group members were compared to actual abatement levels. After conducting some discussion, the simulation was repeated in two of the focus groups.

Focus Group Participants

The Ohio State University Survey Research Center recruited the focus group participants with phone interviews. Names and phone numbers were obtained from several sources, including the individuals in Ohio with pesticide application licenses and individuals with a subscription to *Ohio Farmer* magazine. These two lists were combined, and the duplicates were eliminated. Phone numbers were double checked where possible through phone books obtained in the Internet.

There were two general criteria for participating in the focus groups. First, we were interested in recruiting a set of individuals with certain characteristics. We thus screened individuals to find those farmers who (1) Characterized themselves as agricultural producers; (2) Shared in the decision-making authority on their farms; (3) Had never held political office; (4) Owned more than 100 acres of cropland; and (5) Obtained more than 75% of their annual household income from farming activities. The first three criteria were used specifically to screen a number of individuals out of the sample of names used for selection. Within each focus group, we also tried to recruit individuals with both majority crop and majority livestock operations, and both male and female operators. Although we were unsuccessful recruiting any female operators, two farmers brought their wives to the final focus group and we allowed these individuals to participate in the focus group.

Second, we were interested in recruiting individuals who had a high likelihood of knowing each other directly, or at least knowing of each other. We thus employed sampling that targeted specific zip codes with the hope of attracting individuals who lived relatively close to each other, but who fit the personal characteristics discussed above. As a result, the four focus groups conducted involved farmers from four different watersheds in Ohio: Big Walnut Creek (Delaware and Morrow counties); Bokes Creek

(Union and Logan counties); Paint and Darby Creeks (Madison County); Stillwater River (Darke and Miami counties).

For recruitment, individuals who did not fit the criteria listed above were thanked for their time and never told about the focus groups. The remaining individuals were asked to participate in the specific focus group for their region. Individuals were told they would get a $60 honorarium and travel expenses for their participation. Phone calls were made approximately 1 week in advance of each focus group. A letter thanking the individuals for their participation and directions were sent to the individuals who agreed to participate. Follow-up phone calls for individuals who agreed to participate were made the day before the focus group.

In general, this recruitment procedure yielded the desired number of participants (approximately 10 per focus group), with relatively high levels of participation once individuals were recruited (see table 1). The one exception was the Madison county focus group which yielded lower overall participation. It is unclear what the reason for the low participation was, although we note that the day on which this focus group occurred was one of the few good days that week with relatively cold weather and sunny skies.

The broad characteristics of the farmers who participated in the focus groups are shown in tables 2a and 2b. The participants generally were more than 50 years of age, planted more than 500 acres of land in crops, and owned nearly half the land they planted. Most of the farmers identified themselves as primarily row crop operators, although several farmers were primarily livestock operators. The main crops grown were corn and soybeans, however, a number of farmers also grew other crops. Most of the livestock operators had cattle operations, although one of them had a large hog operation and one had a small poultry operation. Average receipts did vary slightly across the groups. The first two groups had average receipts exceeding $100,000 per year, while focus group 3 appeared to have relatively less income and focus group 4 had relatively higher income. The operators in general, however, obtained a large proportion of their income from farming and not off-farm sources.

On the conservation questions in table 2b, the results indicate that the participants have relatively low knowledge of the TMDL process and relatively few of them currently participate in conservation programs provided by state or federal governments. The most used program is not surprisingly the Conservation Reserve Program. Although not shown in the table, a small number of the participants are enrolled in 2 or more programs (less than 10%). Very few of the participants indicate that they have enrolled in programs that require permanent conservation easements on their property. Approximately 20 – 25 % of the participants did indicate that they participate in watershed group activities.

When comparing the information from the participants to all of the individuals contacted to participate, as well as the US Census for the counties in which the focus groups were located, the samples are quite similar. T-tests across participants and respondents to the phone survey indicate that on nearly all of the questions, the individuals who participated are a random sample of those who passed the initial screening questions. Further, t-tests across the different samples indicate that they are strikingly consistent, although some differences emerge, as shown in table 2. For further description of the statistical tests of the samples drawn for this survey, please contact the authors.

FOCUS GROUP ANALYSIS AND RESULTS

The focus groups provided several key insights into how farmers reacted to the questions discussed in the introduction. In addition, the simulation results provide information on whether farmers would participate in voluntary agreements tied to ex post measures of pollution reductions, and how farmers handle performance and weather uncertainty when they must bear the risk. To analyze the results, the focus group transcripts were first carefully read, and used to develop 16 categories to classify the responses. The transcripts were then carefully analyzed, and each statement was coded into one (or sometimes more) of these specific categories, such as “abatement practices”, “performance of practices”, “effects of weather on performance,” etc. The analysis of focus groups was conducted by three individuals separately and then the responses were compared and disagreements discussed. The transcripts were then loaded in software that allowed us to analyze the responses for content.

Perhaps the most important question faced by group performance contracts is the assumption that farmers, not regulators or conservation employees, are most suited determine how to most efficiently reduce pollution on their farms. The questioning in the focus groups explored this idea directly by asking participants in each of the four focus groups specifically how they would go about reducing nitrogen effluents from their farms. For each focus group, we listed the potential ideas mentioned by farmers for reducing nitrogen, and then compared the lists across focus groups. Table 3 presents the suggested methods and the number of focus groups in which the idea was mentioned. Filter strips, multiple or split applications of nitrogen, and incorporating manure immediately after it was applied were suggested in each of the focus groups. These practices are particularly consistent with guidance provided by many of the recommendations for reducing nitrogen effluents suggested in Ohio by OSU Extension. In addition to the three issues that were raised in four focus groups, tile management and soil testing were suggested in three groups.

Notably, most of the practices suggested by farmers focus on human resource management on the farms, rather than the installation of new technology. Most of these unfortunately, cannot be considered in existing conservation programs that focus on purchasing new technology rather than employing different practices with old or new technology. It is worth noting that farmers in one of the focus groups also mentioned the potential that companies could develop new seeds with altered nutrient requirements, which could potentially reduce the necessity for applying nitrogen fertilizers.

These results suggest that farmers are fairly well versed at the potential types of changes in management that would be required to reduce nitrogen pollution entering streams. To further assess farmer attitudes, their responses to several selected questions or issues were coded as positive, negative, or neutral, and summed (Table 4). The first three questions in table 4 provide more detail on whether farmers believe they could engage in the voluntary program with performance standards. To do so, they would need to understand the practices, estimate the costs of adopting the practices, and estimate the effect of adoption on downstream water quality. In general, farmers were strongly positive about estimating the costs of adopting new practices. In several instances, farmers mentioned that they did not know the costs specifically, but they could find the information by talking with their local extension agents or crop consultants.

The second question assessed whether farmers could estimate the nitrogen reduction in the stream associated with adopting these alternative practices. This question generated a substantial discussion in each of the focus groups, as evidenced by the total comment column. Only 29% of the comments were positive, suggesting that farmers are much less certain about the loading reductions than the costs. However, only 35% of the comments were negative, i.e. indicating that they could not under any circumstances measure loading reductions. A fairly large proportion of the comments were neutral. In part, the large number of neutral comments relates to our interpretation of neutral for this question. In a number of cases, farmers were clear that they did not know the effects of current practices on downstream water quality, nor did they know how changes in practices would alter these impacts, but they believed they could learn about this over time with experimentation. These were interpreted as neutral comments for the purposes of this study.

The issue of flexibility was raised as well in the focus groups because many farmers were believed to have experience with previous government programs that address adoption of single practices across large areas of land (i.e. CRP, WRP). Recent examples include attempts to educate farmers about reduced tillage practices, and the buffer strip program initiated during the Clinton Presidency. Farmers were fairly adamant, as evidenced by 93% of comments being positive, that flexibility would enhance the likely success of the nitrogen reduction problem proposed in this focus group.

Farmers were then asked specifically if they could cooperate with other farmers to reduce pollution, if they believed that shirking would be a problem, and whether peer monitoring would work (see Table 4). These questions were asked prior to running the simulation. Unfortunately, we did not follow these questions up after the simulations due to time constraints in each of the focus groups, although it would have been informative to assess whether attitudes changed during the focus groups. In general, farmers in the focus groups believed they could cooperate with other farmers. In all of the focus groups, at least one of the participants recognized that some members of their community would never cooperate at the level required for reducing nitrogen effluents as proposed here. A large proportion of the comments, however was positive that they could cooperate to solve a specific problem such as outlined in our focus groups.

Farmers were also surprisingly adamant that shirking would not be a problem, with 54% responding negatively to the question about shirking. It was surprising to the researchers that this did not seem to be that big of a deal to the participants, and the question actually generated fairly little conversation (35 comments) relative to some of the other comments. Farmers were also somewhat hesitant about the applicability of peer monitoring, with 38% of the responses suggesting agreement that peer monitoring could work, and 53% of the responses suggesting it could not. This question generated the most conversation overall, and, interestingly, farmers seemed the most clear about their positions, with a relatively small proportion of neutral responses.

Throughout the focus groups, an underlying current in all of the discussions was potential increase in risk farmers would face with performance based voluntary programs. While many policy makers view risk simply as weather risk or technology failure risk, participants in the focus groups also recognized the importance of performance uncertainty, i.e. the possibility that their neighbors will not do what they said they would do and consequently they will not meet the target and get paid. While we did not specifically ask farmers which risk factor (weather, technology, or performance) would be the most difficult to address, the conversation provides some indication about how important they would be. Table 5 presents a summary of the number of comments from farmers aimed at addressing specific sources of risk.

Weather risk was clearly viewed as an important risk farmers would face with a performance based system, however, farmers were aware of both to technology and performance risk. In many instances, discussions on technology risk addressed mainly the use of the proper technology rather than the potential that the technology fails. In other words, farmers would count as a risk factor a program that specifies for them technologies to use, whether or not those technologies will reduce pollution downstream. Farmers appear to worry less about technology failure. Many of the comments on performance risk indicated that farmers recognize that managing practices after they are installed have an important influence upon their performance for downstream water quality.

Table 6 presents the results of the simulated bidding experience conducted in each focus group. In two of the focus groups, 2 and 4, the simulation was repeated. A number of interesting results emerged from the simulations. First, it's notable that some farmers did not participate at all in the experiments, choosing instead to observe. The non-bidders were in general concerned about the game and concerned about getting involved in the contract. Interestingly, throughout the focus groups, discussion about participation often began negatively, for example with comments like this from the first focus group: "*We stood to lose a whole lot more than we ever stood to win. And there's enough gambling in farming now*." After this comment, two others suggested that they had simply played the game for the fun of it. One of the participants, however, stated

> "*…you aren't taking this interview seriously. Somebody isn't, maybe not you as the interviewer, but somebody somewhere is taking this very seriously…So the realistic part of it is even though this is a game, and we had a choice, he didn't represent his real choice. Did you? Did everyone around the table, I would like to know truthfully….*"

He managed to get three "yes" responses before the conversation turned to methods the bidders used to figure out their bids.

Across the focus groups, the most common response for non-bidding was skepticism about the game. Interestingly, despite "bad" weather in the first round of the game in the second focus group, the same number of individual participated the second time. In the fourth focus group, a small number of individuals participated the first round, but participation doubled for the second round. One contributing factor likely was the success of meeting the target observed in the first round, and another reason given was that they understood the simulation better.

Second, despite suggesting that shirking would not be problematic (i.e. Table 4), at least one farmer shirked in the first round of the game in each focus group except the third. In each case, participants in the game were asked to reveal if they shirked and why. In the first focus group, shirking appeared to result from some confusion about how the game was played and in particular how to make a bid in the first place. In the second focus group, two individual shirked in the first round because they were uncertain that they could actually accomplish what they had bid. In the second round, one person shirked, and one person actually abated additional nitrogen. The farmer who abated additional nitrogen suggested that his rationale was that he was already installing filter strips, and he felt he could use them more effectively at low cost to accomplish more nitrogen reduction. In the fourth focus group, one individual shirked in the first round because he did not believe that the program was actually going to work. A typical response for individuals who did not do what they said they would do was "*Well, I figured I couldn't accomplish what I had, I just feared it wouldn't work out*."

When faced with evidence that some individuals are likely to shirk, individual responses to the potential for shirking varied widely among the participants. On the one hand, individuals in all of the focus groups clearly recognized the difficulties they would face working as a team and relying on others. For example, one participant in the fourth focus group noted:

> *"But it's based on a group. It's not based on individual. And that creates the problem as I see it. Because if it's based on a group, it's no different than having 9 ball payers on a softball or baseball team. If they don't all work together, we*

> *are going to lose games. If we all work as a team, we are going to maybe be – we are going to definitely be more successful than if we worked individually."*

When asked directly if they could work together, a common response followed along the lines of one of the respondents in focus group four: "*... I can't get the guy down the stream from me to fix his. It's hurting him and it's hurting me. So I can't even talk him into it for him to make more money, let alone help me sustain my income.*" The focus group responses displayed a clear concern among farmers with contracts that would rely on their neighbors to perform.

Despite the skepticism of a number of the participants, there was an equally vocal group of individuals in each of the focus groups proposing that cooperation was the only way they would be able to solve a pollution problem downstream:

> *"The only way it could be done is… this watershed would have to, everybody would have to get together and if they could get five or seven of them together and you would have to draw up rules and regulations…And it's possible, just to be quite honest with the factory farms coming in… Maybe this table should sit and think about that. Trying to work together. Not that we have to agree on everything, but maybe we can find some common ground."*

The participants thus appear to be fairly confident they could cooperate with other farmers, and that if farmers committed to specific practices, they would make good on their commitments (Table 4). For a number of participants, this is consistent with their actual strategies, when they produced less than they bid for fairly benign reasons, i.e. they made mistakes. Their responses, however, were highly dependent on the terminology used to introduce the idea of cooperation. When asked if they could "control" their neighbor's actions, the participants had strong negative reactions. For instance, a participant in focus group one noted "*we don't have control, we don't want to control the neighbors*." Immediately following that comment the moderator shifted to ask a slightly different question, namely, if there was anything the farmers could do help insure their neighbors cooperation. The responses were substantially moderated, i.e. "*work with them. Let them help you and you help them*", and "*show them that it will work.*" There was clear concern with the idea that one person could control their neighbor, but participants appeared comfortable with positively working with their neighbors to meet the target.

One difficulty in making an overall assessment about how farmers viewed cooperation was that the comments focused on two issues, whether they could convince other farmers to cooperate in order to participate in the group contract, and also whether they could get farmers to meet their commitments once they were engaged in the contract. The participants verbal responses focused most directly on the first issue, i.e. whether they could get other farmers to participate in the first place. For the most part, participants believed strongly that once farmers understood the program, and were committed to it, they would fulfill their obligations. They tended to dismiss the notion that farmers would not meet their obligations once contracted. This is supported by the results from the second round of the simulation in each case produced actual abatement at levels greater than targeted abatement.

From a policy perspective, the problems noted by the farmers in the focus groups can potentially be addressed by changing the contract. For example, the first problem associated with getting a group to cooperate initially can potentially be addressed by changing the payout schedule, such as by introducing a positive initial payment, with annual payments each year the target is met. Although this might induce some shirking and thus reduce efficiency, it is possible that the resulting group contract would regain much of the efficiency by introducing peer monitoring. The simulation results provide some evidence that farmers will meet their commitments if they understand the contract they are signing.

The problem of what to do it is discovered that the target is not met was clearly something about which participants were concerned. On the one hand, a number of participants felt that they could determine who was failing to meet their commitments and likely they could determine why. For example, one individual in the second focus group suggested "*between that [referring to an earlier comment about tracking nitrogen use] and sampling the property lines, I think you could probably figure out what's going on.*" However, as noted in some of the comments earlier, there was clear concern about how the problems would be handled once they were discovered. In designing actual policies, it might be possible to have contracts that last multiple years, with targets that becoming increasingly stringent. This would provide landowners time to adjust and learn about the effects of their practices on water quality downstream, and also to get help from other farmers, particularly with the introduction of new technology.

SUMMARY AND CONCLUSIONS

This paper explores the potential to use group-contracts to introduce water quality performance standards into cost-share programs. Group contracts engage small groups of farmers in the production of pollution abatement in small sub-watersheds. Individual determine their levels of pollution abatement and their cost requirements. However, individual payments are only provided if water quality targets are met. The water quality targets depend on how the entire group of farmers perform in their abatement. This introduces the problem of writing a contract that gives individual farmers incentives to perform pollution abatement even if their individual performance cannot be measured.

To assess the potential for group performance contracts to work with agricultural producers, we engaged farmers in a series of focus groups. The focus groups were designed to elicit their responses to a specific group performance contract. The focus groups were conducted with individuals drawn from specific watersheds within the State of Ohio in order to obtain participant pools with individuals who had a high likelihood of knowing each other. Only individuals who were primarily employed as farmers were involved in the focus groups.

The results of the focus groups suggest that farmers are very comfortable estimating their costs of different practices, but had less familiarity and confidence with estimating the impact of those practices on water quality downstream. With the proper incentives, however, farmers recognized that they could learn how their practices affect downstream water quality over time. Thus, contracts that involved multiple time periods with additional flexibility in early periods would be preferred by the farmers.

The participants were clear that individuals farmers are best suited to choose which practices will be most effective on their land for reducing pollution downstream, although they recognized the need for outside help from extension agents or crop consultants. A contract that allowed flexibility (i.e., did not dictate a specific nutrient reduction practice to be used) would be more effective and cost efficient. This type of contract would differ dramatically from most existing cost-share programs. Rather than providing incentives for any individual in a wide area who is willing to install a particular practice, the contracts suggested in this paper would focus payments on a smaller area and allow flexibility in the choice of practice. Participants recognized that the trade-off for gaining this flexibility would be that they could lose money if they did not meet their targeted pollution reduction (i.e. they would expend money for installing the practices, but receive no payments in return if the target is not met). Contracts that provided a default payments greater than $0 would be more likely to gain farmer involvement.

Participants felt that ensuring cooperation within the group would not be a problem if they all agreed on the goal and the contract, and in particular if they understood the contract. They would feel comfortable working as a team to achieve the goal, as long as they did not have to be responsible for “telling-on” a neighbor, or policing their neighbors. An important conclusion from the discussion was that the participants appeared to be more confident that the target would met if they were able to select the group themselves. They placed a high premium on finding ways to ensure cooperation from the outset of a performance based system, either by selecting the appropriate watersheds for the contract or by selecting the appropriate farmers within a watershed with which to work.

Several substantive suggestions emerged for designing the group contracts. These include allowing a default payment greater than zero and tying only part of the payment to performance. For example, performance based contracts could start with an initial payment to get started, with remaining payments for performance when the group meets specific targets. In addition, the participants suggested that contracts should be multi-year (i.e., at least 5 years). In this context, an initial payment could be made the first year, followed by annual pay-outs in years when the target is met. To allow farmers to learn how changes in their practices affect water quality, payments in the first one or two years could be more flexible than in later years.

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Table 1: Recruitment and attendance data from four focus groups.

Focus Group	Phone Calls	Recruited	Attended
(1) Morrow/Delaware (Jan. 22)	130	12	9
(2) Union/Logan (Feb 26)	123	13	13
(3) Madison (Feb. 28)	103	8	5
(4) Darke/Miami (March 5)	184	14	10
Total	540	47	37

Table 2a: Average responses from focus group participants, farm-type questions:

	FG1	FG2	FG3	FG4
Age?	57	50	50	53
How many acres of farmland did you plant last year?	1053	989	529	624
Of these, how many acres of farmland are owned by you or your family?	574	557	296	323
Primarily (more than 50%) a row-crop or livestock operation? (1) = row-crop;(2) = livestock.	1.17	1.08	1.00	1.14
Which of the following crops did you produce last year? (1) = Yes; (2) = No				
Corn? .	1	1.1	1.25	1.00
Soybeans?	1	1.0	1.00	1.00
Oilseeds?	1.8	1.8	1.63	1.83
Wheat?	1.4	1.3	1.38	1.58
Other crops (specify)?	1.7	1.8	1.75	1.75
Did you raise livestock last year as well? (1) = Yes; (2) = No	--	1.7	1.63	1.75
What is the total number of cattle that you presently own?	0	148	45	65
How many hogs do you own?	500	3	0	0
How many sheep do you own?	0	0	0	12
How many poultry-type animals do you own?	0	10	170	0
Total annual gross sales from farming operation, including government payments.	>100,000	>100,000	100,000	500,000
Percentage of total annual household income derived from agricultural production?	81.17	81	67	73

Table 2b: Average responses from focus group participants continued, Conservation Questions:

	FG1	FG2	FG3	FG4
Have you ever heard of the Total Maximum Daily Load Initiative in the State of Ohio? (1) = Yes; (2) = No	1.67	1.67	1.88	1.86
Do you believe the Total Maximum daily load Initiative will affect the ability of agricultural producers in Ohio to make a profit? (1) = Yes; (2) = No	1	1	2	1
Payments from federal or state conservation programs? (1) = Yes; (2) = No				
Conservation Reserve Program (CRP)?	1.83	1.77	1.88	1.86
Wetland Reserve Program (WRP)?	2	2	2	2
Environmental Quality Incentive Program (EQIP)?	1.92	2	2	2
Ohio EPA Section 319 Funds?	2	2	2	2
Or, other conservation programs (specify)	1.83	1.77	1.88	1.93
Easements on your land precluding future development? (1) = Yes; (2) = No	--	2	1.88	2
Do you participate in any local watershed group activities? (1) = Yes; (2) = No	1.75	1.92	1.75	1.79

Table 3: Practices suggested by farmers and number of focus groups in which the practice was discussed

Practice	**Number of Groups where Discussed**
Install filter strips	4
Multiple or split application of nitrogen/Side-dress (multiple applications during the growing season)	4
Incorporate nitrogen immediately upon application, in particular when applying manure nutrients	4
Tile Management (i.e. plugging tiles and drains periodically)	3
Soil testing to optimize nitrogen application rates	3
Reduce nitrogen application	2
Change rotations to include none nitrogen intensive crops.	2
Change type of fertilizer used/Use a stabilizer	1

Table 4: Summary of Positive and Negative Responses to Selected Questions

	Summary Results - Proportions			Total (+, -, N)
	+	-	N	
Is it feasible to estimate costs of these practices?	0.77	0.15	0.08	13
Is it feasible to estimate the loading reduction provided by adopting these practices?	0.29	0.35	0.35	51
Would you prefer a program that provided flexibility to choose among these options to a program that targeted a specific option?	0.93	0.00	0.08	40
Could you cooperate with other farmers to reduce nitrogen at the common outlet point?	0.63	0.24	0.12	49
Would shirking be a problem for the type of contract proposed in this focus group?	0.29	0.54	0.17	35
Would peer monitoring work?	0.38	0.53	0.09	78
Do you agree with the zero fixed payment in the contract proposed in the simulation?	0.46	0.54	0.00	26

Table 5: Number of comments in each focus group aimed at addressing a specific type of risk associated with reducing nitrogen loadings.

	FG1	FG2	FG3	FG4
Performance Risk	5	4	7	7
Technology Risk	10	3	15	7
Weather Risk	12	7	5	11

Table 6: Simulation Results.

FG	Game	Entries (Farmers)	Average Bid (Range)	Target	A*	Realized A*
1	1	6 (8)	$3,086 (1500- 2600)	22	19	15.2
2	1	7(10)	$1,098 (500 - 2000)	25	22	17.6
2	2	7(10)	$1,285 (500 - 2000)	20	22	**26.4**
3	1	4(5)	$1,319 (1000 - 1450)	13	13	10.4
4	1	3(8)	$1580 (1200 - 1850)	10	9.5	**11.4**
4	2	6(8)	$1834 (1500 - 2000)	23	25.8	**25.8**

Target = target level of abatement bid into the game and accepted.
A* = Abatement effort stated by farmers after the bidding round.
Realized A* = Abatement effort corrected for weather effects (roll of the dice)
Bold numbers indicate instances where the target was met.

Can the Acid Rain Program's Cap and Trade Approach Be Applied to Water Quality Trading?

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EPA's documented success with trading sulfur dioxide emissions under the Acid Rain Program has inspired EPA and others to attempt to translate that approach to address other important environmental programs. The announcement of the EPA Water Quality Trading Policy on January 13, 2003[2] is the most recent example of the appeal of market-based approaches to address environmental problems at less cost. While EPA and several states had previously attempted similar approaches to address water quality issues prior to the successful air emissions trading example spotlighted by the Acid Rain Program[3], their record in achieving the potential cost savings has not been as remarkable. Much of this divergence in economic results should be attributed to the circumstances of working with water pollution rather than air pollution, and working in a watershed rather than an air shed. The fundamental differences of these two pollution media require many of the important elements of a trading program to be addressed very differently. However, there are still many important elements that appear to be key to much of the success of the Acid Rain Program's sulfur dioxide emissions trading – which may be instrumental to the success of any pollutant trading approach – and therefore should be kept in the forefront of designing a water quality trading program. Idaho's Lower Boise River water quality trading framework is an important example of how this can be done.

Design Factors Contributing to the Success of the Acid Rain Program's Trading System

Under the Acid Rain Program, sulfur dioxide emissions from the electric utility industry are limited to 8.95 million tons under a fixed "cap" (while phased in over several years it will be in full effect by year 2010). Utilities are allocated their share of emissions through an allocation of allowances that add up to the tonnage amount of the cap. This approach to trading has since been termed the "cap and trade" model to distinguish it from other approaches that do not use a cap to

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[2] See http://www.epa.gov/owow/watershed/trading/tradingpolicy.html Water quality trading is the same thing as "effluent trading" or "water pollution trading," but is the term formally adopted by EPA under its Water Quality Trading Policy issued January 23, 2003.

[3] The first water quality trading project is usually considered to be the Tar - Pamlico River Basin in North Carolina, with its first implementation strategy involving trading approved in 1989 and revised in 1992.

limit the quantity of allowances or credits traded, and therefore do not limit the total quantity of pollution traded. Under the cap and trade approach, allowances represent an authorization to emit a certain quantity of a pollutant, usually during a designated time period, so the total amount of pollution emitted by the set of sources included in the program is tightly controlled. Each source can capitalize on its own compliance strategy through selling its surplus allowances, or reduce its compliance costs by purchasing allowances from another source that was able to make the reductions more cheaply. Under the Acid Rain Program, an allowance is an authorization to emit a ton of SO_2 in a designated year or any year thereafter, which means they can be saved or "banked" for use in a later year. During the annual reconciliation process, an allowance is deducted from the source's account to cover each ton of SO_2 emitted over the course of the year. Automatic financial penalties and allowance deductions from the next year's account are triggered if the source does not hold enough allowances to offset its emissions at the end of the year.

As explained on the Acid Rain Program's website, the program is designed to accomplish three primary objectives:

> " 1. Achieve environmental benefits through reductions in $S0_2$ and NO_x emissions.
> 2. Facilitate active trading of allowances and use of other compliance options to minimize compliance costs, maximize economic efficiency, and permit strong economic growth.
> 3. Promote pollution prevention and energy efficient strategies and technologies.
>
> Each individual component fulfills a vital function in the larger program:
>
> - the allowance trading system creates low-cost rules of exchange that minimize government intrusion and make allowance trading a viable compliance strategy for reducing SO_2
> - the opt-in program allows nonaffected industrial and small utility units to participate in allowance trading
> - the NO_x emissions reduction rule sets new NO_x emissions standards for existing coal-fired utility boilers and allows emissions averaging to reduce costs
> - the permitting process affords sources maximum flexibility in selecting the most cost-effective approach to reducing emissions
> - the continuous emission monitoring (CEM) requirements provide credible accounting of emissions to ensure the integrity of the market-based allowance system and to verify the achievement of the reduction goals
> - the excess emissions provision provides incentives to ensure self-enforcement, greatly reducing the need for government intervention
> - the appeals procedures allow the regulated community to appeal decisions with which it may disagree
>
> Together these measures ensure the achievement of environmental benefits at the least cost to society."[4]

Some of the elements that have made the Acid Rain Program so successful are attributable to the

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[4] EPA's Clean Air Markets Division website: http://www.epa.gov/airmarkets/arp/overview.html#princips

authorizing legislation that established it as a program and also to the nature of the problem it was addressing. Title IV of the 1990 Clean Air Act Amendments provided a clear statutory mandate for trading and specified the type and geographic set of sources to which it applied. It also states that the Acid Rain Program does not replace or supercede the enforcement of other air programs; rather, its intended purpose is to address an emissions "total loadings" or quantity problem, which it does through a stringent enforcement of the emissions cap. The cap (when it is in full effect in 2010) represents a 50% reduction in overall emissions from 1980 levels.

The significant emissions reduction enforced by the cap also reduces the likelihood of new "hot spots," or areas of localized impacts from an increase in emissions, from being created. This is because the utilities' individual allowance allocations are not enough to cover their levels of emissions from before the program. Since all fossil-fuel fired utilities are required to be in this program, they quickly learned that the compliance strategy of purchasing allowances to offset their sulfur dioxide emissions is usually more expensive and less financially attractive than other compliance strategies that involve emissions reductions. Therefore, the chances of any single source or set of sources in a particular area increasing their emissions from their levels prior to the Acid Rain Program, are lessened considerably.[5] Furthermore, while many interpret the Acid Rain Program's allowance requirement as removing direct regulatory control over the potential for local hot spots, in fact, the required installation of Continuous Emissions Monitors (CEMs) provide more precise emissions data than had been available previously to help enforce the ambient air quality standards.

Both the public's and the market's confidence in sulfur dioxide allowances as a tradable commodity and as the "currency of compliance" is important in order for the allowance to retain its value in the marketplace. This confidence is largely established by the CEMs, which monitor the sources' emissions more accurately and consistently than ever before, so that there is more certainty as to how much is actually being emitted. Buyers and sellers, as well as the public, are assured that no emissions will escape undetected and allowances accurately represent the specific amount of authorized emissions. Adding to the public's and the market's trust in the commodity is the provision for automatic penalties to kick in when a utility fails to hold enough allowances in its account to cover its reported emissions at the end of the year. With the awareness that fines will be imposed swiftly and at a level severe enough to deter violations, market participants can be confident that utility sources will always use allowances to cover their emissions - *i.e.,* that allowances are in fact a valued "currency."

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[5] In fact, the Acid Rain Program's compliance reports from 2000 and 2001 indicate that total SO^2 emissions have decreased significantly since the program took effect and major reductions appeared at the state-level as well. "In 2001 Title IV sources achieved a 33% reduction from 1990 SO_2 levels nationwide. SO_2 emissions in Texas did increase in Phase I; however, SO_2 emissions in the state decreased in Phase II when the Acid Rain Program requirements took effect for Texas sources. Although most SO_2 emissions still occur in the Midwestern U.S., it is important to note that, over time, this same region has also seen the most significant decrease in SO_2 emissions in the country. The highest SO_2 emitting states in the 1990 (Ohio, Indiana, and Pennsylvania), reduced emissions 40% in 2001 (49%, 47% and 22%, respectively) compared to 1990 levels. Other states in the region show similar trends since 1990. SO_2 emissions decreased 59% in Illinois, 41% in Kentucky, 70% in Missouri, 55% in Tennessee, and 49% in West Virginia." http://www.epa.gov/airmarkets/cmprpt/arp01/2001report.pdf

Another important element contributing to the success of the Acid Rain Program's trading system is the provision in the utility's permit that authorizes it to engage in trading. The permit sets the amount of allowances the utility unit holds at any given moment as its SO_2 emissions limit for the purpose of compliance with the Acid Rain Program. The utility unit's initial allowance allocation serves as its starting point, but the limit can be adjusted through buying and selling allowances, without requiring approval on individual trades once the permit is issued. The permit's "pre-approval" of trades is supported by the existence of the cap to address the larger environmental problem, the stringency of the continuous emissions monitoring requirement, and the implementation of the state and federal ambient standards to prevent any adverse impacts locally. The emission limits set under other air programs' permits for state or federal ambient standards essentially determine how much the utility is authorized to emit because the Acid Rain Program only requires the utility to hold enough allowances to offset its emissions reported at the end of the year.

Lastly, while the Acid Rain Program applies specifically to the electric utility industry as the largest source of sulfur dioxide emissions, it also allows for industrial sources of SO_2 emissions to voluntarily join the program. In this sense, the perception by some of the "cap and trade" approach as being overly rigid and restricted to a set of specified sources is not valid. The "opt-in" feature of the program allows for other sources to join if they can prove themselves to be similar enough to the affected sources; in turn, they receive an allocation of allowances that are not included in the cap established for the utilities. An industrial source might choose to opt in if it determines that it could achieve SO_2 reductions at less cost than the utility sources. As part of the "opt-in" requirements, an industrial source choosing to participate in the program must comply with the elements that are required of the utility sources, including installing the continuous emissions monitors and receiving an allocation based on a formula applied to a comparable set of years for determining its historical heat input levels and applicable allowed emissions factor. Although they are not part of the allowances in the cap, the opt-in sources' allocated allowances are indistinguishable from the others for the purposes of trading. In this sense, the cap is being expanded to include a voluntary subset of another set of sources of the same pollutant, and in the same broadly defined air shed, because they are also contributors to the Acid Rain problem.[6]

Can the Cap and Trade Model be Applied to Water Quality Trading Under a Total Maximum Daily Load (TMDL)?

Some may question why water quality trading should be modeled after a successful cap and trade model developed for air pollution. Despite the differences between air pollution and water

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[6] In 2001, there were 11 opt-in units that were allocated 99,188 allowances. These represented only 1% of the 9,553,657 total allowances allocated for the year, and 0.05% of the 19,933,611 allowances available for use in 2001. *Acid Rain Program Annual Progress Report, 2001,* page 7. http://www.epa.gov/airmarkets/cmprpt/arp01/2001report.pdf However, it is debatable whether the opt-in program has been effective in achieving additional reductions at less cost. See Montero, Juan-Pablo, "Voluntary compliance with market-based environmental policy: Evidence from the Acid Rain Program," *Journal of Political Economy* (October 1999) Vol. 107, No, 5 pp. 998-1033.

pollution in defining the tradable commodity, the careful design of the trading program's structure can have a significant impact on how well it accomplishes the environmental and economic objectives it is intended to achieve. In their article titled "The Structure and Practice of Water-Quality Trading Markets" the authors Richard T. Woodward, Ronald Keiser, and Aaron-Marie Wicks[7] examine the structures of markets formed in many of the water quality trading programs across the country. They determine that legal constraints and physical characteristics play a major role in determining the design of the trading program, and that decisions in such areas as how trades will be authorized, monitored and enforced also play a major role in determining what market structure will ultimately form. They conclude that the market structures can be categorized into four main types: exchanges, bilateral negotiations, clearinghouses, and sole-source offsets.[8]

While the Acid Rain Program's SO_2 market has evolved to form the "exchange," supporting the most dynamic level of trading, most water quality trading markets will likely result in one of two forms, bilateral negotiations or sole-source offsets, which achieve most environmental goals but do not fulfill the amount of cost savings that would have been possible under an exchange type of market structure. Yet, as the authors point out, the potentially low volume of water quality trading may never justify the infrastructure needed to foster an exchange type of market structure. However, it should also be argued that the goal of achieving as much of cost savings as possible from water quality trading should not be abandoned. The trading system design has a direct impact on the amount of cost savings that can be achieved, and therefore should be established with that in mind. Even a water quality trading system supporting bi-lateral negotiations can be designed to maximize the administrative efficiency of the trading process and therefore improve its ability to achieve cost savings for all participants.

Decisions concerning the trading system design intended to provide more certainty of environmental outcomes will influence whether or not the market structure is able to provide sufficiently low transaction costs to the program's participants and low administrative costs to the regulatory agency, to achieve its cost savings goal. Even though the market structure for most pollutant trading programs may never match the "exchange" level at the far end of the scale, it is worth identifying the design elements of the Acid Rain Program's cap and trade model that

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[7] Woodward, Richard T., Kaiser, Ronald A., and Wicks, Aaron-Marie, "The Structure and Practice of Water Quality Trading Markets," *Journal of the American Water Resources Association*, (August 2002): 967-979. http://ageco.tamu.edu/faculty/woodward/paps/#Working

[8] In their article, the authors state that an exchange, at one end of the spectrum, is "characterized by its open information structure and fluid transactions between buyers and sellers," while bilateral negotiations require "substantial interaction between buyer and seller to exchange information and negotiate the terms of trade." Clearinghouses link buyers and sellers through an intermediary, such as a retailer who purchases credits from many sources and bundles them together, selling them at a uniform price. Sole-source offsets, on the other hand, may not require any other trading party, but instead can take the form of a trade conducted within a source's own means, or "when a source is allowed to meet a water quality standard at one point if pollution is reduced elsewhere, either on-site or by carrying out pollution reduction activities offsite." *Ibid.*

support the achievement of such impressive cost savings.[9] How these elements may be applied to the design of a water quality trading program should be considered as well.

Many studies have been conducted on how to apply the success of the Acid Rain Program's cap and trade approach to other air quality problems. In their paper "To Trade or Not to Trade? Criteria for Applying Cap and Trade,"[10] the authors Stephanie Benkovic and Joseph Kruger highlight many important questions to consider in deciding whether to apply the cap and trade approach to a particular air quality problem. While they did not extend their analysis to address environmental concerns beyond air pollution, many of the criteria they cite are relevant to determining whether the cap and trade approach should be applied to the design of a water quality trading program for a particular watershed. One of the most important is to determine if the environmental problem can be addressed with such a flexible approach, in which the exact levels of discharge will not be controlled directly but influenced by market forces. For some toxic pollutants, trading has the potential to create adverse local health or ecosystem-related impacts in an area immediately surrounding a facility. They state that "allowing such a facility to buy allowances from other facilities may not fully address the risks caused by its emissions. In fact, it may make a situation worse by causing a 'hot spot' - *i.e.*, an unacceptably higher accumulation of the pollutant in a specific geographic area. Such a case may necessitate controlling all facilities emitting the substance at a certain level, negating the flexibility inherent in an emissions trading program." That is the most important factor to consider in determining whether or not to apply a trading program to achieve any environmental goal, whether it concerns air quality or water quality. Benkovic and Kruger go on to say that "[i]n general, the more a pollutant is uniformly mixed over a larger geographic area, the more appropriate it is for the use of cap and trade."

The remainder of Benkovic and Kruger's article describes other factors to consider in applying the cap and trade approach, and suggest some design features to address conditions that are similar to those occurring in water quality trading. In applying the cap and trade approach to water quality, however, there are also several challenging differences that prevent direct application of some of the design elements they cite, as well as those inherent in the success of the Acid Rain Program's trading system. Instead, it will require an attempt to implement the underlying principle or goal of that element. Among the fundamental differences are those that arise between addressing typically large air sheds versus comparatively smaller watersheds, air pollution versus water pollution, and the differences between the Clean Air Act and the Clean Water Act in regulating identified sources that contribute to a specific pollution problem. The implications of these and other differences are too numerous and complex to discuss here, but a subset of these will be identified in the remainder of the paper as they pertain to differences in approaching the design of similar cap and trade style trading system to achieve water quality

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[9] As stated on the Acid Rain Program's website, "The General Accounting Office recently confirmed the benefits of this approach, projecting that the allowance trading system could save as much as $3 billion per year -- over 50% -- compared with a command and control approach typical of previous environmental protection programs." http://www.epa.gov/airmarkets/arp/overview.html –"A Model Program"

[10] Benkovic, Stephanie and Kruger, Joseph, "To Trade or Not to Trade? Criteria for Applying Cap and Trade," *The Scientific World*, (2001) 1 Also available on the web at http://www.epa.gov/airmarkets/articles/index.html

goals.

Of primary importance in its suitability to a cap and trade approach is the Clean Water Act's provision for the establishment of a Total Maximum Daily Load (TMDL)[11]. The TMDL establishes a cap on the total daily quantity of a pollutant that can be discharged into a specific waterbody or river segment. The conditions requiring a TMDL are generally similar to those that led to the establishment of the Acid Rain Program's cap on SO_2 emissions from electric utilities, despite their compliance with their permits' emission rate limits for $SO_{2.}$ A TMDL is triggered when a waterbody is not able to meet and maintain water quality standards despite point sources' compliance with their National Pollution Discharge Elimination System (NPDES) permit limits, which are set by water quality standards (which are established at the state level due to significant geographic variations in watersheds) or technology-based standards (usually set at the federal level).[12] The problem is the accumulative impacts of the discharge of the pollutant, caused by the total number of sources and the total quantity of their effluent or emissions, and which lead to water quality problems that interfere with the human and biological uses of the waterbody. Permits issued over time for individual sources are not able to identify or address that situation but instead focus on the concentration levels of the pollutant per volume of water or air.

The TMDL establishes a cap under which trading, along the lines of the cap and trade model, could proceed, if all sources under the cap had permits or other legal means of verifying and enforcing reductions. While the Acid Rain Program's cap only covered one sector of fairly large sources, the TMDL must allocate the cap among all identified sources contributing to the pollutant loading in the waterbody. TMDLs must not only assign shares of the cap to the point sources – those that hold an NPDES permit – in the form of individual Waste Load Allocations (WLAs), but also assign Load Allocations (LAs) to different categories of nonpoint sources and to natural background. EPA's current TMDL guidance states that Load Allocations allocations may range from "reasonably accurate estimates to gross allotments."[13] The Waste Load Allocations are then translated from the individual point sources' assigned pollutant loads to an effluent limit in a federally-enforceable NPDES permit, which provides considerable assurance that the reduction assigned through WLAs will be met. The implementation of Load Allocations, however, is left entirely to States and Tribes, with only vaguely worded guidance allowed to be offered by EPA as to how the LA will be achieved. As stated on the EPA Office of Wetlands, Oceans and Watersheds website,

> "States, territories, and authorized tribes should describe a plan for implementing locations for waters impaired solely or primarily by nonpoint sources, including
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> - Reasonable assurances that load allocations will be achieved, using incentive-based, non-regulatory or regulatory approaches. TMDL implementation may involve individual landowners and public or private enterprises engaged in

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[11] The Clean Water Act, section 303, establishes the water quality standards and TMDL programs.

[12] A full definition of TMDLs and how they are established is provided on EPA's Office of Wetlands, Oceans and Watersheds website: www.epa.gov/owow/tmdl/

[13] *Ibid.*

agriculture, forestry, or urban development. The primary implementation mechanism may include the state, territory, or authorized tribe section 319 nonpoint source management program coupled with state, local, and federal land management programs and authorities;

- Public participation process, and
- Recognition of other watershed management processes and programs, such as local source water protection and urban storm water management programs, as well as the state's section 303(e) continuing planning process."[14]

The main similarities of the TMDL's effluent cap to the Acid Rain Program's emissions cap on fossil-fuel fired electric utilities is that the TMDL cap provides a comparable quantitative limit on a single pollutant to a defined geographic area, and that the TMDL cap implements the point sources' share of the reduction goal through federally enforceable permits. The TMDL's key difference, however, is that it requires the inclusion of a much more complete but varied set of sources. Furthermore, since nonpoint sources do not have NPDES permits, the ability to achieve pollutant reductions through the implementation of Load Allocations depends on the rigor of state or local regulations applying to those sources. While some states require nonpoint categories, such as agriculture or forestry, to implement specified Best Management Practices (BMPs), other states prefer a voluntary approach, encouraging the adoption of BMPS with incentives of subsidies or cost-share programs administered at the state or federal level.

Trading under a TMDL between point sources, who, by definition, hold federally-enforceable NPDES permits, appears to fit the Acid Rain Program trading model of a cap-and-trade approach. However, bringing nonpoint sources into the trading environment under a TMDL and with no permit to enforce their reductions poses many challenges that have not yet been addressed by the Acid Rain Program's cap-and-trade approach. The Acid Rain Program's "opt-in" feature allows sulfur-dioxide emitting industrial sources who also hold federally enforceable permits to join the trading program along with the fossil-fuel fired utilities, yet they are required to adopt the same regulatory requirements and their addition to the program serves to expand the cap to a new subset of similar sources. In contrast, bringing in non-point sources under a TMDL-based trading program requires careful consideration of how to define and enforce a pollution reduction from a source without a permit that is very dissimilar to the NPDES permitted point sources that would also be trading under a TMDL. Furthermore, the non-point sources are already included in the TMDL cap, so the real challenge is how to implement trading so that the traded commodity is surplus to the reductions assumed to be taking place by the TMDL, as well as verifiable and enforceable.

While creating an opportunity for nonpoint sources to participate in TMDL-based trading poses many serious challenges, it is worthwhile to study and attempt to resolve these issues through an innovative trading system because the cost of reductions from these non-permitted sources can be considerably cheaper than the cost of reductions required of point sources under a TMDL's

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[14] *Ibid.*

assigned Waste Load Allocations.[15] Since the TMDL's allocation process is not required to address cost considerations, water quality trading provides an important opportunity for lower cost pollution reductions to be identified and implemented in the watershed within the TMDL implementation framework.

Applying "Cap and Trade" Design Elements in the Lower Boise River's Water Quality Trading System

The following section describes the fundamental elements of the cap and trade approach that can be incorporated into a TMDL-based water quality trading program, to ensure it is best equipped to achieve the environmental goal at less cost than would be possible without the use of trading. However, the trading system design must also accommodate the particular challenges of incorporating nonpoint sources into the water quality trading program, while not sacrificing the trading program's mandate to achieve the environmental goal established by the TMDL.

Potential solutions to these challenges are highlighted by a discussion of the design elements established under the trading system developed by EPA Region 10, Idaho Department of Environmental Quality (IDEQ) and the stakeholders of the lower section of the Boise River in Idaho. The Lower Boise River watershed was selected in 1997 as the site of EPA Region 10's first water quality trading demonstration project in the region, launching a three-year collaborative process for developing a trading system to support implementation of the Lower Boise River's phosphorus TMDL. Although the trading system design was completed in 2000[16], its implementation through the issuance of the Lower Boise River TMDL and subsequent NPDES permits that would contain phosphorus limits and authorization to trade to meet those limits has been unexpectedly delayed.[17] Despite the fact that the trading model developed for the Lower Boise River is not tested through implementation, its design was based on careful consideration of other water quality trading approaches, as well as the lead EPA representative's (*i.e.*, the author's) familiarity with both the Acid Rain Program's cap and trade model and examples from a few states' attempt to develop an alternative to a cap and trade program, known as "open market"

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[15] See Faeth, Paul, "Fertile ground: Nutrient trading's potential to cost-effectively improve water quality," *World Resources Institute*, 2000.

[16] See Idaho DEQ's website for a full description of the trading system and the collaborative process used: http://www.deq.state.id.us/water/tmdls/lowerboise_effluent/lowerboiseriver_effluent.htm

[17] This is due to the Lower Boise River TMDL's geographic and environmental link to a delayed set of TMDLs for the Snake River/Hells Canyon complex. The Boise River flows into the Snake River and is its largest source of phosphorous above the Brownlee Reservoir, where significant water quality impacts have impaired the beneficial uses. The Boise River itself is not considered to be impaired by phosphorus under Idaho's water quality standards for nuisance aquatic growth, and therefore the point sources on the Boise River do not currently have phosphorus limits in their NPDES permit. Because the Snake River's TMDL will set the reduction target for the Boise River's TMDL, the trading system cannot be implemented until the series of TMDLs are completed and approved by EPA. The delay (as of April 2003) in Idaho DEQ's submittal and EPA's approval of the TMDLs are for reasons unrelated to trading.

trading.[18]

1. Hybrid Approach to Cap-Based Trading to Allow Non-Point Source Reductions to be Traded

One of the primary benefits of a cap and trade approach, as demonstrated by the successful Acid Rain Program, is the certainty that the environmental goal will be achieved through the strict enforcement of the cap. The certainty that the cap will be maintained is provided through several important program elements: stringent emissions monitoring requirements; the automatic penalties for violations combined with the requirement that any exceedance be offset by allowances deducted from the source's account for the following year; and the trading system's banking system type of accounting safeguards for all allowances circulating in the system to ensure that no fraudulent allowances are created. Together these features ensure the integrity of measuring and accounting for the required pollution reductions needed to maintain the cap so that the sulfur dioxide allowance has value as a tradable commodity.

Prior to the development of the water quality trading system for the Lower Boise River, the relatively few water quality trading projects already in place had emphasized providing as much certainty as possible that the reductions being traded were real and enforceable. In fact, the Lower Boise River stakeholder group that was recruited to work on the trading system design considered the designs used in three different trading projects to help them determine which design would be best for the needs of the Lower Boise watershed, but ultimately rejected the three designs because they did not emphasize the market-based approach to the degree the Lower Boise stakeholders wanted, and decided to design their own water quality trading model.

First, they considered the Tar-Pamlico project in North Carolina[19], which used a group permit to serve as a cap for the point sources and under which trades between point sources would take place. These trades are administered and enforced by the Basin Association, and the members also pay a fee to the North Carolina Department of Agriculture to install Best Management Practices on nonpoint source sites, as part of the agreement for the watershed's unique permit arrangement. The Lower Boise stakeholders were not interested in this model primarily because of the unwillingness of the point sources to be bound to each other under a single group permit and the lack of a direct trading relationship between point sources and nonpoint sources. Second, they considered the Cherry Creek, Colorado project which used a newly created quasi-governmental agency to develop and administer projects to obtain nonpoint source reductions and to sell the resulting credits to willing point source buyers. Since it appeared that all projects

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[18] Examples of "open market"trading include New Jersey's Open Market Emissions Trading or OMET program, http://www.state.nj.us/dep/aqm/omet/ and Michigan's Air Emissions Trading Program, http://www.michigan.gov/deq/0,1607,7-135-3310_4103_4194-10617--,00.html

[19] Links to descriptions of these three projects can be found on EPA's water quality trading website. For Tar Pamlico, http://www.epa.gov/owow/watershed/trading/cs10.htm;
For Cherry Creek, http://www.epa.gov/owow/watershed/trading/bould.htm
For Rahr Malting, http://www.pca.state.mn.us/hot/es-mn-r.html

and trade transactions must pass through this local authority to ensure their validity, the Lower Boise stakeholders rejected this model because they wanted to be able to arrange their own projects through private contractual arrangements. They also were not interested in establishing a local quasi-governmental authority to administer the projects and the trading system. The third trade model they examined was the one used for the Rahr Malting Co. in Minnesota, in which they were issued a permit allowing them discharge into the Minnesota River provided they obtained a specified amount of reductions upstream from at least one of an assortment of nonpoint source sites and BMPS listed in their permit. If they reductions failed to materialize by a set period of time, either through failure to install the BMPs properly or poor BMP performance, then the company must follow a specified construction schedule for technology-based treatment of their discharge, also specified in the permit. Upon hearing that it took more than two years to develop this type of permit, the Lower Boise stakeholder group also rejected this model because they were looking for a more flexible permit that would enable a higher volume of trading to take place on a seasonal or monthly basis, and that allowed the point sources to identify and contract for their own preferred nonpoint source projects. Furthermore, Idaho does not have a delegated NPDES permit program, with EPA Region 10 issuing its permits instead. EPA's current backlog of permits to be modified even without trading provisions discouraged any consideration of a trading system that involved a lengthy permit negotiation and approval process.

The stakeholder group instead decided to pursue a trading system modeled after the flexible permit approach of the Acid Rain Program, which specifies the conditions for trading up-front but then allows the qualifying trades to automatically adjust the permit limit without a formal review process. It also allows buyers and sellers to arrange their trades outside the permit process, only registering the results of each trade in trade recording system. In contrast to the Acid Rain Program, however, the TMDL-based water quality trading system for the Lower Boise River is not based exactly on allowances as a representation of an authorization to emit a specified amount, but instead is a hybrid of that model and a "credit-based" approach that allows non-regulated sources to sell reductions without having to become a regulated source under the program. A "credit-based" approach creates a tradable pollution credit by documenting the one-time or repeated reduction of the amount of pollution discharge for a given period of time. The credit can then be used by another point source to offset its discharge, although the time period in which the credit can be used is an important issue for the trading system design to address.

Under the Lower Boise River's approach, the point source's Waste Load Allocation is the baseline for an authorized amount of effluent to be discharged, and then any measured reductions from that amount can be documented as a tradable credit[20] that can be sold to another point source, to be used to authorize an increase in their discharge above their allocated amount. That portion is very much like the allowance-based, cap and trade system. Where it differs, however, is that reductions from non-permitted, nonpoint sources are allowed to be brought into the system. Those reductions, if created according to the program's requirements, are established as credits

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[20] Since they are allocated to point sources, it would be technically correct to call them "allowances," the term used in the cap and trade approach. However, the Lower Boise River program has chosen to call them "credits" to eliminate confusion when they are intermingled in the marketplace with nonpoint source credits

and then can be used by point sources to allow an increase in their discharge for that same pollutant. It is not the same as the Acid Rain Program's "opt-in" feature, which allows similar types of permitted sources to participate in the trading program. Rather, this hybrid system that intermingles point sources allowances and nonpoint source reduction-based credits would be equivalent to the Acid Rain Program allowing area sources or mobile sources to document their reductions in SO_2 emissions and allow those credits to be intermingled with SO_2 allowances. This type of an approach, however, is not desired nor needed by the Acid Rain Program because they are able to address two-thirds of the emitters of SO_2 by just targeting fossil-fuel fired electric utilities.

The Lower Boise River trading system has developed several features to ensure the validity of the underlying reduction upon which the nonpoint source's credit is based. This is critical to the acceptance of the credit as a legitimate tradable commodity that can be intermingled with the credits sold by the point sources. While point sources have a permit, and therefore an allocation from which credits that are sold to another party can be subtracted and transferred to the point source's account, nonpoint sources must establish a reduction and have the purchasing point source certify the validity of the reduction. Through the submission of the Reduction Credit Certificate (signed by the point source purchasing the credit), the reduction credit is created in the official Trade Tracking System and can then be transferred to the point source's account. These specific features will be discussed later in this paper, but it is important to highlight that distinction here because this is a departure from the cap and trade model which only trades allowances held by point sources. Moreover, the TMDL-based water quality trading system needed to include this design element because nonpoint sources are often some of the most important categories to address in the reduction goals of the TMDL, as well as the source of potentially lower cost reductions.

2. Low Administrative and Transaction Costs through Pre-Established Trading Conditions

Another significant feature of the cap and trade model is its ability to achieve the environmental goal at less cost. In addition to the cost savings from using reductions generated more cheaply by another source, the transaction costs for the point source to use the reductions should be kept as low as possible, without sacrificing the achievement of the environmental goal. It is extremely important to the success of the trading program that these transaction costs not exceed the cost savings derived from allowing actual reductions to be obtained from those who can do it at the lowest cost. In addition, the costs incurred by the regulating agency administering the program should not be excessive over the life of the program, since these administrative costs should also be factored into the decision as to whether or not a trading program is worthwhile to undertake. These are important design principles that should be integrated into the TMDL-based water quality trading system in order for trading to realize its full potential for achieving the TMDL's reduction goal at less cost.

For the Acid Rain Program, the source of these low administrative costs and transaction costs is rooted in how trading is authorized in the sources' permits, how EPA approves the trading transactions, and how it assigns liability for the validity of the reductions. Since the SO_2 trading is authorized in the 1990 Clean Air Act Amendments, EPA was able to establish permits that allow trading with minimal regulatory interference or approval procedures. The permit allows sources to adjust their initial permit limit (as determined by its allowance allocation) automatically through trading, by referring to the Allowance Tracking System as the official record of allowances held in the point source's account. Each allowance held in the source's account allows it to emit a ton of SO_2 for the year designated by the allowance. Compliance is determined at the end of 60 days following the end of the calendar year, by deducting enough allowances held in the account against the sources reported emissions. This calculation is performed in an EPA-administered system called the Annual Reconciliation System. Because each permitted source is held liable for compliance with their trade-adjusted emissions limit, reductions do not need to be verified first before an allowance can be transferred to another source's account. Automatic financial penalties[21] are triggered when the reconciliation system determines that the permitted source failed to hold enough allowances to offset its reported emissions, and the missing amount of allowances are deducted from the next year's account. In this way the environmental goal of the Acid Rain Program is not violated and the permitted source has a strong legal and financial "incentive" to stay in compliance with the allowance holding requirements of the program.

In the Lower Boise River's trading system, the authorization to trade is found in the EPA Water Quality Trading Policy and its interpretation of the provisions of the Clean Water Act. While specific permit language has not yet been written, the Lower Boise's trading framework calls for the permit to allow the point source to adjust its initial permit limit (as determined by its Waste Load Allocation set by the TMDL) automatically through trading, by referring to the Trade Tracking System as the official record of reduction "credits" held in the point source's account, similar to the approach used in the Acid Rain Program. Each credit allows the point source to discharge a unit of phosphorus, which is expressed as "pounds per day," the same unit of measure referred to by the Waste Load Allocation. Reconciliation of the adjusted permit limit (as reflected in the point source's Trade Tracking System account) with their reported discharge amount is done 45 days after the end of the month, to be consistent with the TMDL's targets for demonstrating achievement of the environmental goal and other monthly reporting requirements (e.g., the Discharge Monitoring Report).

Unlike other water quality trading programs, the Lower Boise River's trading framework does not require EPA or state review of each credit transaction by a point source as a formal modification to its NPDES permit. Administrative and transaction costs are held to a minimum, in a manner similar to the Acid Rain Program's system, because the regulator's effort instead has been placed on defining the trading requirements and conditions on trading that must be developed in advance of trading being allowed to take place. Under the Lower Boise River's trading framework, credits

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[21] Title IV of the 1990 Clean Air Act set these penalties at $2,000 per ton and tied the amount to the inflation rate set by the Consumer Price Index. As of 2001, the Acid Rain Program reported the penalty amount to be $2,774. In 2001 these provisions resulted in fines of $30,514 to cover a shortfall of 11 allowances by two electric utility units, and 11 allowances were deducted from their year 2002 account. http://www.epa.gov/airmarkets/cmprpt/arp01/2001report.pdf

must be held in an account in a central trade database, called the Trade Tracking System, in order for them to be transferred to another account in the system or deducted as part of the monthly compliance process with the point source's NPDES permit limit. The point source's assigned Waste Load Allocation is their initial account balance, and they can purchase or sell credits by submitting a Trade Notification form to the Trade Tracking System, which will be run by the newly established non-profit group, the Idaho Clean Water Cooperative. Both the buyer and the seller must sign the Trade Notification Form, authorizing the transfer of credits from one account to the other, but no regulatory review of the transaction is needed. Credits established by nonpoint source reductions, on the other hand, must be created in the Trade Tracking System, when triggered by the submittal of the Reduction Credit Certificate. This document is filled in with information provided by the nonpoint source, calculating the amount of reduction available as a tradable credit (how this is done will is discussed in the next section) and signed by the purchasing point source, certifying that they have verified that the information is truthful and accurate. The document is submitted at the end of each month for which the practice generating the reduction is in effect, so that it is reporting a reduction that already took place. Once the Reduction Credit Certificate is recorded in the Trade Tracking System, the two parties must then submit a Trade Notification Form to transfer the credit to the point source's account so that they can use it to offset an equivalent amount of discharge for the same month. To accommodate the length of time needed to verify and certify the reduction and submit the forms, the point source's required compliance report, the monthly Discharge Monitoring Report, is not due until 45 days after the end of the month to which it applies.

The fact that the point source signs the Reduction Credit Certificate means that liability for the validity of credits used to comply with their NPDES permit remains with the point source. Some water quality trading programs in other states choose to shift that liability to the regulatory agency by requiring credits, or the demonstration of the reductions themselves, to be reviewed and approved by the regulating entity before they can traded. While it may provide more certainty in the validity of the reduction, the significant time delay and uncertainty of approval can be quite burdensome to the point source wishing to use the credit, as well as assign some degree of regulatory liability to the nonpoint source. Both point sources and nonpoint sources bear the sizeable transaction cost resulting from this trade approval process, which often discourages them from participating in very many trades. To minimize those transaction costs as much as possible, the Lower Boise River trading framework keeps the liability for the validity of the credits with the point source, by having them certify the reductions on the Reduction Credit Certificate and be subject to the standard Clean Water Act penalties if a subsequent audit finds they provided a false certification. However, the trading framework lets them manage the risk associated with purchasing reductions from a nonpoint source by whatever terms they choose to include in their private contracts to purchase the credits from the nonpoint sources. These private contracts provide an incentive for both parties to manage the risk inherent in this transaction relationship to the most economically efficient outcome. Other elements in the trading framework seek to minimize the transaction costs associated with trading by providing as much certainty up-front to the point source as to what constitutes a valid reduction by a nonpoint source. These elements are discussed in the next section.

It is important to note that the type of work to be invested in establishing these conditions at the outset of trading should be viewed as roughly the same as would be made in reviewing trades on a case-by-case basis if the permit modification approach were used. The level of effort overall should be considerably less since it is done just once, as part of the design of the program, and with the same information that would be available to a permit reviewer for a case-by-case decision. By also providing clear information to the trading participants at the outset as to what trades are acceptable, the work of reviewing trades is essentially transferred to the trading parties who screen the proposed trades themselves. The regulator's role is then deferred to the compliance and audit processes, which is an appropriate place to review trading activity and to enforce the program's requirements.

3. Determining the Conditions on Trading at the Outset Instead of Trade-By-Trade Review

The work involved in establishing the conditions on trading includes:

a) defining the commodity to be traded so that it is as uniform and consistent in its environmental impact as possible;

b) defining the reduction practice and quantification methods to be used in order for its resulting reduction credits to be approved and considered valid for trading;

c) ensuring the credits generated and traded are surplus to the reductions assumed to be taking place under the TMDL; and

d) determining what other permit limitations should be in place to prevent any adverse local impacts in the waterbody as a result of trading.

The following is a summary of how the Lower Boise River's trading framework addressed these important elements.

a) Defining the commodity: Important factors to consider in defining the commodity to be traded are: form, impact, time and quantity (the latter which will be discussed separately).

Form: The research conducted to support the phosphorus TMDL for the Lower Boise River and the Snake River showed that Total Phosphorus was of concern, rather than its other forms. That meant that even though point sources generally discharge phosphorus in its dissolved form and nonpoint sources contribute its sediment-attached form, the two would be considered equivalent forms of phosphorus for the purposes of trading.

Impact: In the Boise River, roughly 50% of the phosphorus loading is from point sources and 50% from nonpoint sources, but their locations are scattered throughout the watershed. The likelihood of Best Management Practices (BMPs) installed by nonpoint sources resulting in reductions that can be measured in the river is also influenced by where the sources are located in relation to irrigation diversions and return flows to the river. Given that the Boise River itself is not considered to be impaired under Idaho's nutrient standard, the TMDL's reduction target for the Boise River is measured at the mouth of the Boise River where it meets the Snake River, near the small town of Parma. Therefore, the environmental impact of the location of phosphorus reductions along the

Boise River needs to measured in terms of their effectiveness in achieving visible reductions in the phosphorus loadings in the Boise River at the location near Parma. This common of point of reference for comparing the equivalency of their impact is termed "Parma Pounds," referring to how much of a reduction in a pound of phosphorus achieved further up in the watershed will show up at the location near Parma. "Parma Pounds" are calculated by applying up to three sets of ratios to a quantity of reduction at any point in the watershed. The first set of ratios is termed "river location ratios," and they refer to the location of the source's discharge along the Boise River itself. They were developed using a mass balance model that accounts for inputs, withdrawals, and groundwater. The second set is termed "drainage delivery ratios" and they adjust the reduction amount further by applying a set of distance-based factors if the source is located along a creek or drain that flows into the Boise River. Similarly, the third set of ratios, termed "site location factors" adjust the amount even further if the source is located away from the drain or creek, because its reduction impact is less effective due to increasingly indirect hydrological connection to the Boise River.

Time: There are two aspects to the role of time as it relates to water quality trading. One is that the underlying reduction upon which the credit is based must occur in the same time period as when the credit will be used. This time period is determined by the TMDL and is based on consideration of seasonal hydrological flows and related water quality impacts. It also means that water quality trading programs should rarely allow "banking" of credits - i.e., the ability to save credits for use in another time period. In the Lower Boise trading system, credits are not created until the end of the month and rely on documentation that the reduction occurred during that month. Point sources can then only use credits generated in the same month as their discharge of the pollutant to be offset.

The second aspect of time as it relates to water quality trading is that the effectiveness of the reduction practices used to generate credits offered in the market must be aligned with when the point sources will be needing credits, in order for the market for credits to be able to match the available supply and demand. The Boise River TMDL for phosphorus could require reductions during the irrigation season or it could require reductions year-round, but the effectiveness of most Best Management Practices that agricultural nonpoint sources would undertake are limited to the irrigation season because of their interaction with managed water flows and growing seasons. Therefore, if held to year-round reduction requirements and if their own phosphorus discharge amounts do not vary with the season as well, point sources will need to look for credits generated by non-agricultural sources or consider installing treatment technologies themselves.

b) **Identifying the acceptable reduction practices and determining the reduction quantity**: While measurement methods for point source discharges are well established and specified in the NPDES permit, measurement methods for quantifying nonpoint source discharge and reduction amounts are far less known. However, reductions from nonpoint sources will need to be determined with as much accuracy as possible in order for them to be treated as equivalent to point source reductions and established as credits to be traded. Under the Lower Boise River trading framework, a list of approved Best

Management Practices (BMPs) and their measurement or estimation method was established by the state's BMP Technical Committee so that point sources would know in advance what practice and what quantification method was determined to be satisfactory by the regulators.[22] Measurement methods were given preference over estimation methods in that they would receive the full credit amount they measured, while a small "uncertainty discount" would be applied to the quantity determined by the calculation method. However, estimation methods may currently be more accurate overall, given that the performance of many BMPs are heavily influenced by the size of the field and the type of crop planted.

This information provided in advance by the regulator of what constitutes an "approved" credit is important for the market to perform efficiently, since it is a "buyer beware" market. The point source is liable for the validity of the credits it uses, so it needs to know in advance what criteria it should apply in assessing the legitimacy of a credit before purchasing it. Point sources may choose to purchase credits in the open market after they have been created, or in a long-term private contract with the nonpoint source for delivery of a specified number of credits over time.

c) **Ensuring credits are based on reductions surplus to the TMDL's reduction goals**: In the case of trading between point sources, the reductions that are traded are considered to be consistent with the TMDL's reduction goals because the permit limits established by the Waste Load Allocations can be directly enforced under the NPDES permit program. A credit sold and transferred out of the point source's account is a reduction in the source's permit limit; a credit purchased and transferred into their account is an increase in its permit limit.

However, in the case of a nonpoint source generating a reduction to be used as a credit, the TMDL assumes the nonpoint source discharges will not exceed their "share" of their sector's assigned Load Allocation, yet there are no permits for nonpoint sources with which to enforce the reduction goal. Instead, the TMDL implementation plan usually identifies a reduction strategy involving a set of sector specific requirements (e.g., Washington State's Forest Practices Act[23]) or specific state and federal cost share programs and types of BMPs that will be targeted to that watershed, to work towards achieving the reduction goal (e.g., the Environmental Quality Incentives Program (EQIP) sponsored by the U.S. Department of Agriculture's Natural Resource Conservation Service). Some states will also have a minimum set of requirements or set of practices that a category of nonpoint sources will need to implement to be in compliance with the TMDL. In the case of the Lower Boise River TMDL, the state of Idaho relies on targeting farmers in the TMDL's watershed with EQIP cost share funds administered through the Soil Conservation Districts.

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[22] This BMP List is still in draft form, but will be made publicly available as part of Idaho DEQ's rulemaking process for the Lower Boise River's water quality program.

[23] Washington's Forest Practices Rule, WAC 222 http://www.wa.gov/dnr/htdocs/forestpractices/rules/

Since participation in those programs is only voluntary, a more reliable approach for nonpoint source reductions was needed to satisfy EPA's Water Quality Trading Policy that the reductions used as credits be "surplus" to the reductions assumed to be taking place by the TMDL. "Surplus" means that the nonpoint source credits must be based on reductions above and beyond those that an individual nonpoint source must make in order to meet their sector's Load Allocation. Therefore, the Lower Boise River stakeholders agreed that a "voluntary water quality contribution" would be made from each BMP's measured or estimated quantity of phosphorus reduced prior to application of the three sets of ratios to convert it to "Parma Pounds." The amount of the contribution would be determined by Idaho DEQ as part of the TMDL implementation plan, but would be established as an individual farmer's share of the reductions needed to achieve their sector's Load Allocation. While participating in the trading program is voluntary, the "water quality contribution" is required for establishing a credit by a nonpoint source, under the Lower Boise's trading framework.

d) **Establishing protective limits to prevent local impacts from trading:** In addition to ratios that address environmental equivalency based on location, other protective measures may be needed to prevent the creation of a "hot spot" or local impact on water quality. This may be caused by the accumulative loading of the pollutant from dischargers upstream or the discharge of single point source at that particular location due to unique environmental sensitivities in that section of the waterbody. In either case, a limitation in the point sources' permits may be needed to restrict how much that point source may discharge no matter how many credits they hold in their account. This limit setting an upper bounds on how much can be discharged will supercede the authorization to use credits, but not their ability to hold credits or sell them to others. This is similar to the state or federal ambient standard's constraint on how much sulfur dioxide an electric utility may emit, despite the number of allowances they hold under the Acid Rain Program. However, in the case of water quality trading, this limit will be based on how the State or Tribe defines its water quality standard for that pollutant or environmental condition, which may be a narrative standard, such as Idaho's standard for nuisance aquatic growth, rather than a numeric standard for phosphorus. Water quality trading will be best supported if the narrative standard can be translated into a numeric limit for a specific pollutant contributing to the condition that is being addressed, so that the source will have a clear indication in advance of how much it can discharge and not have to revisit any trades it may have conducted. The Lower Boise River trading framework has not yet established that limit for the point sources' NPDES permits because such analysis needs to be based on data and conclusions associated with the TMDL, which is yet to be completed.

The Lower Boise River trading framework was developed by its stakeholders with a careful eye towards maximizing certainty of the phosphorus reductions underlying the tradable credit, while minimizing transaction and administrative costs as much as possible. Its design also reflects an intent to let the market create incentives and competitive pressure for improving the performance of phosphorus reduction technologies and BMPs by letting sources sell surplus reductions as easily as possible. Improving the accuracy of measurement or estimation methods of those reductions is also valued in the marketplace by the point sources' willingness to pay for credits reflecting such improvements. In addition, market participants have an incentive to insist that the list of approved BMPs reflects the most recent research in improving BMP performance and reduction quantification methods.

The Lower Boise River trading framework addresses many of the risks associated with water quality trading with a cost-effective, market-oriented approach. These risks stem from the concern that BMP reductions are not equivalent to point source reductions in terms of their actual effectiveness in reducing pollution between the different geographic locations of the buyer and seller in the watershed, uncertainty that the BMPs are being implemented properly, or that the seller is not liable if the underlying reduction for the credit is invalid. Other water quality trading programs have lumped these risks into a single trading ratio, such as requiring two pounds of nonpoint source reductions be used for every pound of a point source's discharge it offsets. This approach can make the use of credits very costly, which may erode any potential cost savings for the point source. The effect is to discourage point sources from using credits to avoid installing costly compliance technology themselves, and to dissuade nonpoint sources from undertaking any reduction practices that exceed the minimum of what is required. Consequently, the overall cost of implementing the TMDL will be higher than it may have needed to be. Instead, the Lower Boise River trading framework attempted to identify each type of risk and address it separately, with such elements as the location-based ratios, the list of approved BMPs, and the use of private contracts between the trading participants to manage the transaction-based risk themselves. In this way, water quality trading cannot only learn from the cap and trade model in terms of minimizing transaction and administrative costs, but also adapt the model further to incorporate unregulated nonpoint sources, and therefore serve as a model for a the next generation of trading programs that must address a wide variety of trading sources and pollutants.

Conclusion

The remarkable achievements of the Acid Rain Program's SO_2 emissions trading program can be partly attributed to its statutory mandate established by the 1990 Clean Air Act Amendments and the nature of the environmental problem it is designed to address. However, much of the credit should also be given to the design of the trading system it used to achieve the mandated reductions. The cap and trade model provides many important lessons that can be applied to other trading programs to help them achieve their environmental and economic goals. Once the environmental goal is firmly established, the contributing sources identified, and trading is selected as an implementation strategy to achieve the reductions at less cost, careful attention should be paid to how important elements of the program will determine how well the trading system can function. While many will focus on the differences between the regulations and the nature of the environmental impacts involved in air pollution versus water pollution, there are many important lessons that can be applied from the success of the cap and trade model established for SO_2 trading to water quality trading. Moreover, successful water quality trading programs may lead the way in developing our understanding of how such market-based approaches can engage regulated and non-regulated sources in a business-like relationship to accomplish important environmental goals at less cost to society.

Storm Water Trading
Haynes Goddard and Hale Thurston, US EPA, National Risk Management Research Laboratory

Haynes Goddard:

We've been exploring the possibility of using a tradable runoff allowance system to help manage storm water runoff. This is a new line of research not yet supported by any legislation—sort of forward looking. The problem is the growth in impervious surface in urban areas, which leads to increased storm water runoff, which causes flooding, combined sewer overflows (CSOs), damage to stream ecology, and reduced ground water recharge. Traditional solutions from the construction or engineering side involve building something. Generally, the idea is to expand your centralized infrastructure (e.g., collector system sewers, treatment plants, storage facilities, deep tunnels) to handle higher flows and increase storage capacity. Unfortunately, these strategies often result in diminished ecological integrity of streams, and they fail to add to ground water recharge. What's more, the infrastructural approach is quite expensive. Of course that brings up the question of whether there is a cheaper way to address the problem and whether trading might have a role.

We believe there might be a role for some sort of pollution credit trading. It's possible that the total cost of numerous storm water runoff abatement initiatives on individual parcels will be lower than the cost of implementing a more traditional, centralized approach to the problem. Of course you would need some coordinating mechanism to encourage individual parcel owners/managers to invest in the abatement strategies that yield overall cost savings—you need the market incentives. So, we are directing our research toward using ecological economics, where we factor in natural capital explicitly as part of the solution. In other words, we are investigating the economic advantages of using more natural capital (as opposed to man-made capital) as part of the storm water management infrastructure. The idea is to create a market that supports broader use of such strategies as dispersed detention, retention, infiltration, evapotranspiration, and evaporation in storm water runoff management. The acronym for such strategies is BMPs, "best management practices." So, the challenge is to design a market-based incentive system that encourages coordinated investments in BMPs as natural capital, ultimately resulting in a least-cost configuration. Toward this end, we are currently working to identify the properties of an optimal system and checking for cost heterogeneity. The system design will be dependent on these factors.

In our research, we have looked at a multitude of data regarding water flow in streams and rivers. When we plot a stream's water flow (cubic feet per second) over time, we get a highly variable graph with peaks and troughs that echo rainfall events and droughts in the area. Given a static stream capacity, we are interested in comparing exceedances of this capacity prior to development of the area with exceedances after development. Over and over again we find that stream capacity exceedances increase in both number and severity as a watershed area undergoes development. Again, the main issue is the increase in impervious surface area that accompanies standard land development operations and that leads to flooding and all the other problems. The primary runoff policy objective for any storm water runoff trading system is to reduce stream capacity exceedances.

In designing the framework for a trading system that will help achieve this objective, we are presented with a standard cost minimization problem, subject to an explicit stream flow constraint. Natural capital solutions, though relatively inexpensive to implement, can take a while to achieve the level of abatement desired. Traditional, centralized infrastructure solutions, on the other hand, are cost intensive but achieve the runoff abatement desired (and, consequently, reduced exceedances) in a relatively short time period. However, it is not cost-effective to employ major infrastructure investments designed to handle the maximum expected runoff episodes—there would be substantial idle capacity between major rainfall events. We believe that increasing the natural capital component in the ratio of the two technology options will result in fully effective runoff abatement at a reduced total cost. The idea is to find the right combination of investment of BMPs such that the overall costs of staying within the stream capacity are minimized. Then we need to design the trading market system that supports the implementation of the optimal blend of abatement technologies, i.e., the "least cost capital combination."

A critical factor in the design and implementation of a storm water runoff trading system is the individual homeowner. What exactly is the welfare cost at the parcel level? A homeowner is going to lose some utility by having to use some of his land and spend some of his money putting BMP technologies on his property—that's a reduction of his welfare. This a critical issue that we are interested in: just how much is the real cost at the parcel level based on people's willingness to pay? Of course this applies to parcel-level commercial/industrial owners and public entities as well as homeowners.

Remember, the whole idea here is to bring stream capacity exceedances under control. To monitor improvement and success in this effort, it is necessary to establish some baseline standard—say, for example, that we shouldn't exceed stream capacity more than X-percent of the time. The difference in this problem is that an explicit probabilistic, or stochastic, constraint is introduced. The relationship between stream flow and exceedances is used to show the cumulative distribution probability indicating how often we will exceed a given stream capacity based on stochastic (i.e., meteorological) events. A note on language: Engineers typically talk about storm water control in terms of "hundred-year floods" and "twenty-year floods." In "exceedance" terms, a hundred-year flood would correspond to a 1% exceedance, and a twenty-year flood (which occurs five times as often) would correspond to a 5% exceedance.

Our model accounts for the fact that storm water or hydrologic outcomes tend to be log-normally distributed. So, we can create a graph showing the current exceedances of our chosen standard and compare this with a graph showing projected exceedances after the introduction of BMPs coordinated through trading, noting the shift in the mean and variance. The model has some notable first-order conditions: We are minimizing cost with respect to household investment, with two corresponding issues of interest—the mean and variance of the log normal distribution. What is of interest is that we have expressed marginal costs in units of reduction of probability of exceeding the stream standard. Our plan is to incorporate these conditions into the actual design of the trading system, but we have not yet done that.

So, we believe that dispersed investments in BMPs will likely be part of a least-cost solution to managing storm water runoff. Furthermore, we think that runoff credit trading is going to be a viable mechanism for fostering and coordinating parcel-level BMP investments. Of course, for trading to be viable, there must be available, affordable technologies that will work at the parcel level. They do exist, but much more needs to be known about how well they work and what they cost. Of course, there also has to be cost heterogeneity; in this case it's spatial, largely, but it also has to do with the willingness of people to participate in the trading market. This issue is dealt with in more detail below.

Hale Thurston:

Taking this discussion from the theoretical to the practical, let's look at how we sort of applied these concepts to a small watershed in Cincinnati, at least in a modeling stage, and then where we want to go from here as far as perhaps actually applying it in real life. The three main issues to explore are:

- First, our hydrology—how we went about establishing the point-sourcification of this non-point source problem by determining each property owner's excess runoff using hydraulic modeling.

- Second, and foremost, the actual trading as we envision it now.

- Third, and aftmost, some of the ongoing research and future research we intend to get into to make this as realistic as possible.

The Shepherd Creek area on the west side of Cincinnati was chosen as a pilot project, case-study area specifically because it has some heterogeneous land use—there are some housing developments, some commercial property, and some large ranch-type parcels. Shepherd Creek flows into the west fork of Mill Creek, which goes on into the main Mill Creek, which you may have heard about as a fairly degraded watershed in Cincinnati. Also, these portions of Shepherd Creek (SC) are highly degraded due to high peak volume runoff during storm water events.

In the case study, we first collected as much data as possible in ARC View and tried to point-sourcify the individual parcels in the Shepherd Creek area. This involved compiling parcel boundary data from the Hamilton County auditor and imagery collected from the Cincinnati-area GIS fly-over to help identify impervious surface. Using Microsoft Excel to perform various calculations on the pertinent parameters, we were able to estimate the pre- and post-development runoff from each parcel. The difference then between the pre-development and post-development values is the excess storm water runoff that, in our trading scheme, each parcel owner is responsible for. It may turn out that the specific ecological constraint for a particular area will not require abatement to pre-development levels, which will enable us to reduce each parcel owner's obligation by a corresponding factor.

Now, once we've assigned individual parcel values, how do we control this excess storm water runoff that's causing the degradation in the stream in the SC area? A necessary but not sufficient condition for any trading scheme to take place is that we have heterogeneous cost and control. There are a variety of BMPs available to different parcel holders for controlling storm water runoff. These include infiltration trenches, dry wells, rooftop storage, green roofs, vegetative filter strips, rain barrels, swales, porous pavement, engineered landscapes, and reduced use of curbs and gutters, among others. Crunching the numbers in Excel again, and assuming that each parcel holder uses the least-cost technology available to him to abate the storm water runoff that he is responsible for (or assuming, alternatively, that he buys allowances from a clearinghouse—a storm water utility or something), we estimated a permit value of $5 per cubic foot of storm water detained. In our calculations, this trading scheme solution ends up being somewhat less costly than the large infrastructural solution to the problem for detaining storm water.

Our first extension then is to say, "Well, maybe we don't have all the costs factored into our cost functions for these BMPs." So my first point of attack was to try to establish residential opportunity costs. To my knowledge, Sample, et. al. is the only one heretofore who have addressed the opportunity costs of devoting portions of residential parcels to management practice. They used real estate tax appraisal values in their study. Along the same lines, we used a hedonic analysis to try to establish market value for this land that was going to be dedicated to BMP. We ran a hedonic estimation on some 24,000 observations—the dependant variable, of course, being the sale price, with the standard cast of cost-factor characters: number of baths, square footage (including the total square footage of the parcel size), etc. The estimated coefficient on net loss, which was the net parcel size—that's net the house, the approved building on the lot—was approximately 27 cents. The estimated coefficient then is the marginal value of an additional unit of the thing.

It's important to note that the opportunity cost of commercial property is probably going to be significantly higher than that for residential property—you know if you take away a parking space or something like that from a commercial property, it's probably a more costly trade-off than a homeowner's giving up garden space to install a BMP. So far this is what we've got, and so our cost function, instead of just being 4.94 times the quantity dedicated to it, is also plus this 27 cents times the footprint of the property.

Going forward, we want to develop our market plan more fully and flesh out the legal framework that will support it—Punam Parikh is helping us address some of those tough but critical issues. We also want to use some continuous hydrologic modeling as opposed to the single-event storm modeling we used to generate our data for the case study, and we need to look into trade ratios and what we call "wetspots" as opposed to hotspots. Obviously we have to look at opportunity costs for commercial properties if these non-point sources are all going to trade with each other. In our SC case study we used sort of an experimental auction approach to trading allowances to help us verify our initial cost estimates. Expanding on this idea will also help us see what people are willing to pay for land use that increases runoff—or demanding as payment for agreeing to have runoff-decreasing BMPs in their yards. We really do want to make this a practical application of trading.

Experimentation with Watershed-based Trading Using the Internet[1]

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ABSTRACT

Watershed-based trading programs may result in cost-effective improvements in water quality. However, a variety of implementation issues need to be resolved before trading will become broadly acceptable. *NutrientNet* (www.nutrientnet.org) is an e-marketplace designed to provide easily accessible and user-friendly tools to estimate and trade nutrient credits over the Internet. This tool is designed to (1) lower transaction costs of trading by easily identifying market participants, (2) standardize nutrient credit estimation to establish credibility and (3) track trades efficiently for oversight by government agencies and the public. A *NutrientNet* user can identify and characterize their operation, estimate baseline and mitigated nutrient loadings, review expected costs and potential number of credits available to buy or sell, and trade credits at the Website marketplace. *NutrientNet* has been developed for the Kalamazoo watershed in Michigan and is currently being developed for a sub-basin in the Chesapeake Bay watershed. Development and market experimentation with the Website suggests *NutrientNet* may be a useful tool for States to aid in meeting water quality objectives.

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[1] Opinions and assertions expressed in this paper are solely those of the authors and do not necessarily represent the views of the U.S. government.

DISCUSSION

Background on Watershed-based Trading

Watershed-based trading programs—where pollutant credits and resource rights are clearly defined, enforceable, tradable, and typically capped within watersheds—may improve or preserve water quality more efficiently and effectively than alternative, conventional approaches. Defining and creating a tradable commodity, such as a phosphorus reduction credit, is contingent on being able to quantify and enforce the pollutant source, loading, and/or amount sequestered or utilized. As a result, tradable credits allow two parties to shift allocation of regulatory responsibility in order to lower pollution control costs.

The U.S. Environmental Protection Agency (EPA) finalized the National Water Quality Trading Policy in January 2003 to provide guidance for States to implement watershed-based trading programs that will potentially reduces the cost of compliance with Clean Water Act regulations. The conceptual framework for watershed-based trading has become clearer over time with greater experience using appropriate trading program criteria. Lessons learned from various trading pilot studies helped shape the Water Quality Trading Policy through the identification of successful programs and approaches, as well as understanding obstacles and barriers to trading. Successful implementation of watershed-based trading programs will depend on the development of innovative tools to break down barriers and facilitate trading.

Overcoming Certain Barriers

A variety of implementation issues need to be resolved before trading will become broadly acceptable. Some of these issues include: transaction costs, the credibility of nonpoint source load reductions, and sufficient public oversight. Transaction costs can preclude trading if they are too high. It is therefore essential to keep them low by providing easy means for market participants to find each other and to identify how many credits they have to sell or need to buy. For there to be credibility in the nutrient credits generated by agricultural or other nonpoint sources, standard estimation methods must be used. Essentially, watershed managers, the public, and the buyers need to be assured that all nutrient credits are estimated in the same way. Lastly, there has to be a relatively simple way to record trades so that the relevant government agencies and the general public know what is taking place.

The Internet has emerged as a promising tool for meeting these needs. A trading Website such as *NutrientNet* (www.nutrientnet.org) provides a simple way for buyers and sellers to connect. It also makes it relatively easy for both point sources and nonpoint sources to estimate their pollution remediation costs and potential nutrient credits available or needed through trading using standard, consistent methods. Finally, *NutrientNet* makes the record of trade (registry) readily accessible. This paper will describe *NutrientNet*, report on development and experimentation using *NutrientNet*; and summarize future activities and next steps.

NUTRIENTNET

What is *NutrientNet*?

NutrientNet is an e-marketplace designed to provide easily accessible and user-friendly tools to estimate and trade nutrient credits over the Internet. Not only does *NutrientNet* provide a market floor for buyers and sellers to locate each other, but it also allows point sources and farmers to estimate the cost and amount of nutrient reduction credits they are able to achieve using standardized estimation tools.

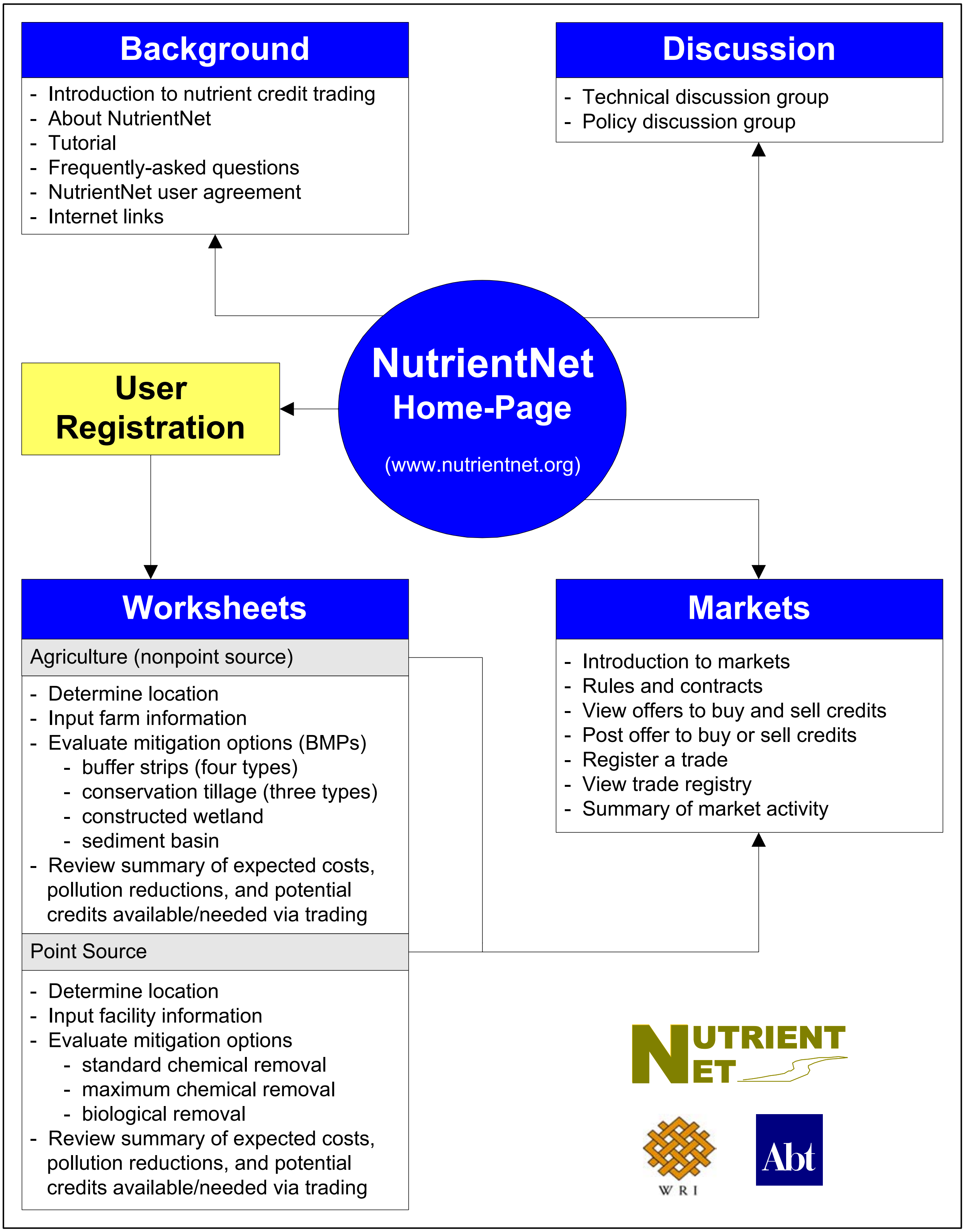
An overview of the *NutrientNet* Website is described in Figure 1. Specifically, *NutrientNet* is designed to serve the following functions:

- Provide potential market participants and other stakeholders with background information on nutrient trading;
- Provide farmers, municipal treatment works, and industrial plants with tools for estimating releases of nutrients to surface waters from their operations, exploring reduction options, and estimating the costs of achieving reductions;
- Help market participants identify potential trading partners;
- Track the volume and type of trades within a watershed;
- Share lessons learned about trading across the watersheds where it is being tried or considered; and
- Provide information on water quality problems and trading as a possible means to address them.

Using the *NutrientNet* Tool

Accessing the *NutrientNet* trading tools begins once the user has registered. Depending on their operation, the user clicks on the "agriculture" or "point source" worksheets and locates their farm or facility within a particular watershed using a geographic information system (GIS) interface. This allows the Website to retrieve valuable site-specific information -soil type, slope, distance to streams, etc.- that is used by the estimation tools to determine the amount of nutrients entering nearby waterways. The use of a GIS interface reduces the cost that users would incur if they were to collect these data to estimate their nutrient runoff. The user inputs additional site-specific parameters -current production and nutrient management activities, wastewater treatment practices in place, etc.- that are also used to calculate the baseline nutrient loading.

Figure 1. NutrientNet Internet Tool Overview (www.nutrientnet.org)



Next the user inputs design and cost parameters for the potential mitigation options available for implementation. This information is integrated with existing models of nutrient management, runoff reduction rates, and the efficiency of wastewater treatment facilities to assess the cost effectiveness of reducing nutrient loads by implementing the selected nutrient management option(s).

For potential sellers of nutrient credits, the user is shown a summary of the estimated number of credits available for trading based on their nutrient load reduction, as well as the expected cost. For potential buyers of nutrient credits, the user is shown the cost of implementing the different types of treatment practices, as well as the number of credits necessary to come into compliance with permit restrictions and/or water quality standards. Figure 2 illustrates worksheet results based on parameters from an example farm and wastewater treatment facility. The displayed results, particularly the break-even cost per credit, are a reference for the user for establishing an offer price to buy or sell potential nutrient credits.

NutrientNet allows users to post offers to buy or sell nutrient credits at an e-marketplace, contact each other via e-mail securely through the Website, negotiate/exchange their nutrient credits, and complete trades. A prototype registry tracks the trades that occur, providing government agencies and the general public with an easily accessible oversight tool. *NutrientNet* also presents general information about nutrient trading along with rules, regulations and contracts for each trading program and links to pilot trading programs throughout the United States.

Figure 2. Hypothetical Results for a Nonpoint and Point Source *NutrientNet* User

Worksheets

Agriculture (Nonpoint Source)

Best Management Practice[a]	**Implementation Cost per Year**	**Cost per Pound of Phosphorus Runoff Reduced**	**Cost per Phosphorus Credit ($)**[b]	**Credits Available for Trading**
With cost sharing[c]				
Conservation Tillage (No-Till)	($390)	$0	$0	0
Grass Filter Strip	$685	$3.85	$7.70	53
Both Options	$295	$0.93	$1.86	18
Without cost sharing[d]				
Conservation Tillage (No-Till)	$1,410	$4.75	$9.51	148
Filter Strip	$1,140	$6.43	$12.90	89
Both Options	$2,550	$8.05	$16.10	159

Point Source

Treatment Practice	**Phosphorus Reductions (tons/yr)**	**Total Annual Cost (millions)**	**Cost per Pound of Phosphorus Runoff Reduced**	**Credits Needed for Comply with Regulation**	**Credits Available for Trading**
None	0	$0	NA	22,800	0
Standard Chemical Phosphorus Removal	9.1	$0.60	$32.70	4,600	0
Maximum Chemical Phosphorus Removal	12.2	$0.66	$26.80	0	1,600
Standard Chemical Phosphorus Removal with Filtration	13.7	$1.23	$44.70	0	4,600
Biological Phosphorus Removal	9.1	$0.34	$18.90	4,600	0
Biological Phosphorus Removal with Filtration	13.7	$1.17	$42.60	0	4,600

[a] The current version of NutrientNet includes available tools for evaluating conservation tillage (10% mulch, 20% mulch, and no-till), filter strips (grass, hay, timber, multi-species), constructed wetlands, and sediment basins. For this example, only no-till and grass filter strips were evaluated.

[b] This cost represents the break-even cost per credit to farmers for generating the expected number of nutrient credits. Presumably the user would use this estimate to base their offer to buy or sell nutrient credits in the marketplace. The cost per phosphorus credit reflects a 2:1 trading ratio, which is applicable to nonpoint sources. This means every two pounds of phosphorus reduced is equivalent to one phosphorus reduction credit. Most watershed-based trading programs include a trading ratio to account for the risk and uncertainty associated with nonpoint source pollution control effectiveness.

[c] In most instances, the proportion of nutrient credits generated through implementation of best management practices subsidized through cost share programs are not available for trading. In other words, farmers are typically restricted from receiving compensation twice for reductions in nutrient loadings.

[d] A farmer who assumes all best management practice implementation costs would be allowed to trade up to 100 percent of the expected credits generated.

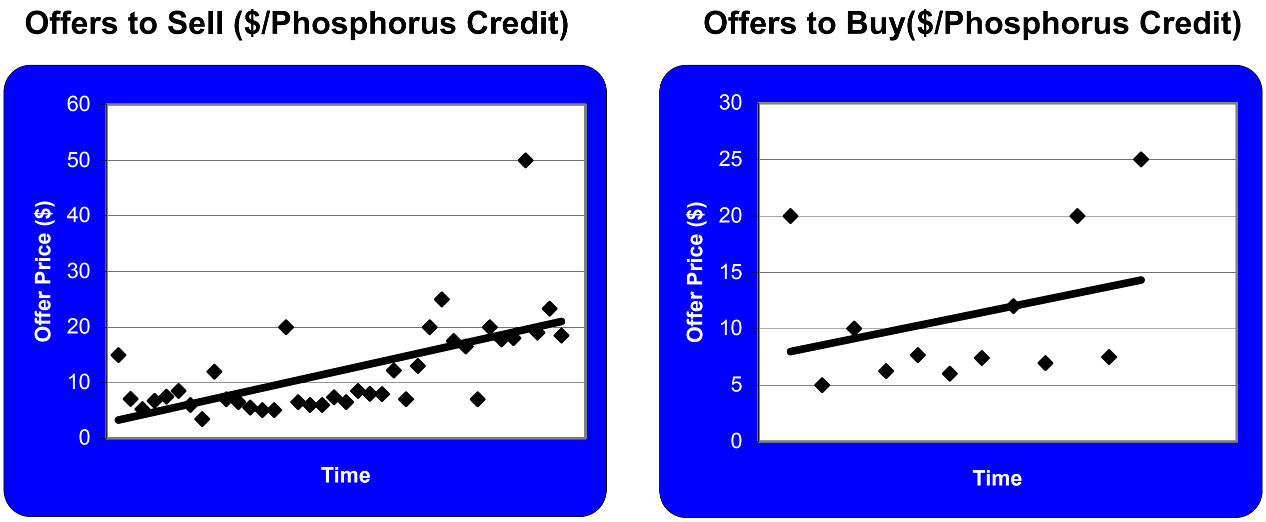
Experimental Use and Application of *NutrientNet*

A demonstration version of *NutrientNet* has already been developed for the Kalamazoo River Basin in Michigan. In this case study, phosphorus reduction credits are assessed and traded using *NutrientNet*. The Website has been tested and evaluated on several occasions among various stakeholder groups and interested parties, including farmers in the Kalamazoo watershed and EPA staff. These 'play at trading" exercises have yielded excellent feedback that is being incorporated into future versions of the Website. Figure 3 illustrates the marketplace results from one of these "play at trading" exercises.

Figure 3. Results From a Recent Demonstration Using NutrientNet to Trade Phosphorus Credits Among Hypothetical Farmers and Wastewater Treatment Facilities

Three-Day Phosphorus Credit Market, Kalamazoo, Michigan

Number of Participants: 49
Offers to Sell: 38
Offers to Buy: 12
Total Trades: 26
Total P Credits Traded: 12,833
Total Phosphorus Potentially Reduced: 23,188 lbs.



The three-day phosphorus market demonstration resulted in 26 total hypothetical trades (12,833 credits) with a potential reduction of more than 23,000 pounds of phosphorus. The demonstration offered a glimpse of the market activity to be expected with a live watershed-based trading program using *NutrientNet*. The market price per phosphorus credit increased over time as sellers with relatively low asking prices were dealt with first and credits became scarcer over time. In this demonstration there were insufficient credits available to clear the market, however, one buyer was able to aggregate credits and resell the bundle to another buyer at a significantly higher asking price.

NutrientNet for the Kalamazoo watershed currently includes Michigan-specific policy, economic, and modeling considerations. Through further enhancements to NutrientNet, we anticipate NutrientNet to be fully compatible with Michigan water quality regulations (finalized November 2002) and in accordance with EPA's National Water Quality Trading Policy.

The Future of *NutrientNet*

NutrientNet is currently being developed for the Potomac watershed, a sub-basin within the Chesapeake Bay watershed. For this case study, nitrogen credits will be tradable based on modeling and estimation tools specific to the Potomac watershed. The following activities are planned for this new application of *NutrientNet*:

- Alignment of policy considerations with EPA's National Water Quality Trading Policy;
- Improvement of nutrient transport modeling capabilities;
- Expansion of economic modeling capabilities;
- Diversification of the suite of pollution control options available;
- Upgrade of *NutrientNet* code with a more robust computer programming language; and

- Expansion of the functionality of the Market section.

The development of *NutrientNet* for the Chesapeake Bay is important not only for improving water quality conditions in the Chesapeake Bay but because of the valuable information that can be obtained through the development of pilot trading programs. Because of the Bay's size and its multiple jurisdictions, it is the optimum system to test how to implement trading programs in multiple watersheds of different sizes and with different regulatory requirements that together form a compact. By developing *NutrientNet* in coordination with the different State agencies in the Bay we can test and compare the development of pilot programs that will be specifically designed for each watershed permitting system, regulatory requirements (types of NPDES permits and whether a TMDL is in place), type of nutrient (nitrogen or phosphorus) and size of the watershed. What we learn from this project will serve to understand how to better develop and implement successful trading systems in other regions of the United States leading to substantial improvements in water quality nationwide.

IMPLICATIONS

We anticipate the lessons learned from the development of *NutrientNet* will enhance State and national water quality trading policy considerations through ongoing effort to address implementation issues. Specifically, use of *NutrientNet* may facilitate the development of successful watershed-based trading examples and help identify critical constraints and opportunities for broader implementation of appropriate policies. The Internet-based approach used to integrate GIS and water quality modeling with economic considerations and the development of a robust nutrient credit marketplace may also aid States considering implementation of a watershed-based trading program.

Water Trading: Bringing Non-Point Sources into the Fold

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The Water Trading session of this workshop has produced four very interesting papers that fit together nicely with a common theme. Alan Randall's paper (Sohngen 2003) suggests a voluntary program in which farmers are encouraged to form groups to reduce their non-point source pollution – nitrogen, in this case. The reduction of nitrogen loadings to the waterway is accomplished through the implementation of "Best Management Practices," or BMPs, with the performance being measured as the entire group's performance in achieving the pollutant reduction.

Mr Randall's paper both informs and is informed by Claire Schary's paper (2003). In this paper, Ms. Schary lays out the desirable design elements that one would want in a water quality trading system and then shows how those elements are being applied in the Lower Boise River. Ms. Schary is informed by Mr. Randall's paper in that group contracts could be considered for the trading program being implemented on the Lower Boise River. However, Mr. Randall is also informed by Ms. Schary paper in that the design elements that she lays out should almost certainly be present in any trading scheme he proposes. While the pollutants of concern in the two papers are different – they plan to trade phosphorous credits on the Lower Boise – the two schemes are basically the same. Farmers in the Lower Bosie basin are induced into participating in this program and then asked to reduce their non-point source pollutant through the use of BMPs.

Our third presenters, Mr. Thurston and Mr. Goddard, are informed by Ms. Schary's paper in the same way; the trading scheme that they propose should include the design elements that she details. Their set of papers (Thurston, et. al. 2002, Goddard 2003, Thurston 2003) deal with a different pollutant, storm water runoff, but the fundamental concepts are the same as with the others. Non-point source polluters (residential and commercial properties, in this case) are being induced to participate in a trading scheme with the promise of potentially profitable credit sales, and the pollution is reduced through the use of BMPs.

Finally, Mr. Landry's paper (Landry and Faeth 2003) offer us an internet-based system by which all of the previously mentioned trading schemes could be implemented, the NutrientNet system. I actually participated in one of the trial markets for this system and the Kalamazoo River Basin trading scheme used there involves all of the same elements as we have been discussing. Farmers producing non-point source pollution – phosphorous again – sell pollution credits to point sources for a profit in exchange for implementing BMPs.

The common theme to all of these papers, which by now is obvious, is that in each case we are bribing non-point source polluters to participate in the system and implementing BMPs.

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What I would like to do is to is to offer some constraints that regulators face in trying to actually set up these trading schemes. Now, in doing so, it may appear to the causal observer that what I am doing is trying to stick my finger in the eye of a program that has been shown by many, many journal articles to produce a lower-cost solution than the traditional approach. And, in fact, that is what I am doing; but let me explain.

Here, I am borrowing a story from an article by Gregory Mankiw (1990) on the acceptance of advances in macroeconomic theory by practitioners. When Copernicus introduced his heliocentric system, the idea that the planets revolve around the sun, he originally used circular orbits to explain the planetary movement rather than elliptical orbits. Now there were a number religious reasons for the resistance to the Copernican system, but to an academic at the time, this was a much more elegant system than the prevailing Ptolemaic system. However, from a practitioner's point of view, if you were going to navigate a ship at this time, the Copernican system was less well known and was originally less reliable than the prevailing system. Given a choice between the two, the practitioner would opt for the old system. Eventually, however, as the Copernican system was refined, it was ultimately accepted as better than the Ptolemaic system, and you wouldn't think of using anything but that system and its subsequent advances today.

I believe that we can draw an analogy to where we are today with trading systems. As I said, there are many, many journal articles that show that the trading schemes produce a lower cost solution than a command and control option. From an academic point of view, this is a much more elegant system. And yet, there is resistance to its adoption. What I would like to do it to describe some of the constraints that practitioners of these schemes face when trying to implement them on the ground.

Legislative and Regulatory Contraints

I will begin with some legislative and regulatory constraints. Currently, point sources are regulated, under the authority of the Clean Water Act (2003), through the EPA's National Pollutant Discharge Elimination System (NPDES) permit program. Point sources are any discernible, confined and discrete conveyances, or any vessel or other floating craft from which pollutants are discharged into waters of the United States. Under the NPDES, industrial, municipal, and facilities other than individual homes must obtain permits, which limit the amount of this discharge (EPA 2003b). The performance of treatment and control technologies required for these wastewater discharges are dictated by the EPA's effluent guidelines (EPA 2003a). So there is direct, regulatory control over point source pollution.

This is not at all how the EPA deals with non-point source pollution. By and large, non-point source pollution is controlled through state management programs, technical assistance, grants, and information provision. So why the disconnect? Why not simply control non-point source pollution in the same way as point source pollution, by requiring the non-point source polluters to obtain permits and subject themselves to technology-based guidelines? The answer has to do with the way in which these two sources are regulated under the Clean Water Act (2003). Under this Act, point sources are specifically subjected to the NPDES system. Non-point sources, on the other hand, are covered under Section 319 of this Act. Here, there is no mention of direct control, only the indirect control measures (grants, etc.) mentioned above. This has generally been interpreted to mean that the EPA has weak regulatory authority over non-point sources. So, the Agency is resigned to controlling these source through voluntary measures, such as trading schemes and BMPs.

Another problem has to do with locating the non-point source polluters. Under Section 308 of the Clean Water Act, the EPA has the authority require owners and operators of point sources to provide records and reports related to pollutant discharges. This means that the EPA is able to send out letters to these sources ("Section 308" letters in Agency parlance) requesting information so that it may design optimal regulation. Not so with non-point sources. And, even if the EPA could survey them, in many cases it doesn't even know where the non-point sources are. This was true with the EPA's recent Concentrated Animal Feeding Operation (CAFO) rule. Farms, in general, are non-point source polluters, but the Clean Water Act allows the EPA to designate certain farms as CAFOs and reclassify them as point sources. In effect, we are relabeling the non-point sources as point sources, and thereby providing the regulatory hook, including the ability to send out 308 letters. The problem was that we don't know where the farms are. The U.S. Department of Agriculture has this information, but they are prohibited from using the data for regulatory purposes. What, ultimately, was done for that rule was to predict the pollution from "model farms" and then estimate the location of these farms for the regulation. This location estimate may or may not reflect reality. The point is that without detailed knowledge on the location of non-point source polluters (knowledge that we generally do no have), regulating these sources is very difficult except using a voluntary, opt-in program like trading.

Public Reaction Constraints

For some, this type of voluntary trading may be acceptable, and even desirable. For other, it is an anathema. This is evident in the various articles and editorial that have been written in the past objecting to these types of schemes (for example, the editorial by Sandel (1997)). It is important to recognize that some will have a visceral reaction to any trading schemes, and this will inhibit the implementation.

Another common public reaction is a call for uniform regulation. There seems to be a perceived "fairness" in having all entities regulated to the same level of emissions. This, however, is precisely what the trading scheme is attempting to avoid. The reason that trading schemes produce a lower-cost solution than the command-and-control regulatory approach is exactly the fact that entities have a different pollution discharge. Low cost abaters pollute less and high cost abaters pollute more. The public's perceived "unfairness" of this scheme will also affect its implementation.

We must also look at the behavioral responses associated with the trading scheme once it has been implemented. In particular, we have to consider the effect of subsidies and other cost-sharing efforts. The reason that this is important to mention is because economists often skip these issues since they are transfer payments. In the economic social cost calculus, transfer payments are not counted as social costs. But they are important in determining the success of a trading scheme. For example, during the beta testing of NutrientNet at the EPA, I was a non-point source polluter responsible for selling my pollution credits. I had to consider the profit of selling my credits both with and without cost-sharing. Ultimately, I decided that it was more profitable for me to not accept the government cost-share money since I could sell more credits. The point is that these things have important behavioral consequences even if they do not affect the social welfare calculations.

Environmental justice concerns also affect the public's reaction to these types of schemes, particularly when they are contrasted with taxation. This is illustrated with the stormwater runoff trading scheme suggested by Thurston and Goddard. The comparison that they make is trading versus a big, publicly-funded infrastructure project. Not unsurprisingly, they find that the trading scheme is cheaper than the infrastructure project. The problem is that who is being taxed appears to matter to the public. If the public infrastructure project is be partially funded through corporate taxes or user fees, then it might be more desirable to the general public even if it is more expensive. Particularly if the trading scheme would require low income and minorities to potentially buy pollution credits.

Benefits and Costs Calculation Constraints

Lastly, I'll mention a few constraints associated with the calculation of benefits and costs. While there are some human health consequences associated with water pollution control, they tend to be small. Particularly given the small magnitude of the expected improvements and the current level of pollution in these streams. The greater benefits category is improved recreational opportunities. In terms of producing a willingness to pay value, I would argue that economist have more tools and wider acceptance of the valuation techniques for human heath benefits. To get at national-level recreational benefits and, perhaps more importantly, non-use benefits, we are probably relying on contingent valuation, CV, surveys. These are more controversial, particularly to the Office of Management and Budget, than revealed preference approaches.

With water pollution, there is also the problem of which pollutants are included in the willingness to pay calculation. In air pollution regulation, there is a tendency to address issues one pollutant at a time. This may be because the human health consequence of each pollutant can be measured. In water pollution regulation, however, there has been a tendency to measure things using an index, such as an index of water quality or an index of biological integrity. If people have a stated willingness to pay to improve water quality in general, which pollutants are included in the index matters.

This is important since trading schemes usually involve trades of a single pollutant. If, however, water quality is a mix of pollutants, then the benefits gained from the trading scheme will be affected by pollutants which are not being traded. It is also important if pollutants which were previously not considered part of the index were later regulated and added to the index. If the addition of new pollutants dramatically affected the value of the index, then it could cast doubt on the benefits calculations.

Once a defensible willingness to pay is obtained, there is still the problem of how to associate it with stream miles. In the Lower Boise River trading scheme, "Parma Pounds" were used to normalize the effluent by the impact that it has on Parma. This is a recognition of the fact that a single downstream point needs to be identified to calculate the trading ratios. Improvements in water quality can then be measured at this point. The problem is that willingness to pay for recreational benefits and non-use benefits applies to the entire stream reach. To calculate the benefits of improvements correctly, you must distribute the willingness to pay value across all of the stream miles in the rivers system and assess the improvements at each mile. This will impact not only the magnitude of the benefits from this type of program but, I would argue, possibly the direction of these benefits as well.

Additionally, there are temporal considerations. That is, it is important to specify how long the improvements will occur. If we have to distribute the willingness to pay value across all river miles, then we also have to distribute it across all time. It is then unclear how to account for very short-term improvements in water quality, such as those obtained with storm water trading. In the most simplistic application, we divide the willingness to pay for improved water quality by 365 days to get a daily value. The implication is that the benefits are diminished dramatically when the improvements only occur sporadically.

Finally, there are considerations with calculating the social cost these schemes. The result that trading schemes produce lower-cost solutions to pollution regulation than command-and-control measures is based on an estimate of the cost of compliance. However, to properly measure welfare effects, we must consider the cost, in time, of both learning a scheme and implementing it. While this may not tip the balance against trading schemes, it does change its relative efficiency.

In conclusion, I should reemphasize that the purpose of my comments is not to suggest that we should not implement these water pollution trading schemes. In fact, I am a big fan of this type of market mechanisms. My purpose here today is to serve as a foil; to list some of the difficulties that regulators face in implementing these programs. If we can address these difficulties, then we move closer to both implementation and a realization of the cost-savings implied by the literature.

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Discussion: Water Quality Trading

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Any brief, critical synopsis of four distinct research and policy efforts is a challenge at best, as the reviewer bears responsibility for disentangling a complex tapestry of ideas and reweaving them in a manner that resonates with a similarly engaged audience. The task is made more difficult when each of the original projects is of the high quality demonstrated here today. Clearly the entirety of each effort reviewed cannot be covered. Thus, from the outset, I wish to offer my apologies to each of the investigators, in case my attempts to caricaturize their research diminishes or otherwise waxes over the solid contributions made by the research and policy efforts underlying each presentation.

To synthesize these four presentations I have chosen to organize my thoughts along the following two issues:

1. Can we extend theoretical foundations and the success of SO2 "Grand Policy Experiment" to water quality allowance/credit trading for non-point source pollution?
2. Should we be looking beyond allowance/credit trading when addressing incentive mechanisms from non-point source pollution?

Within the first theme I further arrange my commentary in accordance with Goddard and Thurston's statement: "Two necessary conditions for tradable allowance regimes to be cost reducing are that: i) There be sufficient difference in abatement cost across parcel owners so that potential cost savings can be realized by market exchange of runoff control; and ii) The transactions costs of such programs be no greater than the gains achieved." Throughout I should also note that I will largely remain in my academic comfort zone by directing the bulk of my comments toward the Randall et al. and Goddard and Thurston presentations. I trust, perhaps naively, that my co-discussant from the EPA will have more to say on the field implementation projects.

1.i: Goddard and Thurston - "Is non-point source control potentially cost-effective for urban storm water runoff?"

Standard economic presentations of pollution control policy make the important distinction between efficiency and cost effectiveness. Efficiency focuses on maximizing the net benefits of pollution control, which conceptually occurs where marginal costs equal the marginal benefits of abatement. Rather than seeking an optimal level, cost effectiveness instead takes an exogenously determined target level of abatement and seeks to minimize costs of achieving this objective. For the inclusion of non-point sources abatement to be more cost effective than relying solely on point sources, the abatement costs of at least some non-point sources have to be lower than those of point sources. In order for trading programs to potentially reduce costs relative to more traditional command-and-control methods, the marginal abatement costs need to differ substantially between traders.

Whereas the policy literature generally recognizes that the marginal costs of non-point sources pollution abatement may be lower than those of point sources, and conventional wisdom suggests that agricultural non-point source pollution control in particular offers the potential to cost-effectively achieve abatement levels in a given watershed, such relationships have not been adequately investigated for urban runoff. In a very original effort, the three papers provided by Goddard and Thurston in preparation for this conference[1] offer a considerable step forward in addressing this critical information gap. Together these papers provide a nice systematic evolution toward "other-than-engineering" costing approach. I see this progression as establishing a standard for future efforts to systematically evaluate the viability of including non-point source trading into pollution control regimes.

In the first paper (Thurston et al, forth.), a 'simple' engineering approach suggests that there is ample heterogeneity in abatement costs associated with controlling excess non-point source runoff. Moreover, at this dispersed engineering stage, non-point source pollution appears to be cost-effective relative to centralized engineering approaches that will involve substantial public investments. In obtaining this result, the analysis relies on best estimates of runoff control associated with particular management practices.

Importantly, Goddard and Thurston do not stop with a simple engineering analysis of excess non-point storm runoff, recognizing that the heterogeneity in implementation costs is not simply comprised of differential installation and maintenance costs and the physical characteristics of the land. They correctly argue that a more complete accounting would include the opportunity costs of private land diverted from other uses. Thurston uses standard hedonic pricing (property value) approaches to estimate the opportunity cost of alternative best management practices for individual parcels. As would be expected, accounting for this opportunity cost somewhat erodes the cost effectiveness of using dispersed non-point source pollution controls relative to the centralized option.

Moving in an alternative, but complementary, direction the Goddard paper adopts an ecological economics approach in which stream flow serves as an explicit constraint to preserve stream and riparian habitat, and in which chance constrained modeling is used. This latter restriction alters the planner's choice framework to focus on the incremental costs per unit of reduced probability of exceedence of the norm or stream standard. As such, it more closely reflects the extreme event nature of many water quality issues.

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[1] All comments in this discussion paper are directed towards the papers provided by the authors previous to the Washington D.C. meeting, and to the actual May 1 presentations. Final papers may differ from the ones provided to Poe.

I encourage the researchers to continue along these more recent lines of thought, and to recognize that there will be great benefits from this research regardless of whether they accept or reject the hypothesis that non-point source runoff control can be a cost-effective means of meeting water quality targets. While doing so, I urge them to further move in the direction of behavioral and ecological economics perspectives along the following lines. First, rather than assuming "rational behavior" in which participants will trade based on narrow economic concepts of gains and losses, actual behaviors need to be incorporated into their modeling. Real humans making real decisions do not act like profit maximizing automata. Indeed, the foundation of the growing field of behavioral economics is that people do not necessarily behave in accordance with such neoclassical notions of rationally. Kahneman, Tversky, Thaler and others have long demonstrated this point using simple laboratory experiments. One famous example being the so-called endowment effect in which an individual's maximum willingness to pay for a simple commodity such as a university coffee mug is much lower than the minimum price at which they would sell that same mug. I have every reason to believe that such willingness to pay/willingness to accept disparities will prevail when personal property such as "my land" is involved[2]. While such disparities may not greatly affect the fluidity of a tradable permit system once it has been established, it will certainly dilute anticipated cost gains determined by assuming rational behavior.

A second line of investigation that I would encourage is to move beyond the ecosystem as a constraint focus. I agree that a precautionary approach to protecting in-stream services is needed. But given that constraint there may be alternative interior solutions of pollution control that exist over and above the cost-effective option. If we were to take in-stream benefits into account our focus would change to maximizing the net benefits subject to meeting safe minimum standards. Such an approach has long been used in water and ecosystem policy (e.g. Loomis, 1995).

1.ii: Schary, and Landry and Faeth: "Reducing transactions costs in watershed-based trading"

A convenient way of remembering the components of transactions costs is the acronym <u>ICE</u>: <u>I</u>nformation, <u>C</u>ontracting, and <u>E</u>nforcement. Having previous experience with the acid rain allowance trading program, which demonstrated that tradable programs can "work roughly as the textbooks describe" (Schmalensee et al., 1998), Schary logically uses this successful program as a guide. Have no doubts, setting the bar at the SO_2 standards has led to an extremely inventive and innovative program design for the Lower Boise River and one can only hope that authorization for implementing this program will ultimately be attained. Nevertheless I see the potential for greater lessons-to-be-learned not from emulating a program that may serve as an elusive pinnacle, but rather from building from a foundation of errors gleaned from other water quality trading programs. While I sense that Schary has indeed conducted and internalized such an exercise, such lessons-to-be learned were not provided in the May 1 presentation.

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[2] Further, with the advent of West Nile Virus it is likely that certain homeowners may be very reluctant to encourage surface or near-surface water accumulation in their yards and properties.

In using the SO2 program as a standard bearer, it is important to realize that that program had several features that primed it for success: uniform mixing, numerous point sources, cap-and-trade, continuous monitoring, an exchange institution etc. As Schary clearly recognizes, it would be a stretch to assume these features hold for watershed level water quality issues. The differences between the two situations are substantial, perhaps even non-comparable. And I would guess that many of the managers launching into previous water quality trading projects made a similar proclamation to that made by Schary that "there is nothing wrong with the design". Yet, in spite of such like claims, very few water quality "trades appear to have actually taken place" in the United States (King and Kuch, 2003). Retrospective analyses of on-the-ground pilot trading programs have concluded that the lack of trades can largely be attributed to inherent design flaws in the individual programs that were not a-priori identified (e.g. Fox River - Hahn, 1989; Tar-Palmico – Hoag and Hughes-Popp, 1997; Lake Dillon –Woodward, 2003). This is not to say that the Lower Boise design has inherent flaws. Rather, I am impressed by the considerable details and obvious thought that have gone into calculating Parma pounds and other trading ratios. Such efforts will surely reduce information and contracting transactions costs, increasing the likelihood of future trades. Yet, I would be further reassured that we were not reinventing a flawed wheel if instead of limiting the focus to emulating the SO_2 success, Schary could provide details on why previous water trading programs have failed and how the Lower Boise program has been designed to account for flawed design features. Such an effort would offer a considerable complement to the present focus on replicating national air quality programs at a watershed level.

I have little in the way of comments on the Landry and Faeth presentation, except to applaud (like I do Schary) their innovative efforts to reduce information and contracting costs. In a practical sense, I fundamentally believe that reducing transactions costs will greatly improve the likelihood of transaction taking place. From an academic and reviewer's perspective, I remain keenly interested in how the hypothetical information about how the auctions were structured. I simply need more information than the summary paper provided in order to adequately comment on this aspect.

Since this is a conference about trading, I should note that there appears to be gains to trade from collaboration between these two innovative efforts. Although Schary indicates that the Lower Boise is structured as a "bilateral trade" and Landry and Faeth focus on a "clearing house" structure that puts likely buyers and sellers in contact for subsequent bilateral negotiations, they are both focusing on the same critical issue of providing relevant information to participants and facilitating contracting. It would be wonderful if these two efforts could collaborate and learn from the other.

While much attention is given in these two papers to reducing the information and contracting element of transactions costs, little attention is given to enforcement. It is widely observed that maintenance components of many CRP contracts are not being implemented, and I would suspect that the same would hold for urban runoff (my children would likely dig trenches through any swale!). It is this problem that Randall et al. take on directly.

2. Randall et al. - "The Problem of Enforcement"

In their research effort, Randall and colleagues (Sohngen et al.) reject the notion of relying on tradable pollution permits because of the well-known asymmetric-information issues plaguing non-point source pollution control: adverse selection and moral hazard. As an alternative to credit trading programs, these researchers pursue a voluntary auction-based approach to solve the adverse selection problem of not knowing the abatement costs of individual farms (and hence not being able to identify the farms with the lowest abatement costs). The moral hazard or enforcement problem is resolved by a group "all or nothing" contract that pays based on whether ambient water quality measures at a given location are less than or exceed a given target. It is argued that group pressure and commitment will reinforce financial incentives to behave in a group-regarding manner.

The threshold abatement model suggested by Randall et al. is a "razors edge" analogy to the provision point mechanism long discussed in the private provision of public goods literature. Such modifications of voluntary contributions mechanisms for funding public goods have been in the economics literature since at least Brubaker (1976), with the Nash equilibria properties established in Bagnoli and Lipman (1989). I use the term "razors edge" to highlight the extremity of the "all or nothing" feature of the proposed mechanism, and to contrast it with the less extreme money-back-guarantee (i.e. if the threshold is not reached, all contributions are returned) and excess rebate (i.e. if the threshold is exceeded either benefits are extended or excess funds rebated in a proportional manner) modifications been shown to increase the efficiency of the provision point contributions mechanism (Isaac et al., 1989; Marks and Croson, 1998; Rondeau, Schulze and Poe, 1999)

The innovation in this application is that rather than groping to one of the infinite number of Nash equilibria combinations of contributions that exactly sum to the threshold level, Randall et al. have the participants define a baseline threshold and Nash equilibrium combination of abatement. This is an important practical contribution as it is transparent to the participants that any unilateral deviation from the agreed group contract will probabilistically make the individual worse of. Hence, it is costly to defect. I also find the moving from the field to the lab approach a refreshing alternative to theoretical formulation completely removed from reality.

Nevertheless, as with any new mechanism, moving from concept to reality and reality to concept is a tremendous hurdle, a point that is adequately demonstrated within the credit trading program depicted in Schary's presentation. Two related complications seem to arise within the Randall et al. mechanism. First, although the theory assumes risk neutrality it appears that the existence of non-participation amongst individuals (who would likely benefit from participating) would be an indicator of risk aversion. Reflecting this possibility, the Sohngen et al. paper notes that non-bidders were in general concerned about the game and concerned about getting involved in a contract. Personally, I have no problem in assuming neutrality in laboratory test of a theory assuming neutrality. However, by starting in the field and learning through focus groups, Randall et al. bear the onus of reflecting what is learned in the focus groups.

Regardless of whether it is caused by risk aversion or not, the end result is that there are some non-participants in the watershed. As such there is a stochastic element completely out of the control of the participating group of farmers, which very much undermines the incentives of the voluntary all or nothing program. This stochastic nature may be perfectly correlated with bad weather rolls of the dice. In such an instance the magnitude of the variation in pollution will depend upon the relative number of participants and non-participants – i.e. it is not possible to maintain a ± 20% weather variation when participation rates vary. Even more complex is the situation where the variation in runoff on non-participating farms is not perfectly correlated with the stochastic variation on participating farms. For example, non-participating farmers may choose to expand herd size or other potentially polluting input. In either case the additional randomness associated with non-participants adds an uncontrollable element in decision-making and would hence impact, and perhaps undermine the strategies of the participants.

There may be ways to minimize non participation and hence regain control of the incentive mechanism. Variants of money-back-guarantee and excess rebate schemes have been shown to vastly increase participation rates in contribution mechanisms, and it seems reasonable to extend these design features to the current mechanism. Another possibility that seems particularly suited to the small watershed orientation of this project is to allow for collusion. For example, recent experimental research on the well-known Segerson group-enforcement mechanism (1988) show the effectiveness of this mechanism is greatly enhanced by cheap talk (Vossler et al, 2002). Other possible ways to encourage participation should definitely be explored. Until the problem of non-participation is resolved, implementation of the proposed mechanism will be problematic.

Concluding Comments

In an e-mail communication prior to this meeting, Alan Randall noted "It's hell to be a discussant!" I thoroughly disagree. The array of conceptual to implementation presentations at this meeting are destined to make a contribution toward assessing the viability of and implementing market mechanisms for addressing water quality problems. It is a pleasure to see such progress and to have the opportunity for timely exposure to these substantive efforts. In closing, I wish compliment the USEPA Nation Center for Environmental Economics and the National Center for Environmental Research for their foresight in sponsoring these efforts, and to specifically applaud each of the PIs for pushing forward our knowledge in this area

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May 1, 2003 11:25AM
Question and Discussion Session

Q. John Braden, University of Illinois at Urbana – Champaign:
I'd like to ask Claire, who is working in what I view a realistically sized watershed for this kind of program., if she has given any thought to what the really effective number of participants in a market might be? You say that it's really the people close to Parma that will make the big difference. How many sources are there both of point and non point in that domain?

A. Claire Schary:
There are about a dozen point sources. I think there are only going to be about 8 or 9 that would actively be looking to purchase credits. And on the non point side it's voluntary. So I think they will be slow to come to the table and I don't know how many farmers will eventually make it there. We are still waiting for that TMDL. When it is implemented, in place then I think more people will be looking at the size of the reductions that are actually needed. We think that they will actually be required to reduce 80% of the phosphorus loadings in the river when it actually comes through. I think that will bring point sources to the table very quickly and then the non point sources will slowly start filtering in and look more at how they can lump some of the reductions together. It's going to take time to get them used to working with each other. I don't know how many ultimately will be there. I think it will start small and eventually build up some volume.

Q. Charlie Kolstad, Bren School, University of California,
Also for Claire. It's a little unclear for me exactly how far you've gone out of your office with this experiment into the field. I wonder if you can give me a sense of who in the river basin tends to be supporting this activity and who tends to be reluctant viewer of the potential trading system. Not individuals but groups of folks.

A. Claire Schary:
Well initially it was only the point sources that were supportive especially the representatives for the city of Boise. But then the non point sources, once we agreed to certain basic conditions that we are not talking about bringing them into the regulatory world, they really saw this first as a Trojan horse to trap them into regulation. We made it clear that no this is not what this is. We even modified our language somewhat you saw that when we came up with the term water quality contribution. It's an euphemism and everybody knew that it was. It's a sign of respect for the fact that they are not regulated, they are not required to participate, they are not required to reduce. So eventually they came on board and really realized that this is a great opportunity actually to sell another type of commodity. In fact, they are now looking at CO2 trading. They have already identified a list of practices that they can use to sequester carbon. They are really getting on the trading bandwagon so to speak. The environmentalist representative who is no longer with the group, Idaho Rivers United, saw this as a great opportunity also to get the TMDL implemented. So she was just making sure the measurement methods and baselines and all that were consistent with the TMDL. She was pretty broad minded. But unfortunately the Idaho Rivers United did not replace her

so we don't have the full environmentalist support for trading. We had her support. Overall, most environmental groups agree that this makes sense for this watershed but they are not ready to bless trading overall. But we didn't encounter any other opposition there aren't any environmental justice concerns. We have already addressed the issues for hotspots so we didn't have any real opposition once we worked out the basic conditions of trading.

Q. Sarah Lynch, World Wildlife Fund,
I was wondering if anybody on the panel could comment about what they see as more ideal characteristics of a watershed that make it more amenable to trading? That could be the politics, it could be the watershed characteristics, it could be type of pollution….whatever you think is important.

A. Lynda Wynn,
First it seems like you have to have some sort of reasonable split in who is contributing to the pollution between point sources and non point sources. Because the regulatory driver is going to be either TMDL or some other kind of water quality based limit in a NPDES permit. You have to have a sufficient number of point sources present to do that half of the bargain and then you have to have a sufficient,… I'm talking about point and non point source trading. There is certainly point source to point source trading would be another scenario. Then you would have to have non point source contribution to the load that both potential trading partners and load reduction would be achieved through the swapping that would take place through trading. Claire mentioned the TMDL. If the reductions needed under the TMDL are so rigorous that basically everybody is going to have to do everything they can to meet the reductions there will be limited ability to trade. In terms of pollutants, that's a debatable point but my opinion expressed in EPA policy is if you stick with nutrients and sediments that are less likely to have a localized impact that makes things less complicated. Those particular pollutants are quite amenable to trading scenario.

A. Claire Schary:
I would just add that we are still learning what kind of pollutants can be traded. What are their physical characteristics. One important point is they need to stay somewhat whole so that you can see the same pollutant at one point in the watershed and as it moves down the river it hasn't degraded or transformed in a different type or form of that pollutant. Phosphorus seems to stay whole overall. In Oregon we are working on figuring out how to trade temperature in water. That has proven a little more difficult but yet we know the benefits will exceed the costs so we are still working through it. Maybe in a year or so we can give a presentation on that when we figure it all out. Right now we're still trying to figure out how you can translate…you've got a point source that has to meet a limit and in this case there probably will only be one or two point sources in this watershed in Oregon and that will be a successful trade if they can identify a set of practices they want to implement upstream on farmers land and that one trade will still result in a tremendous amount of cost savings and a greater amount of benefits. I would consider that to be a success but it's not going to the dynamic trading that we are talking in the lower Boise. So we will have to be more flexible in terms of how we define success in trading. But

temperature is something you could require the point source to reduce it right at their discharge pipe but the whole river won't stay cool overall so you have to find practices that result in actual reductions in the watershed where you need them to take place not just at the specific point where the practice is happening. There's a lot of different factors to concern.

A. Mark Landry
I just had one quick point that we are seeing that one size does not fit all. I think that what Lynda is mentioning is that EPA is working on a tool to help identify where trading is appropriate or not. I think that will be a critical piece to help assist implementation to help states to see if they have the ingredients that are necessary. As we have talked about today there are so many barriers, concerns and issues that may or may not be unique in certain watershed. So this type of assessment may be really critical.

Q. Peter Kuch, Resource Economist,
I guess this is for Claire Schary. How does the TMDL on the Lower Boise deal with the non point sources there is a load allocation, an aggregate load allocation to the non point sources. How do you figure out what is activity above and beyond the requirement of the load allocation collectively to the non point sources that is potential to generating credits?

A. Claire Schary:
Well technically there is still no TMDL for the Lower Boise. We have to have one established first for the Snake river because that's going to tell us how much the Boise river is going to have to reduce. And I have told you how all the TMDL are being held up due to politics to Idaho.

Q. Peter Kuch, continued
As you conceived it then.

A. Claire Schary:
As we conceived the Boise TMDL would assign a load allocation to the agricultural sector. It's a group. And then it's up to the state to propose a program. This is standard to all TMDL's

Q. Peter Kuch, continued
Then how can you be sure the non point sources won't be regulated.

A. Claire Schary:
Well, Idaho will make sure they are not regulated. But the state approaches implementing the load allocation by establishing a cost share program with state and federal funds. They identify practices that farmers should take on and they offer them cost share to get implemented and there is never enough money to go around. So we are fitting in with that by coming up with a specific list of BMPs that we think are most effective at reducing phosphorus. Those are the ones that a point source knows they have to find a farmer who is willing to install that practice and then write a private contract to make sure that is will take place. And the point source is assuming that liability to make

sure that BMP is in place for the quantity that credit represents. If the farmer fails to do any of that it's the point source that has to go out and find another credit. They enforce however they want to the terms of the private contract. That's not our business. We just keep going after the point source and they said they were happy with that cause that's the reality of achieving a TMDL in Idaho.

Q. Bob Hearne, North Dakota State University,
Kind of a follow up of Greg's point to Allen but I think the direction is to Claire and Lynda. Do we have a clear sense of the law on takings if we establish a TMDL and that means we would require some type of management practices for non point source pollution. Do we know where the property rights are?

A. Lynda Wynn,
TMDL under the Clean Water Act only establishes an obligation on permanent point sources. So there is no obligation under TMDL by federal law imposed on non point sources. Now a state could choose to, as part of implementing a TMDL, impose some sort of requirements and then presumably they'd have to deal with your question. But it doesn't come up as a national matter.

A. Hale Thurston,
I can add to that a little bit. We are keenly aware in our pilot project of property rights issues. The legal scholar, Epstein, talks to that quite a bit. Mostly what it boils down to is something about if a bit of the community is served then is should be able to be legal probably from a state point of view not a federal. To me it sounded like an pareto efficiency condition and we're looking it to that. Indeed the good of the watershed would be improved.

Q. Charlie Howland, US EPA, Office of Regional Counsel,
I am coming from the perspective of a very ignorant neo-economist. I think it's Claire that made that point that has come up in the last three questions, that the only regulatory hook is on point sources. It seems to me that that's the absolute key point that there can never be an actual market in trading among non point sources. That's the whole reason why there's a need for the regulatory system in the first place. There's not a system for protecting private property rights that is in any way practical. I guess my question is, isn't this whole thing, isn't this trading scheme almost everyone has described hinged on the ability for the point source polluter to carry social good load of enforcing this against all the non point source polluters and it would only work if there was at least one point source polluter in the watershed.

A. Alan Randall
In the world as we know it I think you are exactly right. That is the tendency would be to hold the point source responsible for the condition of the watershed in total and have the point source then try to negotiate with non point sources. If we could be relieved of the constraint of dealing with the world as we know it. I think we are free to imagine a regulatory framework on non point sources. The reason I say that is, I do want to get in the point, that the scheme that we are working with could work if in a framework in

which non point sources were regulated to a total because what you would have is the totality of the non point sources contracting in exactly the same way with a sub set among them who are the lowest cost abaters. In one sentence, the Coase theorem applies to this arrangement as well. We could imagine that although the counter weight is that it is so hard for us to imagine a system that isn't based on the principle of sending money to farmers.

A. Mark Landry

I'd like to add one point and that is as economists we know that a market can only function if we have clearly defined property rights. With that comes liability, and of course all these issues that are being raised. This begs the question why not permit or allow some kind of market maker. For example, mitigation banking there are entities that take on that liability and match these entities together and allow that liability to be transferred and held on a responsibility of that intermediary. That is a potential opportunity here as well for these types of nutrient credits or whatever type of pollutant credit or some type of aggregator to bear the responsibility and provide those enforcement mechanism, etc., so that a point source would be alleviated of that liability. I would argue that there would be room for that in water quality trading.

A. Claire Schary:

Yes, you are right. It's the point source that gets the regulatory driver. They are the ones that have to reduce and that pushes them to the table looking for cheaper ways of doing it. The only other model I have seen that has tried to reassign a liability once two parties want to trade with each other is in the state of Michigan. So once again there isn't a project yet that implements this. But their trading rules as I understand them is once a farmer wants to create a reduction they submit a farm plan to their state Department of Agriculture who then takes on the regulatory role and enforces that farm plan. If the farmer fails to follow the plan the state department of agriculture goes after them and the point source isn't liable. That's the only other way I have seen it but it's still the point source that's the driver for bringing the market together. So having a third party match them would still require a point source to be on the hook for making reductions overall.

Q. Michael Hanemann, University of California Berkley,

I wanted to pick up two points. One is the issue of BMPs was raised provocatively by Alan. BMPs are using in the context of many things not just trading. The question is what do we know about how well they work? What do we know about what would make them better and more reliable or less reliable? And the remainder of the issue in water markets is: are people selling paper water rather than real water? I had an experience negotiating BMPs in urban conservation. The whole question of are the savings attributed to the BMPs is are they real or imaginary? A part of this is that you do an ex ante analysis. What experience do we have in ex post ground truthing and follow up? And almost as a theme for a conference, what do we know about BMPs and how they work and how they can be revised. The second point relating to this is futuristic but I've been having discussions with the Dean of Engineering on campus, who's very interested in development of futuristic remote sensing technology involving things like smog dust. Not satellites but really dispersed nano….things like the size of flies which go out there and monitor. This is a real issue. Is there a scope for trying to think about new technologies and target some areas which would essentially measure non point sources? If you look at many areas including SO2 trading it's the improvement in measurement technologies, continuous emissions, computer data bases which make markets possible. So is there an area where we could try and look at improved measurement technology that would shift the regulatory boundary with regards to non point sources pollution in the future?

A. Alan Randall
Of Michael's first question…I have the same question. What do we really know about BMPs. I'll just leave it there. The second one, is whether high tech monitoring has the prospect to making a difference. I think there is a conjunction in there that is high tech monitoring in conjunction with regulatory caps. I think those things together worked in the case of trading among point sources. I don't know if the conjunction is literally unbreakable. We've always knew some things about what point sources were doing we've gotten better at it. Conjunction with a regulatory cap really matters.

A. Hale Thurston
We think that's what we are doing using high tech, hyper spectral fly-overs and what not to actually identify what's coming off at an individual parcel level using newer technologies to actually pin point how much impervious surface is on a given parcel and how much is given off – modeling it at that level.

Q. Gillian Foster, Office of Management and Budget,
I have a question about your price estimates and how you used your price estimates to pitch the trading schemes to the non point source owners and how those price estimates compared to their other economic activity with their land?

A. Claire Schary:
I was going to say this and also in answer to the previous question…In the beginning of the Lower Boise process we actually did a quick and dirty analysis, I will not even call it a economic analysis, but we tried to figure out was there a market and that's when we found out there really isn't a lot of research on BMPs and the ability to reduce phosphorus. We found out there was a lot on sediment. We had to do some extrapolation knowing that phosphorus attaches itself to sediment particles and we could make some assumptions on their effectiveness in reducing phosphorus. We did find that based on the cost studies of sediment that we figured out, ignoring monitoring costs, that they were reducing phosphorus somewhere between 5 and 20 dollars per pound. It really varied because some BMPs are really simple to install like a filter strip or sediment pond that actually captures the sediment, and then you know the sediment isn't being dumped straight into the river that it is effective in stopping the phosphorus in reaching the river. The other things like switching to sprinkler systems and drip irrigation are incredibly expensive for the equipment and operating costs. But they are almost 100% effective in stopping erosion so therefore they are 100% effective in reducing phosphorus. On the

point source side, the first level of technology was fairly cheap especially for the city the size of Boise. It was about 20-50 dollars per pound but it was the second and third tiers of technology that got incredibly expensive. They saw that if they were going to be required to reduce their phosphorus by 80% it was going to cost up to 100 dollars per pound. So they saw trading as a way to trade at that margin for the stage 2 and stage 3 levels of reduction. For the smaller municipalities… Parma is a very small town under a thousand people. Star is a collection of about 200 people and they never really built a sewage plant so they are trying to avoid that cost all together. So they would probably be trading for their entire allocation.

Remarks of Governor Christine Todd Whitman,
Administrator of the U.S. Environmental Protection Agency,
at the
EPA Conference on Market Mechanisms and Incentives
Washington, D.C.

May 1, 2003

Thank you,Tom, for that introduction. I'm pleased to be with you today for this important conference. There is a simple truth underlying this meeting – a truth that I believe needs to be applied more broadly to this country's approach to environmental protection.

That simple truth is this: the power of the market can bring about powerful environmental results. It can help us leave America's air cleaner, its water purer, and its land better protected than we found it – which is, after all, the true measure of environmental success.

Over the years, the EPA has made good use of market-based incentives to produce environmental results. You can go as far back as 1977, when the Clean Air Act was amended to allow for market-based offsets and trading to reduce air pollution. Over the years, additional efforts, such as the Acid Rain program, have used the power of the marketplace to improve our living place – planet Earth.

The evidence is there – market mechanisms and incentives work – especially when they are based on sound science, and not political science – and when they also factor in economic science. The acid rain program is Exhibit 1 – it has reduced acid rain quicker, at less cost, and with greater compliance than anyone expected – and has far outperformed its regulatory counterparts. There's no doubt that the invisible hand of the market can outperform the heavy hand of regulation.

This year, President Bush is working to extend the power of the market even further, to achieve even greater improvement in America's air quality. In his State of the Union address in January, the President identified passage of his Clear Skies Act of 2003 as one of his top environmental priorities for the year. I'd like to tell you about Clear Skies.

Clear Skies is a mandatory, market-based program that will bring about the greatest air quality improvements in a decade. It also represents the most aggressive effort in history to reduce air pollution from electric utilities.

Clear Skies will sweep away all the ambiguity and confusion that the complex web of current laws and regulations engender. It will do that by requiring mandatory reductions – that's mandatory reductions – of 70 percent in three of the most dangerous air pollutants emitted by power plants – nitrogen oxides, sulfur dioxide, and mercury. But rather than have EPA tell every utility what it has to do with every smokestack at every power plant, Clear Skies will use a cap and trade program to achieve significant pollution reduction.

Over the first ten years, Clear Skies will remove 35 million more tons of NOx, SO_2, and mercury from the air than would be achieved by the current Clean Air Act in the same time frame. We will do it without inviting endless litigation and without sending energy costs sky high.

Clear Skies will also bring important health benefits to the people of the United States. Every year, Clear Skies will prevent 12,000 premature deaths and will eliminate the need for hundreds of thousands of hospital visits. It will also reduce by 15 million the number of days each year when millions of asthma sufferers and others with respiratory illnesses can't go to work, school, or carry out their normal day to day activities.

I should also mention that we are calling this plan "Clear Skies" for a reason – because it truly will make America's spacious skies noticeably clearer. We project improvements in visibility of 3 to 4 deciviews, which is the visual equivalent of a decibel. When one deciview yields a perceptible improvement in visibility, achieving a 3 to 4 deciview improvement means you won't be able to miss the improvement Clear Skies will deliver.

In addition, Clear Skies will help the hundreds of counties that are currently in violation of fine particle and ozone standards. Today, the responsibility of bringing those counties into attainment falls to the states and localities – who often pass the buck to local businesses and consumers. Under Clear Skies, the vast majority of these counties will be brought into attainment – without forcing states and localities to pass more regulations to achieve greater reductions.

This approach is not some theoretical experiment. It is modeled on the most successful air quality program of recent years – the acid rain program that I mentioned a few minutes ago. It is also predicated on that simple truth I mentioned at the outset – never underestimate the power of the market to produce environmental results.

Of course, we are not limiting our market-based efforts to one program. There are numerous other areas where we are unleashing the power of the markets to produce real results., Earlier this year I announced our new Water Quality Trading program. You've already heard about some of the local successes water quality trading has brought about. We want to extend those successes all across the country.

The 11 pilot projects we've initiated will help prove to the skeptics that by providing economic incentives to encourage positive environmental action, we can reduce the threat to America's watersheds from both point and nonpoint source pollution.

While wading around in water issues, I should also mention that we are working on proposals to promote market incentives for wetlands protection by private land owners. In cooperation with a number of our federal partners, including the Army Corps of Engineers and the Departments of Interior and Agriculture, we have reaffirmed our commitment to "no net loss" of wetlands and have made a new commitment to using market mechanisms and incentives to meet that goal.

In addition, we are working to marry the need to cleanup America's brownfields with incentives for productive reuse for those lands once they are cleaned up. Last month, I announced EPA's new Land Revitalization Agenda. This program will use the economic incentives that come from the productive reuse of once-contaminated property to accelerate the cleanup of those properties.

Of course, in moving forward with programs such as these, we don't come up with something that sounds good and run out and do it. First, we do the research and the analysis to determine whether what sounds like a good idea really is a good idea. Only after testing that idea – and finding that it has merit – do we move forward. That's the difference between sound science and "political" science when it comes to environmental policy making.

That is why this conference will be so useful to us as we look at other ways we can extend market incentives to other specific areas of environmental protection. The various sessions being held are exploring some of our most important priorities. I look forward to hearing more about the ideas that they cover.

I also hope that this conference will help spark a wider dialogue – and eventually greater understanding by the public – of just how effective such approaches can be. All of us who know that market incentives work need to make sure we let others know the same thing.

The environmental challenges we face in this new century are different, and in many ways more difficult than those we faced 30 years ago. These challenges call for solutions that are designed and tailored to meet them. We can't afford to fight the last war on pollution – we have to be ready to fight the next one. By adding a full array of market mechanisms and incentives to our arsenal, we will be able to leave our air cleaner, our water purer, and our land better protected for our children and theirs.

Thank you.

Market Mechanisms and Incentives: Applications to Environmental Policy

PROCEEDINGS
SESSION TWO

MARKET MECHANISMS IN ENVIRONMENTAL POLICY: A PANEL DISCUSSION

A WORKSHOP SPONSORED BY THE US ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS AND NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH

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Session II Proceedings

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Session II: Market Mechanisms in Environmental Policy: A Panel Discussion **Page**

Tracy Mehan, Assistant Administrator, US EPA, Office of Water

I. Office of Water Objectives

The Office of Water focuses on economics, environmental ecology, and human health when setting its objectives. Currently, a central issue contained within these objectives is monetizing ecological benefits. Presently, the Clean Water Act (CWA), while moving beyond health issues, still has to explore issues fundamental to biological and physical integrity of streams. Moreover, while CWA costs are well documented, ecological benefits have proven to be more difficult to quantify, especially in the non-cancer sector.

The Clean Water Act is presently dealing with several issues as they relate to the interface of economics, environment and ecology. First, the price mechanism is a significant issue in dealing with the investment gap as it relates to water, drinking water, and wastewater infrastructure over time. At present, the United States has the lowest average household cost in terms of paying for infrastructure than any other member countries of the Organization of Economic Cooperation and Development (OECD). Second, mitigation banking in the wetland area is being tried as a least cost market based approach. Third is the whole issue of water quality trading which is the focus of this presentation.

II. Current CWA Status

At present, the CWA is moving away from "end of pipe" solutions and towards examining diffuse sources. The bulk of water quality problems today center on non point source discharges. In addition, the CWA is moving from technology based end of pipe solutions, to achievement of water quality standards as the endpoint to judge the success of the CWA's progress. This will take time as the CWA has been in general, a single purpose tool centered on point source discharges. In addition, cost barriers must be faced as we are seeing increased costs for incremental gains in clean water.

At present, the Office of Water is looking to work with USDA on issues such as Farm Bill implementation, with the Office of Air on issues such as mercury and nitrogen deposition in the Chesapeake Bay, with the Coast Guard controlling ballast water discharges of exotic species, and state and local governments on land use and construction. An important objective is to increase the incentive portion of the CWA, including trading, while still protecting the environment.

III. Water Quality Trading

The Office of Water was drawn to trading based on successes of the Clean Air Act, in particular the acid rain trading program. A significant effort is presently underway to integrate the trading concept in a multitude of clean water programs. One of the main reasons for this is economic: EPA estimates of savings from potential point-to-point; point-to-non point; and pretreatment trading range from $658 million to over $7 billion annually.

Trading may lower costs significantly in certain instances. For example, the World Resources Institute recently completed a study on benefits of trading phosphorus credits between point sources, non point sources and diffuse runoff sources in three watersheds in Michigan, Minnesota, and Wisconsin. The study concluded that the cost estimate for point source controls ranged from $10.38/lb in Wisconsin to $23.89/lb in Michigan, and that trading between point and non point sources may reduce control costs to $5.95/lb in Wisconsin to $4.04 in Michigan.

The success of Long Island Sound (Connecticut) point-to-point nitrogen trading between Publicly Owned Treatment Works is a specific example of significant savings based on trading. This project expects to save over $200 million, and achieve water quality standards 4 to 5 years ahead of time.

The Office of Water is mindful of the technical challenges in creating a market or framework for trading. A key difference with air trading is that the pollutant reductions in air trading are very typically fungible and measurable with CEMS (Continuous Emissions Monitoring Systems) and other such tools. There is no real corollary to this in most water trading scenarios. It is believed that the new January 13 Water Quality Trading Policy will provide an authoritative road map to outline the path forward to assist in achieving water quality standards through trading.

Even with trading as a key tool, emphasis on water quality standards must be kept in mind. A significant concern with trading revolves around potential hotspots and distribution impacts. These concerns are shared by the Office of Water and our endpoint is the achievement of water quality standards themselves. While these standards are largely driven by the states and as such, vary across the country, such standards are in essence our equivalent of the MACT (Maximum Achievable Control Technology) air standards, and must be adhered to as we work our way through trading scenarios.

IV. Future Vision of a Nutrient Trading Program

Imagine an Upper Mississippi or Upper Ohio trading program that provided benefits to the water in the immediate vicinity. This program provides an impetus to achieve a 25-30% reduction of loading to the Gulf of Mexico and begins to roll back the hypoxia problem. At the same time, this program allows members of the Chicago Climate Exchange to purchase credits generated by farmers (with Farm Bill funding) to create greenhouse gas emission credits for NOx, which provides a significant benefit in terms of water quality and carbon sequestration. This scenario allows for multiple benefits with a least cost approach to achieving multiple goals. We need to take advantage of the Farm Bill investment that Congress has decided to make in American agricultural conservation and use it to advance water quality goals.

V. Questions and Answers:

Q: How would you envision all the issues of agricultural subsidies fitting into a nutrient trading program?

A: There are people who are very concerned with allowing credits to be generated through government subsidies, but that is the system we have and must work with. Maybe I don't understand your question.

Q: If the activities have been subsidized, and is part of the baseline, how does that generate a credit?

A: It may or may not be part of the baseline. It is unclear how the USDA will deploy these resources; whether it will be a traditional agricultural program that will be arrayed, laid out as an entitlement program to farmers with a given type of operation. Some people may or may not avail themselves to such a program. In the case of a concentrated animal feeding program, they may get a partial payment for an on-site lagoon system. So they may need the EQUIP money, dollars from a point source looking to buy credits, and dollars from the Chicago climate exchange to sweeten the deal. In this case, what is the term? Will this be done in perpetuity or just in the short term? While I see your point, it is more of a theoretical question, and I think the more difficult question is whether they are going to put in buffer strips in perpetuity or not, which would be more relevant to the carbon and greenhouse gas emission issues and we would need it on the water side at least for the 5 year term NPDES permit. This is a work in progress, done in the spirit of continuous improvement. There will be trial and error, experimentation, failures, but hopefully people will see the economic and environmental logic of this and will make an effort to try it out.

One last thing. Think of all of this as three legs of the milk stool which includes trading, TDMLs, and watershed based permitting. These options allow you to pick and choose the option that best applies to your particular situation.

Market Mechanisms

(Emissions Trading)

1:30-2:30pm

Jeffrey Holmstead, Assistant Administrator, US EPA, Office of Air

Panel session with Tracy Mehan and Paul Gilman

Intro

The Administration has proposed to expand the Title IV cap and trade approach to NOx and mercury through Clear Skies legislation. The Clear Skies proposal—and the other multi-pollutant bills being considered by Congress--are proof positive that market mechanisms have truly arrived as a broadly accepted component of the Government's approach to air pollution.

I know you'll be hearing more about Clear Skies during this conference. I'd like to use my time this afternoon to talk about the many other areas in which the Air Office uses market-based approaches.

Beyond Title IV—market mechanisms over the last 20 years

The Air Office has been using market mechanisms for much longer than most people realize. EPA's first major success in implementing a market-based environmental policy began in the 1980's with the lead phase-down. Historically, lead was added to gasoline to inexpensively boost octane levels, but it also had serious side effects on human health. In response, EPA developed an averaging, banking and trading program to phase-out lead from gas. The program was a total success. Atmospheric concentrations of lead were reduced more rapidly than anyone had anticipated. No price spikes occurred and the program saved around $225 million in compliance costs.

A few years later, EPA adopted a market-based permit system to implement the phase-out of CFCs and other ozone-depleting substances. This strategy was unique in that it included a concurrent excise tax. The result was that the switch to non-ozone-depleting substances was made faster and with less cost than initially estimated. Today, we are using the same method to reduce HCFC use.

Market Mechanisms at Work Today

Since the 1990 Clean Air Act amendments, market mechanisms have become a part of nearly every action we take.

- The NOx SIP call was built upon a regional cap and trade format.
- The offset requirement for new sources constructed in nonattainment areas is also a form of trading.
- Each of EPA's major mobile source rules—including Tier II, the Heavy-Duty Diesel Rule, and the proposed non-road rule—are built on an averaging, banking and trading framework. Even lawnmower makers can trade emissions credits.

We've learned a lot over the last ten years. We know that market mechanisms encourage technological innovations, lower compliance costs, and can bring about early action. We've also learned a great deal about the industries we regulate—which will serve us well in years to come. For example, engine manufacturers are reluctant to trade credits with other companies, however they take full advantage of this flexibility within their own company.

However, as we look to the future of market mechanisms and environmental policy, it will be important to keep a few things in mind:

--Ensuring that a market-based approach achieves equal to better environmental results—to avoid the regulatory relief stigma;
--Recognizing that the EJ community continues to be skeptical;
--Including robust compliance monitoring.

Future Uses

Open Market Trading

Open market trading is a promising approach, although it needs more study. You may have heard that New Jersey and Michigan and the City of Chicago have experimented with open market trading. The result has been mixed.

If properly designed and implemented, I believe this type of trading could be a great tool for areas with the toughest pollution problems. We know that Clear Skies, along with our existing control programs, will bring most of the country into attainment with the air quality standards. Yet, for some areas, like southern California, robust, local measures will be essential. Open market trading programs encourage emissions reductions from the smallest of sources. We've already seen that the possibility of generating open market credits has encouraged diesel retrofit and idling reduction.

Clear Skies

International Trading

Clear Skies includes a provision to study how trading might be expanded beyond US borders. I expect that this issue will gain momentum in coming years.

VOCs

VOC trading is also an area we are putting some thought into. Because of the fugitive nature of VOCs, this presents a challenge.

I imagine that each of you will play a role in designing and evaluating the future role of market mechanisms in environmental policy. I welcome your ideas and your assistance.

May 1, 2003 2:00PM
Question and Discussion Session

Q. Peter Kuch, Resource Economist:
This question is set in the context of Clear Skies but as it applies to water, Mr. Mehan—please feel free to give an answer. It's about the difficult question of allocation. For the most part, emission trade, or cap-and-trade, programs have used to allocate, for free, the allowances to polluters, and there is a notion that there might be good efficiencies or other properties to auctioning them or using other methods, auction in particular, and I believe that Clear Skies has an auction provision. The question I have is: There will be a lot of negotiating about Clear Skies and similar proposals—where in the politics of this does this fall as an important issue? What other things might you give away before you had to give away an auction or vice versa?

A. Jeff Holmstead:
I mentioned before that pollution taxes was a very efficient way of achieving pollution reductions. Auctions are the most efficient way of distributing allowances, but I think it has some of the same political problems. We do believe that for efficiency purposes an auction is the right way to go, but I can't say that that's one of our highest priority issues. So it's something we do believe in, and we know that there are other people who, understandably, would rather not have to pay for something that they might be able to get for free through the political process, and at this point, our real goal is to get 50 votes in the Senate and 218 votes in the House, and we're looking at a lot of different ways that we might be able to do that.

A. G.Tracy Mehan:
From the water perspective, it really is a whole different parallel universe. First of all, it's an extremely federalized program in that 45 states have delegated authority to carry out the Clean Water Program. This is where the TMDL program can have a lot to say, because under a TMDL (total maximum daily load), when it's approved by EPA (usually it should be done by the state and approved by the EPA), it will do a waste-load allocation to the point sources, so specific point sources will get an allocation. Then it's either a gross-load allocation to the non-point sources or sometimes there could be sub-categorization depending on the data. But, the one universe is regulated—the other is not. Right now, at least among point sources—you know, even without a TMDL—there are usually off-line negotiations and then they come in and all the point source discharges will lay it out to the permit writers, say in a state agency, and you're overall okay. You meet the technology-based standards and whatever we think we can do on the water quality standards, and then they all agree to it.

I think it's going to be very different and it's going be driven, again, state-by-state and watershed-by-watershed depending on what sorts of mechanisms the local jurisdictions are going to want to put in place—so, much more of a mixed bag.

Q. Mark Landry, Abt Associates:
My question is for Assistant Administrator Mehan. I am curious to know what dialogue or collaborative efforts the Office of Water is making with USDA, particularly NRCS, in terms of facilitating trading—perhaps some kind of integration of the water quality trading policy with the conservation emissions grants program. Can you speak to this?

A. Tracy Mehan:
Well, I can tell you that for 2003 I did a little memo—and if you asked me what my four priorities given a discretionary dollar given a discretionary time, given a discretionary political capital, what I would put it on, one of those top four was the strategic partnership with agriculture. Again, this a whole 31 years later where we're moving to the whole watershed, clearly this is a huge opportunity. I think agriculture realizes that with human beings sprawling out over the landscape, second homes, suburbanization, they're rubbing elbows with civilian non-farm populations so they've got problems there they have to deal with whether they want to or not. We've got the wind to our back with the Farm Bill resources under the conservation title, so this is from the USDA-level down to the state conservationists we are on a tremendously positive engagement with agriculture at all levels—a lot of goodwill after we resolved the KAFO rule—very much engaged on what we can do on the upper Mississippi—Bruce Knight and I have talked quite a bit—he's the chief of the NRCS, and he's very committed to trading. He appeared with Governor Whitman at the roll-out press conference of our Water Quality Trading. We're looking at innovative grants—we are heavily, deeply engaged with agriculture.

It was funny, I gave a talk yesterday for a hundred environmental engineers from Ford Motor Company and boy, do they want to talk to you! [Jeff Holmstead]. I was glad to be invited—a friend from Michigan invited me down to Norfolk, where they were meeting, and I agreed to talk to them, although I don't talk to industry groups much anymore. Instead, I'm talking to the National Association of Conservation Districts, club plane managers, land managers, agriculture and forestry types. We have an effluent guideline going through here from industry, but again, we're moving to the whole watershed, and agriculture is a premier partner in that whole effort.

Market Mechanisms and Incentives:
Applications to Environmental Policy

PROCEEDINGS

SESSION THREE

CARBON TRADES AND TAXES

A WORKSHOP SPONSORED BY THE US ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS AND NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH

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Session III Proceedings

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Second-Best Pollution Taxes in the Economics of Climate Change[*]

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ABSTRACT

Under first-best conditions, taxing greenhouse gas emissions at a rate equal to the discounted marginal cost that present emissions impose on future society would maximize the welfare gains generated by climate change mitigation measures. In this setting, the discount rate would be set equal to the marginal productivity of private capital. Based on a numerically calibrated model of the links between climate change and the world economy, this paper shows that using this so-called "first-best decision rule" may substantially understate the emissions tax rates that maximize welfare when the resulting revenues are used to reduce distortionary taxes on returns to capital. Using emissions tax revenues to reduce labor taxes, in contrast, results in an optimum with comparatively low welfare gains. In this case the first-best decision rule provides a good approximation of the second-best emissions tax. The lowest welfare gains and second-best emissions taxes emerge in the case where emission tax revenues are recycled through the use of lump-sum income transfers.

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INTRODUCTION

Market-based incentives have emerged as important tools in environmental policy. While the environmental statutes of the 1970s emphasized “command-and-control” regulations and technology-based standards, the 1990 Clean Air Act amendments laid out a tradable permits scheme to achieve a 50% rollback in sulphur dioxide emissions from major stationary sources. More recently, economists have called for the use of greenhouse gas emissions taxes to address the threat of global climate change. In one early study, Pearce (1991) suggested that a greenhouse gas emissions tax might generate a so-called “double dividend,” supporting both cost-effective emissions reductions and accompanying improvements in the efficiency of existing tax systems. Pearce’s claim rests on the observation that an emissions tax of reasonable magnitude would raise quite substantial revenues.

The basic theory of environmental taxes was described in Pigou’s seminal work *The Economics of Welfare* (1920) and was updated and extended by a later generation of environmental economists (Baumol and Oates, 1975). According to Pigou, pollution taxes serve to promote two key objectives. First, they provide incentives to balance the costs and benefits of polluting activities. Second, they ensure that the public is duly compensated for the harms caused by environmental externalities. In the Pigovian framework, the optimal tax rate is set equal to the marginal cost pollution imposes on society. This approach has found extensive applications in real-world policy analysis and plays a key role in the economics of climate change (IPCC, 2001).

The Pigovian model assumes a first-best world characterized by perfectly efficient markets and public policies. In real-world economies, however, existing taxes on labor and capital impose deadweight losses that impair the efficiency of resource allocation. Under second-best conditions, optimal emissions taxes may diverge from the marginal social cost imposed by pollution (Sandmo, 1975). This observation touched off an interesting debate on the fiscal impacts of environmental taxes.

On one side of this issue, Bovenberg and Goulder (1996; see also Parry *et al.*, 1999) cast doubt on the "double dividend" hypothesis. Bovenberg and Goulder analyze a model in which environmental taxes are introduced to an economy with pre-existing tax distortions. In this model, the second-best level for the environmental tax is generally lower than the marginal cost of pollution. Bovenberg and Goulder reason that environmental taxes exacerbate the distortions caused by income and payroll taxes. This cost implies that Pigou's rule for achieving first-best resource allocation may overstate optimal tax rates in the presence of pre-existing taxes.

An alternative perspective is offered by Shackleton *et al.* (1996), who employ a computable general equilibrium model to investigate the impacts of a greenhouse gas emissions tax on the U.S. economy. This model suggests that a moderate emissions tax would lead to net increases in economic growth and welfare if the revenues it generated were used to offset distortionary taxes on returns to capital. Such benefits would arise even in the absence of direct environmental benefits.

The purpose of this paper is to explore the connections between these seemingly divergent findings from the previous literature. In particular, the paper explores the second-best greenhouse gas emissions taxes that arise in a simplified model of climate change and the world economy that accounts for the influence of pre-existing taxation on markets for labor and capital. In the past, studies of second-best environmental taxes have focused mainly on static models that abstract away from issues of decision-making over time, while dynamic models that integrate the costs and benefits of greenhouse gas emissions abatement have generally abstracted away from issues of taxation and government expenditure.

The analysis concludes that a standard “first-best” decision rule tends to: (a) understate the optimal greenhouse gas emissions taxes that arise when the resulting revenues are used to reduce distortionary taxes on returns to capital; and (b) overstate the optimal emissions tax when revenues are recycled using lump-sum income transfers. Intermediate results occur when emissions tax revenues are used to reduce labor taxation. Under the first-best decision rule, the emissions tax is set equal to the discounted marginal cost that present emissions impose on future society, taking the marginal productivity of private capital as the appropriate discount rate.

THE MODEL

The analysis is patterned after Coleman’s (2000) study of optimal tax policies in a competitive, intertemporal economy. Based on a set of empirical assumptions that pertain to the United States, Coleman developed a representative agent model of the interplay between households and producers in the presence of distortionary taxes. To link Coleman’s framework to the economics of climate change, the present paper adopts this model in several respects. Most importantly, it revises the model’s representation of technology and preferences to include the costs and benefits of greenhouse gas emissions and the accumulation of greenhouse gases in the atmosphere. In addition, it recalibrates the model based on a set of stylized facts that apply to the overall world economy. A full discussion of the model and its supporting assumptions is provided by Howarth (2003). For the present purposes, attention will be limited to a brief overview of the model’s general structure.

Household Behavior

The household sector of the economy is represented by an infinitely-lived, representative agent that seeks to maximize the objective function:

$$V = \sum_{t=0}^{\infty} N_t u_t(c_t, l_t, S_t) 0.838^t \tag{1}$$

under conditions of perfect foresight. In this specification, N_t is the population at date t, measured in billions of persons; c_t is per capita consumption, measured in U.S. dollars at year 2000 prices; l_t is a measure of labor effort, defined as the proportion of non-sleep hours a typical person spends at work; and S_t is the atmospheric stock of carbon dioxide, a greenhouse gas that adversely affects global climate, measured in billion metric tons of carbon. Time is measured in decades with the period $t = 0$ interpreted as the interval 2000-2009.

The utility function takes the form:

$$u_t = \ln(c_t) + 1.37 \ln(1 - l_t) + \ln\big(1 - 0.031(S_t - 590)/590)\big). \tag{2}$$

This specification gives rise to realistic levels of consumption, labor effort, and capital investment. In addition, the parameters of the utility function imply that a doubling of the carbon dioxide concentration relative to the pre-industrial level of 590 billion tons entails a welfare loss that is equivalent to 3.1% of consumption. The specific damage coefficient is chosen based on the IPCC's (1996, ch. 6) conclusion that a doubling might impose a cost equivalent to 1.75% of economic output.

Based on data from the United Nations (2001), the model assumes that world population grows from an initial value of $N_0 = 6.1$ billion persons according to the difference equation:

$$N_{t+1} = N_t + 0.31 N_t (1 - N_t / 10.9). \tag{3}$$

This equation provides a good fit to observed population trends in the late 20th century, and implies that global population achieves a long-run value of $N_\infty = 10.9$ billion.

Each member of the household holds the capital wealth k_t (measured in year 2000 dollars) and earns income by renting labor and capital services to the production sector at the wage rate is w_t and the interest rate r_t. Governments tax the income earned on labor and capital at the rates τ_{lt} and τ_{kt} while providing a transfer payment π_t to each individual. Under these conditions, the household faces the budget constraint:

$$c_t + k_{t+1} - k_t = (1-\tau_{lt})w_t l_t + (1-\tau_{kt})r_t k_t + \pi_t . \tag{4}$$

Taking prices, public policies, and the state of the environment as fixed at each point in time, a rational household would manage its decisions concerning consumption, labor effort, and net capital investment to maximize the objective function (*V*) subject to this budget constraint.

Producer Behavior

The production possibilities of the economy are determined by the prevailing capital stock ($K_t = N_t k_t$, measured in billion dollars), the labor supply ($L_t = N_t l_t$, measured in billion workers), and carbon dioxide emissions (E_t, measured in billion tons) according to the expression:

$$N_t c_t + G_t + K_{t+1} - K_t = A_t K_t^{0.4} L_t^{0.6} - 0.389 K_t - 486 E_{0t} \left(\frac{E_{0t} - E_t}{E_{0t}} \right)^{4.32} . \tag{5}$$

In this equation, net economic output is divided between consumption, government expenditure (G_t, measured in billion dollars), and net capital investment. A_t is a time-varying parameter that measures the level of total factor productivity, while $E_{0t} = B_t A_t K_t^{0.4} L_t^{0.6}$ is the level of carbon dioxide emissions that would occur in the absence of emissions control measures. Potential emissions are proportional to the level of gross economic output, with the parameter B_t interpreted as a time-varying coefficient that determines the emissions intensity of production.

In this economy, production is carried out by competitive firms that rent labor and capital from households at the wage rate w_t and the interest rate r_t. In addition, firms pay a tax τ_{Et} on each unit of greenhouse gas emissions. Given rational behavior, firms maximize their profits by equating the marginal productivity of each factor of production with the prevailing price or emissions tax rate. Because the production function exhibits constant returns to scale, the value of output is just sufficient to cover the cost of purchased inputs. Hence profits are zero at each point in time.

As Howarth (2003) explains, this specification is based on plausible assumptions concerning the economic costs of carbon dioxide emissions abatement (IPCC, 2001; Weyant, 1999). In particular, emissions may be reduced by 20% relative to unconstrained levels at a marginal cost of $10 per ton. Given a 40% emissions abatement rate, the marginal cost of emissions control rises to $100 per ton. The model maintains Coleman's assumptions that: (a) labor and capital respectively account for 60% and 40% of the value of gross output; and (b) the capital stock depreciates at the rate of 4.8% per year.

The initial capital stock is $K_0 = 151{,}000$ billion dollars, while total factor productivity grows at an initial rate of 0.106 per decade from a starting value of $A_0 = 2473$. The growth rate falls linearly to a value of zero three centuries from the present. These assumptions were calibrated based on production statistics from the International Monetary Fund (2002).

Based on data from the IPCC (2000), the model assumes that carbon dioxide emissions would start out at 7.97 billion tons per year in the absence of control policies, which implies that the emissions-output coefficient assumes an initial value of $B_0 = 0.000179$. Since future technological progress will lead to declines in emissions intensity, the model assumes that B_t decreases at the rate of productivity growth. Although more detailed models represent emissions as an explicit function of land-use changes and the combustion of fossil fuels, the approach taken here provides a realistic time path for emissions when judged in comparison with the IPCC's (2000) comprehensive review.

The Global Atmosphere

The impacts of carbon dioxide emissions on future environmental conditions are represented using the functional form and parameter values adopted by Nordhaus (1994). In this specification, the atmospheric stock of carbon dioxide follows the recurrence relation:

$$S_{t+1} = 49.0 + 0.917 S_t + 0.64 E_t . \tag{6}$$

This equation is based on the assumptions that: (a) the natural or pre-industrial stock of carbon dioxide is 590 billion tons; and (b) excess levels of carbon dioxide are removed from the atmosphere at an annual rate of 0.86%.

Taxation and Government Expenditure

Completing the model requires a description of the approach that policy-makers take to choosing the various instruments that are under their control. To address this issue, the model assumes that governments maintain balanced budgets in each period, setting the value of public expenditure and transfer payments equal to the total revenues obtained through taxation so that:

$$G_t + N_t \pi_t = \tau_{lt} w_t L_t + \tau_{kt} r_t K_t + \tau_{Et} E_t . \tag{7}$$

Given a set of feasible public policies – i.e. a choice of the variables G_t, π_t, τ_{lt}, τ_{kt}, and τ_{Et} for each period of the model – the behavior of households and firms defines a competitive equilibrium for the world economy and its relationship to the global environment. While the model does not explicitly consider the social benefits provided by public expenditures, it is natural to suppose that government spending provides amenity benefits and/or augments private-sector productivity.

CLIMATE CHANGE POLICY SCENARIOS

The purpose of this paper is to explore how environmental taxes interact with pre-existing taxes on capital and labor in the context of a dynamic model of the links between climate change and the world economy. In addressing this issue, it is useful to consider the welfare implications of five different policy regimes that differ in terms of their assumptions concerning emissions tax rates and the means through which governments return environmental tax revenues to the private sector. The details of each policy regimes may be described as follows.

Business-As-Usual

In the *business-as-usual* (BAU) scenario, governments tax labor income and returns to capital at the common rate $\tau_{lt} = \tau_{kt} = 1/3$. Half of the resulting revenues are used to finance public expenditures, while the remainder is returned to households in the form of transfer payments. While this setup does not correspond precisely to the tax policies of any one nation, data from the Organization for Economic Cooperation and Development (1998) suggest that the assumptions of this case are broadly representative of conditions in the world's advanced industrial nations, which dominate both global economic output and greenhouse gas emissions. In addition, these assumptions are numerically similar to those used in Coleman's (2000) analysis of U.S. fiscal policies. In the business-as-usual scenario there are no efforts to control greenhouse gas emissions. Hence the carbon dioxide emissions tax is set equal to zero at each point in time.

The "First-Best" Decision Rule

Under the *first-best decision rule*, policy-makers tax carbon dioxide emissions at a rate equal to the discounted marginal cost that present emissions impose on the future economy, interpreting the marginal productivity of capital – measured using the rental price of private capital (r_t) – as the appropriate discount rate. In formal terms, this approach yields the tax rate:

$$\tau_{Et} = \sum_{i=1}^{\infty}\left(MC_{t+i}\frac{\partial S_{t+i}}{\partial E_t}\prod_{j=1}^{i}\frac{1}{1+r_{t+j}}\right). \tag{8}$$

in which the expression:

$$MC_{t+i} = -N_{t+i}\frac{\partial u_{t+i}/\partial S_{t+i}}{\partial u_{t+i}/c_{t+i}} \tag{9}$$

represents the marginal cost that carbon dioxide imposes at date $t+i$, which depends on the prevailing population size and individuals' marginal willingness to pay to reduce carbon dioxide concentrations. The term $\partial S_{t+i}/\partial E_t$ captures the impacts of current emissions on future environmental quality.

In the absence of distortionary taxes on labor and capital, this decision rule would be sufficient to achieve a first-best outcome that maximized the perceived welfare of a representative household (Brekke and Howarth, 2003, ch. 7). In this scenario, policy-makers maintain public expenditures (G_t) at the levels that arise under business-as-usual, while releasing the revenues raised by the emissions tax through the use of lump-sum transfer payments (i.e, increases in the value of π_t).

Second-Best Emissions Taxes

In the remaining scenarios, the carbon dioxide emissions tax is chosen at each date to maximize the perceived welfare of a representative household (V) subject to the full set of technical constraints and equilibrium conditions that characterize the economy's development over time. In these scenarios, the level of public expenditure is fixed according to the time path that prevails under business-as-usual. Since carbon dioxide emissions taxes raise revenues and since governments (by assumption) maintain balanced budgets, it is necessary to describe how governments release emissions tax revenues to the private sector. For the sake of analysis we focus three alternatives in which emissions tax revenues are used to provide:

1. Increased lump-sum transfers (π_t) – the *lump-sum recycling* scenario.
2. Reductions in labor tax rates (τ_{lt}) – the *labor tax recycling* scenario.
3. Reductions in capital tax rates (τ_{kt}) – the *capital tax recycling* scenario.

As we shall see, these various policy regimes differ importantly with respect to optimal emissions tax rates and the net benefits they provide to society.

RESULTS

The main results of this analysis are described in Figures 1-3. Under business-as-usual, carbon dioxide emissions rise from 8.0 to 24.8 billion tons over the course of the next century. Given this emissions path, the atmospheric stock of carbon dioxide rises to 1438 billion tons in the year 2100 – an increase of 144% relative to the pre-industrial norm.

The first-best decision rule supports a carbon dioxide emissions tax that rises from \$25 per ton in 2000 to \$183 per ton in 2100. The imposition of this tax restricts the level of emissions to 5.9 billion tons in the present and 12.8 billion tons in 2100 – figures that are (respectively) 26% and 48% below the levels that would prevail under business-as-usual. These emissions reductions give rise to a very substantial welfare gain. In comparison with business-as-usual, application of the first-best decision rule yields net benefits of \$14.8 trillion. [This figure was calculated by dividing the net increase in social welfare (*V*) by the marginal utility of consumption in the initial period.]

Of the various policy regimes considered in this analysis, the largest welfare gain arises in the capital tax recycling scenario. In this case, a comparatively low carbon dioxide emissions tax is prescribed in the initial period of the analysis. This result holds because the short-term capital stock is fixed according to past investment decisions, so reducing capital taxation in the immediate short run does not provide incentives for increased investment. In later periods, however, the emissions tax is substantially higher than the level prescribed by the first-best decision rule, rising to a full $280 per ton in the year 2100. In the capital tax recycling scenario, emissions are limited to a value of 6.4 billion tons in the present decade and 11.3 billion tons in the year 2100. In the context of the model, using the revenues raised by the emissions tax to reduce distortionary taxes on returns to capital generates quite substantial efficiency gains. In comparison with business-as-usual, the capital tax recycling scenarios generates total net benefits of $23.1 trillion.

The lump-sum recycling scenario, in contrast, performs relatively poorly. As Bovenberg and Goulder (1996) emphasize, the imposition of environmental taxes can exacerbate the inefficiencies imposed by pre-existing taxes under certain circumstances. In the scenario under discussion, this so-called “tax interaction” effect limits the second-best carbon dioxide emissions tax to $13 per ton in the present decade and $144 per ton in 2100. Over the course of the next century, carbon dioxide emissions rise from 6.2 to 13.6 billion tons, with a net welfare gain of $15.5 trillion.

Intermediate results occur in the labor tax recycling scenario. With the exception of the first period of the model – in which labor tax recycling supports a relatively high emissions tax – the carbon dioxide emissions tax rates and emissions levels that arise under this policy regime are closely comparable to those prescribed by the first-best decision rule. Nonetheless, using emissions tax revenues to reduce distortionary taxes on labor income yields quite substantial economic benefits. Viewed as a whole, the labor tax recycling scenario yields net social benefits of $18.6 trillion – a figure that is $3.7 trillion higher than the level obtained under the first-best decision rule but $7.6 trillion below the net benefits provided by capital tax recycling.

Figure 1: Carbon Dioxide Emissions Tax
(U.S. dollars per ton, 2000 prices)

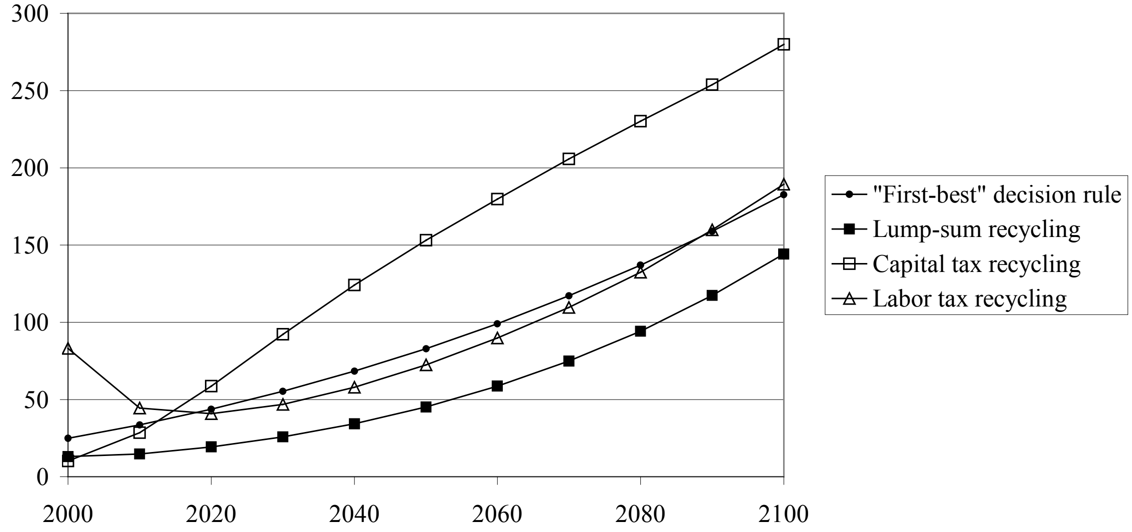


Figure 2: Carbon Dioxide Emissions (billion tons per year)

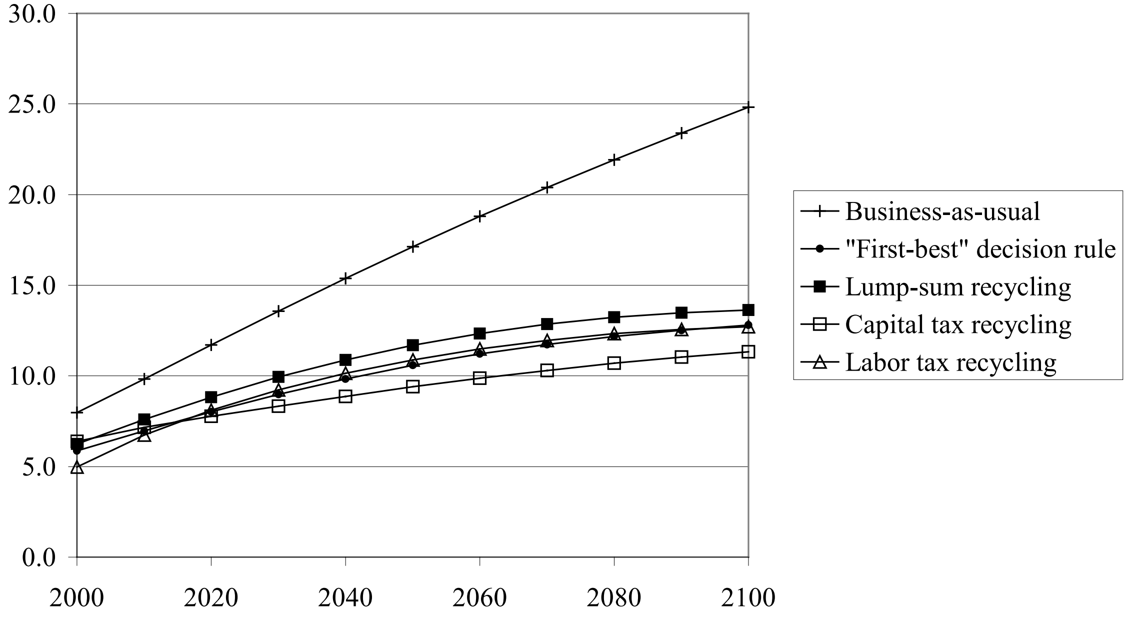
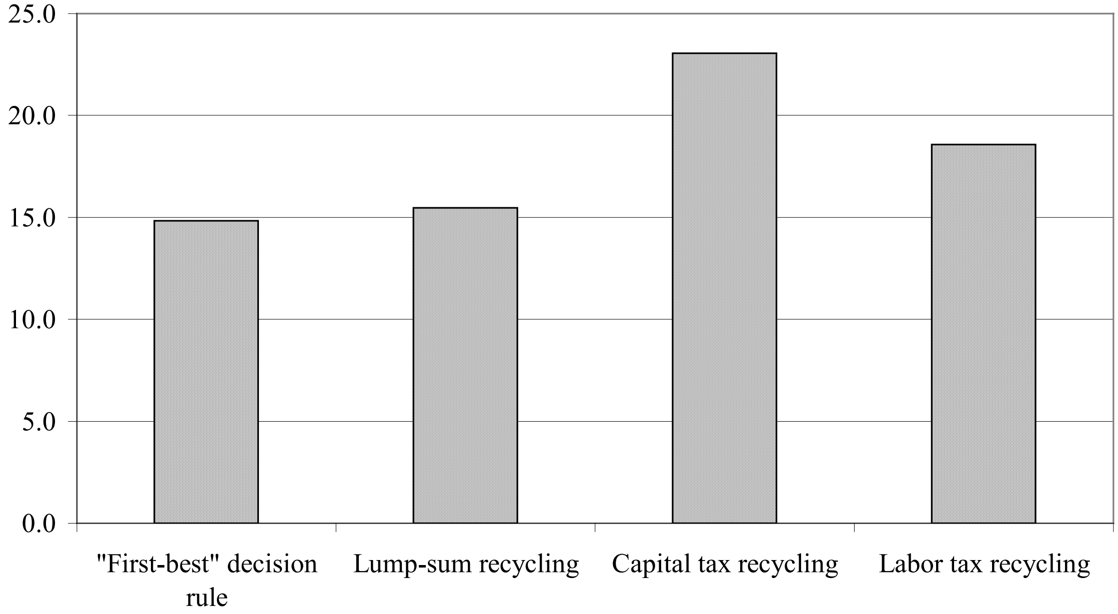


Figure 3: Welfare Gain Relative to BAU (trillion U.S. dollars, 2000 prices)



CONCLUSION

The literature on market-based instruments for pollution control emphasizes that – under certain conditions – tax interaction effects provide a reason to impose second-best pollution taxes that are lower than standard measures of the marginal benefits of pollution abatement (Bovenberg and Goulder, 1996). This result has been explored principally in the context of static models that abstract away from the impacts of taxation on capital investment and economic growth.

Building on the previous work of Shackleton *et al.* (1996) and Coleman (2000), the present study integrates the costs and benefits of greenhouse gas emissions abatement in the context of a dynamic model of climate change and the world economy. In this model, tax interaction effects support the imposition of relatively low emissions taxes when the resulting revenues are returned to the private sector in the form of lump-sum transfer payments. Mid-range emissions tax rates and net social benefits emerge when emissions tax revenues are used to reduce labor taxes.

Much larger welfare gains occur, however, when emissions tax revenues are used to reduce distortionary taxes on returns to capital investment. Given capital tax recycling, the optimal emissions tax is substantially higher than a standard (first-best) measure of the discounted marginal benefits of emissions control except in the immediate short run, when the capital stock is fixed so that reducing capital taxes does not alter incentives to invest.

These results rest on a highly simplified model that abstracts from many complexities of real-world economic and environmental systems. The analysis suggests, however, that the use of dynamic models can yield important insights regarding the links between fiscal policies and environmental taxation.

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Environmental Taxation Revisited

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ABSTRACT

This paper reexamines second-best environmental taxation at two levels. At the first level, the analysis compares the optimal environmental tax to marginal social damage ("the Pigouvian rate") using two alternative definitions of marginal social damage, one based on the social marginal rate of substitution between environmental quality and income, the other based on the sum of the private marginal rates of substitution. The comparisons are shown to lead to divergent inferences and predictions about the cost, benefits, and optimal levels of environmental policy in second-best settings with revenue-motivated taxes. At the second level of analysis, we test the validity of these alternative sets of predictions using numerical models for three types of externalities. The results are incompatible with claims made in the recent literature, but are consistent with the predictions that emerge when the social marginal rate of substitution is used to define marginal social damage: the optimal environmental tax is found to rise with an increase in the revenue requirements by identical amounts for all three types of externalities; the welfare changes are identical as well, as are the gains from "green tax reform." These results run counter to the claims in the recent "tax interaction" literature which predict large differences in the optimal environmental taxes and welfare changes between amenities versus income or productivity externalities. The discrepancies in these predictions are traced to the use of a definition of marginal environmental damage which does not reflect social valuations. Overall the analysis here concludes that environmental protection and the provision of other public goods are complementary rather than conflicting government goals.

I. Introduction

A central task in environmental policy making is to appraise the costs and benefits of alternative policy goals and instruments. Among possible instruments, environmental taxes have long been favored by economists as mechanisms to internalize the external costs of pollution. This preference dates back to Arthur Pigou (1920; fourth edition 1932) who called for equating the value of the marginal social net product with the value of the marginal private product. He showed that a first-best "Pigouvian tax" set equal to the marginal social damage will fully internalizes the external costs of pollution.

In second-best economies where environmental taxes are considered alongside distortionary revenue-motivated taxes, Sandmo (1975) provides analytical results for optimal taxes which integrate revenue-raising and environmental objectives. His implicit expressions, however, do not provide transparent guidance for setting policy or for evaluating the welfare implications of specific policy changes.

Renewed interest over the past decade in environmental taxation has been due in part to attention to climate change and other environmental issues, and also to recent theoretical literature which has emphasized comparisons between the first-best Pigouvian tax and the optimal environmental tax in a second-best setting as a way to asses the effects of second-best settings on the benefits and costs of environmental policy (e.g., Bovenberg and de Mooij 1994; Parry 1995; Bovenberg and Goulder 1996).[1] Based on evaluations of whether the second-best optimal environmental tax will typically lie above or below the first-best Pigouvian tax, direct

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[1] See also Fullerton (1997), Bovenberg and de Mooij (1997), Goulder (1995), Parry, Williams and Goulder (1999).

inferences have been made in this literature about the costs and potential gains from environmental policy.

In general, the authors of these analyses found that the second-best optimal environmental tax typically lies *below* the Pigouvian rate, and from this they infer that the marginal cost of environmental policy must be rising with the marginal cost of public funds (Bovenberg and de Mooij 1994). They conclude further that the ‘Pigouvian principle” must be modified in the presence of distortionary taxes in order to recognize that as public funds become more costly in a second-best setting “the government will find it optimal to cut down on public consumption of the environment by reducing the pollution tax” (Bovenberg and Goulder 1996). These conclusions also cast doubts on the potential for welfare-improving, revenue-neutral environmental tax reform: the authors conclude that “the gains from using pollution tax revenues to substitute for labor tax revenues tend to be more than offset by the cost of exacerbating the preexisting distortion in the labor market (Parry 1995). The authors ascribe these unexpected results to the existence of a previously unrecognized “tax interaction effect” (e.g., Goulder 1995; Fullerton 1997; Parry, Williams and Goulder 1999). These findings have also been used to judge the validity of the “double dividend hypothesis,” which suggests that the revenue-neutral substitution of environmental taxes for revenue motivated taxes will produce two benefits, one related to the correction of the externality and the other related to improved efficiency of the tax system (see Tullock 1967, Pearce 1991, Terkla 1984, Lee and Miseolek 1986). Indeed, the finding that the optimal environmental tax is less than the Pigouvian rate has been put forward as evidence which “reveals how the intuition of the double dividend argument goes wrong” (Bovenberg and de Mooij, 1997).

More recently, several additional analyses involving externalities other than amenities have been evaluated in second-best settings such as those involving highway congestion, health, or productivity. The results from these studies differ from those just summarized, indicating that the optimal environmental tax will be equal to the Pigouvian rate in the case of highway congestion and productivity (Parry and Bento 2001, Williams 2002), and possibility for health effects as well (Williams 2002). These authors attributed their results to previously-unrecognized "tax interaction effects," but in these cases they identify a "benefit-side tax interaction effect" which exactly offsets the adverse "tax interaction" distortions.

The current analysis reexamines optimal environmental taxation in first- and second-best settings for three types of externalities. As in recent literature, the optimal environmental tax is compared to the "Pigouvian rate" that fully internalizes the externality. We note, however, that two different definitions of the Pigouvian rate are possible, one based on the social marginal rate of substitution between the environment and income, and the other defined as the sum of private marginal rates of substitution. These two different expressions are found to be equal only at the first-best optimum, and this raises an unavoidable question of which measure will better serve as a benchmark, or yardstick, against which to compare the optimal environmental tax in second-best settings. In particular, we want to determine which of these measures can be compared to the optimal environmental tax as a way of making inferences and predictions about the costs and benefits of environmental policy.

In the analysis below, we find that when compared to marginal social damage (MSD, based on the social marginal rate of substitution), the second-best optimal environmental tax is generally higher than the Pigouvian rate, and rises with an increase in the revenue-requirement. The same relationship holds for all three kinds of externalities, and the results are consistent with the welfare changes which occur based on numerical simulation models for the U.S. economy where carbon taxes are introduced to address externalities from climate change.

By contrast, the sum of individual's marginal rates of substitution, or "marginal private damage" (MPD) is found to have no consistent relationship to either the second-best optimal environmental tax or marginal social damage across different types of externalities. Moreover, the evidence suggests that inferences about the welfare changes associated with environmental policy are not straightforward when based on the relationship between the optimal environmental tax and MPD. Large differences in the relationship between the optimal environmental tax and MPD across the three types of externalities are shown to occur even though the welfare changes are identical. Policy implications of these findings are discussed.

II. The first-best "Pigouvian tax"

Analytical derivations of the first-best Pigouvian tax can be found in many places in the literature. The aspects of these well-known derivations that we wish to highlight here can be seen transparently in a model with only one-good, where *m* identical households maximize utility by allocating an endowment of time, y, between leisure, l, and labor supply, y-l. In this stylized model, "full income" is taken to be the time endowment y, which households allocate between leisure and labor supply. In the second-best setting introduced below, a portion of this income is allocated to government to fund public goods. In ours and others' stylized models, revenues are simply returned lump sum to households.

Production is assumed to take place according to a linear production technology with only labor as an input. Output takes the form of a private consumption good, x, that creates an externality. Units are normalized so that private marginal rates of substitution between x and l are unity in the absence of a tax t on x, where the price $p=(1+t)$. Environmental quality, E, is defined as $E = e(mx)$, $de/d(mx)<0$.

Amenity externality

In the case of an "amenity externality" the household's maximization problem can be represented as

$$\begin{aligned} &\underset{X,L}{\text{Max}}: \quad \mathrm{u}(x,l,E) \\ &s.t. \quad (\lambda) \quad (y-l)+g=(1+t)x \end{aligned} \tag{1}$$

where households take government transfers, mg, and environmental quality, E, as given. Let λ denote the Lagrange multiplier on the household budget constraint, reflecting the private marginal utility of a unit of income.

We define our social optimization problem as one of choosing optimal taxes to maximize social welfare, W, defined as the sum of individual utilities. For the amenity externality case, the basic problem is:

$$\begin{aligned} &\underset{t_x}{\text{MAX}}: \quad m\begin{bmatrix} \underset{\text{X,L}}{\max} : \mathrm{u}(x,l,E) \\ s.t. \quad y-l+g=(1+t\ )x \end{bmatrix} \\ &\qquad s.t. \quad mg = mtx \\ &\qquad\qquad E = e(mx) \end{aligned}$$

(2)

Taking the dual approach we can define the Pigouvian maximization problem in terms of the household's indirect utility function $v(p_x; y,E,g)=u(X^*(p_x;y,E,g), L^*(p_X;y,E,g))$, where the maximum value of u depends only on the taxes (implicit in p_x) and the parameters y, E and g.

We can express the social optimization problem with the Lagrangian equation involving households' utilities as well as constraints on revenues and environmental quality:

Max: $$\Box = mv(p_x; y, E, g) + \mu(mt_x x - mg) + \phi(e(mx) - E).$$

(3)

These social constraints reflect limits of feasibility for the optimization problem which households are assumed to ignore, and represent essential elements which distinguish social valuations from private valuations.

We can derive the marginal social values for y and E using the Envelope Theorem which provides us with an expression for the rate of change of the maximum value of the objective function, where all variables adjust optimally in response to a change in a given parameter.

The social marginal utility of exogenous income, denoted by α, can be expressed as

$$\frac{\partial W}{\partial y} \equiv \alpha = \lambda + \mu\left(t\frac{\partial x}{\partial y}\right) + \phi e'\left(\frac{\partial x}{\partial y}\right). \tag{5}$$

where this expression includes the sum of gains from individual consumption, plus the gains from the marginal propensity to pay taxes out of income, plus the welfare change from the marginal propensity to pollute out of income. The first two of these terms were originally recognized by Diamond (1985) in defining the social marginal utility of income (but in a model which did not consider externalities). The social marginal utility of income is used extensively in the optimal tax literature, for example in evaluating the optimal provision of public goods (see Auerbach 1985, p. 111).

The value of the Lagrangian multiplier ϕ can be interpreted as the social marginal utility of environmental quality: relaxing this constraint marginally, or exogenously adding one unit, would raise social welfare, *W*, by direct and indirect ways. We can write this as

$$\frac{\partial W}{\partial E} \equiv \phi = m\left[U_E + \mu\left(t\frac{\partial x}{\partial E}\right) + \phi e'\frac{\partial x}{\partial E}\right]. \tag{4}$$

Here we see that the social value of a unit increase in environmental quality has a direct value to households equal to mU_E, and also a social gain pertaining to the marginal change in tax payments when environmental quality increases. This second positive term is tempered by a third negative term owning to marginal changes in polluting activity in response to environmental improvement. For example, a decrease in air pollution may cause individuals to decrease their use of air conditioning, which further lowers pollution from the energy source.

In this first-best case with no distortionary revenue requirement, all revenues are returned lump-sum to households. As a result, an incremental change in *g* has the same effect on welfare as an incremental change in *y*. This implies that in this first-best case $\mu=\alpha$, the social marginal utility of income is equivalent to that for revenues.

The first-order condition for a representative household in our model is

$$-\lambda x+\alpha\left(t\frac{\partial x}{\partial p}+x\right)+\phi e'\frac{\partial x}{\partial p}=0 \tag{6}$$

This can be rearranged to isolate t as

$$t=-\frac{\phi e'}{\alpha}+\frac{(\lambda x-\alpha x)}{\alpha\frac{\partial x}{\partial p}}.$$

By inspection we can see that if λ=α then the second term above drops out leaving t=-ϕe'/α. Substituting this expression into the definition for α in (5) we find that, indeed, if t=-ϕe'/α, that α=λ. Substituting t* into (4), we see that the latter two terms cancel so that ϕ=mU_E. We thus have two expressions for the first-best optimal environmental tax:

$$t^*=-\frac{\phi e'}{\alpha}=\frac{mU_E}{\lambda}. \tag{7}$$

This result reflects the marginal rate of substitution between *E* and *y*, or "marginal social damage" (MSD), defined here as the welfare change from environmental damage (in utility units) divided by the social marginal utility of income. At the first-best optimum this expression of social values is equal to the private marginal rate of substitution summed across households (or ∑MRS), which we will refer to as "marginal private damages." The rule which equates benefits from a public good to ∑MRS has been referred to as the "conventional rule" (Atkinson and Stern 1974).

From Sandmo (1975) we can confirm that this result holds for the general case with *n* goods. Sandmo's expression for the optimal tax on a polluting good in a second-best setting can be rearranged and written using current notation as

$$t^* = \left(\frac{\mu - \lambda}{\mu}\right) R(1+t) - \frac{\phi e'}{\mu} \tag{8}$$

where ***R*** is the "Ramsey tax term." In the first-best case with no binding revenue-requirement, $\mu = \alpha$ and the Ramsey term on the right-hand side of (8) drops out so that the expression reduces to $t^* = -\phi e'/\alpha$.[2]

For completeness, the full expression for the first-best Pigouvian tax is

$$t^* = \frac{-\phi e'}{\alpha} = \frac{-m\left[U_E + \mu\left(t\frac{\partial x}{\partial E}\right) + \phi e'\left(\frac{\partial x}{\partial E}\right)\right]e'}{\lambda + \mu\left(t\frac{\partial x}{\partial y}\right) + \phi e'\left(\frac{\partial x}{\partial y}\right)} = \frac{-mU_E}{\lambda}e' \tag{9}$$

Productivity externalities

In the case of a productivity externality, our model involves labor productivity h=*h*(*E*) so that the household maximization problem is

$$\begin{aligned} &\underset{X,L}{\text{Max}}: \quad \mathrm{u}(x,l) \\ &s.t. \quad (\lambda) \quad (y-l)h(E) + g = (1+t)x \end{aligned} \tag{10}$$

And the social tax problem becomes:

$$\underset{t_x}{\text{MAX}}: \quad m\left[\begin{array}{l}\underset{x,l}{\max}: \mathrm{u}(x,l) \\ s.t. \quad (y-l)h(E)+g=(1+t\ )x\end{array}\right]$$
$$\begin{array}{l} s.t. \quad mtx = mg \\ \qquad\quad E = e(mx) \end{array} \tag{11}$$

Following the same approach detailed above, and for simplicity taking *yh* to be a unit of income, we have

$$\frac{\partial W}{\partial(yh)} \equiv \alpha = \lambda + \mu\left(t\frac{\partial x}{\partial(yh)}\right) + \phi e'\left(\frac{\partial x}{\partial(yh)}\right) \tag{12}$$

$$\frac{\partial W}{\partial E} \equiv \phi = m\left[\lambda(y-l) + \mu\left(t\frac{\partial x}{\partial h}\right) + \phi e'\left(\frac{\partial x}{\partial h}\right)\right]h'. \tag{13}$$

As with the model above, we can substitute (18) and (19) into the first-order condition to obtain

$$t^* = \frac{-\phi e'}{\alpha} = \frac{-m\left[\lambda(y-l) + \mu\left(t\frac{\partial x}{\partial h}\right) + \phi e'\left(\frac{\partial x}{\partial h}\right)\right]h'e'}{\lambda + \mu\left(t\frac{\partial x}{\partial(yh)}\right) + \phi e'\left(\frac{\partial x}{\partial(yh)}\right)} = -m(y-l)h'e' \cdot \tag{14}$$

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[2] The expression derived by Bovenberg and Goulder (1996) for a second-best model using an income tax

where once again substituting t*=-ϕe'/α into both numerator and denominator sets the second and third terms in both numerator and denominator to have equal values and opposite signs, so that we can also write this as t*=-*m(y-l)h'e'*, which is just equal to the loss in output for the economy as a whole.

Income externalities

In this third type of externality referred to as an "income externality", our stylized model makes the underlying resource and source of full income, *y*, a function of environmental quality such that *y*=*y*(*E*). The household maximization problem is

$$\begin{aligned} &\underset{X,L}{\text{Max}}: \quad \mathrm{u}(x,l) \\ &\quad s.t. \quad (\lambda) \quad (y(E)-l)+g=(1+t)x \end{aligned} \tag{15}$$

And the social optimization problem becomes:

$$\begin{aligned} \underset{t_x}{\text{MAX}}: \quad & m\begin{bmatrix} \underset{\text{X,L}}{\max}: \mathrm{u}(x,l) \\ s.t. \quad y(E)-l+g=(1+t\ )x \end{bmatrix} \\ & s.t. \quad mtx=mg \\ & \qquad\quad E=e(mx) \end{aligned}$$

(16)

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normalization also reduces to this same expression in the first best case where α=μ and terms λ/λ can be cancelled.

Similar to the approach followed above, from the Envelope Theorem we have

$$\frac{\partial W}{\partial y} \equiv \alpha = \lambda + \mu\left(t\frac{\partial x}{\partial y}\right) + \phi e'\left(\frac{\partial x}{\partial y}\right)$$

(17)

$$\frac{\partial W}{\partial E} \equiv \phi = m\left[\lambda + \mu\left(t\frac{\partial x}{\partial y}\right) + \phi e'\left(\frac{\partial x}{\partial y}\right)\right]y' = m\alpha y'. \tag{18}$$

And the first-order condition gives us the optimal tax expression

$$t^* = -\phi e'/\alpha = -my'e'. \tag{19}$$

The sum of marginal private damages in this case is $(-m\lambda y'/\lambda)e'$ which can be simplified as $-my'e'$. Thus, for this third type of externality, both definitions of marginal damages, MSD and MPD will have the same value in the first-best setting.

To summarize, the Pigouvian rate which fully internalizes the marginal social damage from pollution can be expressed in two ways. First, it equals the social marginal rate of substitution between the environment and income. Intuitively this definition corresponds to Pigou's call for equating the value of the marginal social net product with the value of the marginal private product, since the cost of polluting is set equal to the social marginal utility of the environment, and converted into monetary units by divided by the social marginal utility of income. Second, at the first-best optimum the social marginal rate of substitution and the sum of private marginal rates of substitutions between the environment and income are equal, so that the

Pigouvian rate can also be expressed as “marginal private damages”, summing the private marginal utility of the environment across households and using the private marginal utility of income.

When operating at the first-best optimum, either of these two expressions will do since they have the same value. In a second-best setting, however, they are not equal so that the question naturally arises; which of these expressions should be used as a benchmark for a) setting environmental policy and b) making predictions about the costs and benefits of environmental policy reforms?

III. Second-best optimal taxes

Before commenting on the question just posed, we want to derive expressions for the optimal environmental tax in a second-best setting in which government revenue-requirements involve distortionary taxes. For this we turn to a more general model with *n* goods, but maintaining the same general formulation as above for each of the three types of externalities. For each model some essential elements are presented here, others are presented in Appendix A. The resulting expressions for the optimal environmental tax follow closely those derived by Sandmo (1975).

It is well understood that when the financing of public goods requires distortionary taxes, the optimal provision of the public good will generally not follow the “conventional rule” which equates the ∑MRS to the marginal rate of transformation due to the added cost associated with the excess burden of raising revenues with distortionary taxes – but with the possibility of exceptional circumstances in which a positive income effect could offset this (Atkinson and Stern 1974)). This result holds when an increase in a given public good requires higher outflows of public funds. In the case of environmental quality, however, more of the public good will coincide with a higher inflow of public funds from a pollution tax (unless demand is elastic). Given this difference between public goods where provision is correlated with positive government expenditures and those correlated with negative public expenditures, the effects of the cost of public funds on their provision may well go in opposite directions.

Before developing a set of analytical models and optimal tax expressions, it is useful to point out that some of the expressions found in the recent literature will differ in appearance from those in the prior optimal tax literature and the models presented below because they have normalized the tax program with an income (labor) tax rather than expenditure taxes for raising revenues. This leaves the untaxed good to be the non-polluting consumer good. Since an income tax will be equivalent to uniform taxes on all expenditures, it can serve as an optimal revenue raising tax if all goods are equal substitutes for leisure. However, this difference in normalization is understood have no effect on the actual outcomes of the optimization problem being addressed (Schöb 1996, Fullerton 1997).[3]

Amenity externality

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[3] Although the normalization of the tax rule does not affect any real variable, it can affect the relationship between the sum of marginal private damages and the social value of public goods (Atkinson and Stern 1974). In the current model with income (leisure) as the untaxed goods, an increase in tax rates does not affect units of income, either private or social. Thus the effects of a change in revenue requirements can be interpreted without also needing to account for changes in units. However, with the labor-tax normalization used in the recent literature where the untaxed good is non-polluting consumption, this consistency in units of income breaks down. An increase in revenue requirements raises the labor tax, which has the effect of altering the gross income (leisure) necessary to make possible consumption of one additional unit of the untaxed consumer good. As taxes rise, a unit of consumption stays the same from the household's perspective, but the autonomous income corresponding to that unit of consumption increases. In this formulation, the gross income (and its social value) corresponding to a unit of the clean good will necessarily rise with the revenue requirement, not because of a change in marginal social values but because the unit is growing proportionally with the labor tax. Thus, the numerical value of marginal social damage may decline with rising revenue requirements even if the utility function is linear. This is because the social unit of income is growing in size, so that fewer units will correspond to a value of MSD, even if the value would be constant if units were unchanged.

For the case of an amenity externality, the problem can be formulated as one in which m identical individuals maximize utility $U = u(x_0, x_1, x_2, \ldots, x_Z, \ldots, x_n, E)$ for goods $j = 0, \ldots, n$, where leisure is x_0 and where labor supply is taken out of a time endowment, y, so that labor supply equals $y-x_0$. Units are chosen for goods and income so that all pre-tax prices equal one, and where there are n-1 non-polluting x goods (excluding leisure) and one good x_z which produces an environmental externality. The consumption of x_z is assumed to erode the environment, E, where $E = e(mx_Z)$ and where ${de}/{d(mx_Z)} < 0$.

In the amenity case, labor productivity, h, is constant, so that aggregate output is defined as $m(y-x_0)h = \Sigma m x_i$. Transfers of mg are financed by distortionary taxes, and E enters the utility function directly. Each household's maximization problem can be stated as

$$\begin{aligned} &\underset{x_0 \ldots x_n}{Max}: \quad u(x_0, x_1, \ldots x_n, E) \\ &s.t. \quad (y - x_0)h + g = \sum_{j=1}^{n} (1 + t_j)x_j \end{aligned}$$

The Lagrangian expression for each household taking E and G as given is thus

$$\square = u(x_0, x_1, .. x_n, E) + \lambda\left[(y - x_0)h + g - \sum_{j=1} (1 + t_j)x_j\right] \text{ for } j = 1, \ldots, z, \ldots, n. \qquad (20)$$

Consumer prices are given as $p_j=1+t_j$ for j=1 to n, but where income is untaxed, so that $p_0=1$.

The first-order conditions for each household take the form

$$U_j = \lambda(1 + t_j) \qquad j=1, \ldots, n$$

$$U_o = \lambda h$$

j=x₀.

Our social optimization problem can be stated as

$$\begin{aligned}
&\underset{t_1 \ldots t_n}{Max}: \quad m\left[u(x_0, x_1, \ldots x_n, E) \;\; s.t. \;\; (y - y_0)h + g = \sum_{j=1}^{n} (1 + t_j)x_j \right] \\
&s.t. \qquad m\sum_{j=1}^{n} t_j x_j = mg \\
&\qquad\qquad E = e(mx_Z)
\end{aligned}$$

(21)

Taking the dual approach, we define the household's indirect utility function as $v(p_0, p_1, \ldots p_n, y, g, E) = u(X_1^*(p_0, p_1, \ldots p_n, y, g, E), X_2^*(p_0, p_1, \ldots p_n, y, g, E), \ldots X_n^*(p_0, p_1, \ldots p_n, y, g, E)$, so we can state the social optimization problem as the Lagrangian equation

$$\square = mv(p_0, p_1, \ldots p_n, y, g, E) + \mu\left[m\sum_{j=1}^{n} t_j x_j - mg \right] + \phi\left[e(mx_Z) - E\right].$$

The first-order conditions are

$$-\lambda x_j + \mu\left[\sum_i t_i \frac{\partial x_i}{\partial p_j} + x_j \right] + \phi^a e' \frac{\partial x_Z}{\partial p_j} = 0 \quad \forall \;\; j \neq 0 \cdot$$

(22)

from which the term involving environmental damage, denoted as $\phi^a e'$, is

$$\phi^a e' = m\left[\frac{\partial U}{\partial E} + \mu \sum_i t_i \frac{\partial x_i}{\partial E} + \phi e' \frac{\partial x_Z}{\partial E}\right] e' \cdot$$

(23a)

For productivity and income externalities, respectively, the corresponding expressions for marginal social damage in utility units are:

$$\phi^p e' = m\left(\lambda(y - x_0) + \mu \sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial h} + \phi e' \frac{\partial x_Z}{\partial h}\right) h' e'$$

(23p)

$$\phi^y e' = m\left(\lambda h + \mu \sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial y} + \phi^y e' \frac{\partial x_Z}{\partial y}\right) y' e'$$

(23y)

From the expression in (22) we can see that the environmental component of the optimal tax will be a function of these expressions in utility units, ϕe’, which includes the direct loss to households, the loss of revenues due to changes in consumption, and the indirect losses to households from the environmental consequences of changes in consumption of the polluting good. Unlike the first-best optimum, however, the second and third terms in this expression do not cancel, so that the optimal tax cannot be said to be a direct function of the sum of marginal private damages in utility units. The private costs of the tax correspond to the first term – the revenue raising value corresponds to the second term. Similarly the social marginal utility of income is no longer equal to the private marginal utility of income, but for the *n*-good model is,

$$\alpha = \lambda + \mu \sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial y} + \phi e' \frac{\partial x_Z}{\partial y}$$

where the second and third terms are no longer of equal magnitude and opposite sign. The optimal taxes are derived in Appendix A for each type of externality. From the first-order conditions we see that if the revenue recycling benefits of taxing pollution exceed the private costs at MSD, then the optimal tax can be expected to exceed MSD. This observation about the first-order conditions is similar for all three types of externalities, but without more information or restrictions on the model, the result is ambiguous.

If we place restrictions on preferences so that all goods are average substitutes for leisure (as has been done in some of the recent literature), we can rearrange the optimal tax expressions to isolate their environmental components. Defining τ^* as the differential between the optimal taxes on polluting and non-polluting goods, ($\tau^*=t_z-t_j$), the optimal environmental tax for the amenity case, and for the other two types of externalities as well, can be written as

$$\tau *_Z = \frac{\alpha\left(1 + t_j\right)}{\mu}\left[\frac{-\phi e'}{\alpha}\right] \tag{24}$$

The term in square brackets is MSD. We know that α/μ is less than one, and that $(1+t_j)$ is greater than one, so the question of whether τ^* is greater than or less than MSD is an empirical question, which will depends on preferences and tax levels which influence the parameters in (24). We evaluate this expression below using numerical general-equilibrium models. Values for these parameters commonly used in the literature, however, suggest that the optimal tax will generally exceed MSD.

As with the first-best case, some additional insight can be found by substituting the optimal tax (24) into the first-order conditions (22) and rearranging. Denoting the optimal revenue-raising tax on all goods as t_j* (including x_z), and the environmental component of the tax on x_z as τ_z* so that $t_z^*=t_j^*+\tau_z^*$, we can rearrange (22) and express it as

$$-\lambda x_j + \mu\left[\sum_i t_j^* \frac{\partial x_i}{\partial p_j} + x_j\right] - t_j^* \phi e' \frac{\partial x_z}{\partial p_j} = 0 \quad \forall\ j \neq 0 \tag{25}$$

At the optimum, a portion of the optimal environmental tax offsets the third-term in (22), the environmental consequences of dp_j. A portion of the optimal environmental tax expression remains, however, which is positive for all goods except x_z (*e'* being negative). This added welfare gain, at the optimum, is an increasing function of the optimal revenue-raising tax, and also an increasing function of marginal environmental damages (in utility units). It reflects how raising the tax on other goods will reap additional revenues from the pollution tax, aside from those necessary to offset any added environmental damage. In the case of x_z this term in negative because raising the tax on x_z discourages payment of additional pollution taxes (but we cannot determine from this that the optimal environmental tax is less than MSD). For the tax system overall, this term reflects a complementarity between government's revenue-raising objectives and environmental protection.

IV. Numerical model

The analytical expressions derived above give rise to predictions about the benefits and costs of environmental policy which differ from those found in the recent literature. Indeed, the present results would appear to support the existence of a "revenue-recycling" effect, but provide no evidence of negative or positive tax interaction effects: the optimal tax expressions derived above do not differ across types of externalities. To test these alternative predictions and the explanations which underlie them, we can employ some simple numerical models to confirm or refute the predictions of these two competing analyses with their differing conclusions about the changes in environmental taxes and welfare gains or losses when revenue requirements exceed those made available with a first-best Pigouvian tax.

As Sandmo pointed out (1975), when government needs to finance public goods, the revenues made available by a Pigouvian tax should be used first, since they represent a non-distorting source of public funds. If government were to return these revenues to the economy lump-sum, while at the same time introduce distortionary taxes to raise an equal or larger amount of revenues, this would clearly be a more distorting tax system than one that used the Pigouvian revenues to satisfy part or all of its revenue requirements. This aspect of the complementarity between environmental taxes and revenue-motivated taxes is not in dispute. It can be interpreted as one component of the "double dividend" (Bovenberg and de Mooij 1994).

Once these first-best Pigouvian revenues have been used up, however, additional revenues will require distortionary taxes and it is here that the issue of a "tax interaction effect" emerges. From a first-best starting point, a rise in revenue requirements above those made possible by the Pigouvian tax should lead to a reduction in the optimal environmental tax for an amenity externality according to the recent literature. In the case of an income or productivity externality, however, the optimal environmental tax will remain equal to marginal damages because of a benefit-side tax interaction effect which exactly offsets the cost-side tax interaction effect. Because of the presence of one or both of these tax interaction effects, large differences in welfare changes are expected between the amenity externality (with its cost-side tax interaction effect) and either the income or productivity externalities (with their benefit-side tax interaction effects). Moreover, starting from a second-best setting which ignores externalities, we expect that revenue-neutral environmental tax reform will produce much lower benefits for the amenity case than for the other cases.

Here we employ a general-equilibrium model that characterizes carbon emissions and climate change damages for the US economy based on data from 1995. The model is similar to one used in Parry, Williams and Goulder (1999), a version of which was also employed in Jaeger (2002). In the current context we utilize three versions of the model, one for each of the three types of externalities identified above. In each case, the model is calibrated so that the first-best optimum is the same for all three models. This gives our analysis a common starting point, one where MSD and MPD have the same value, and where both expressions are also equal to the Pigouvian tax. Given this common reference point for these nearly-identical models, we can perform several straightforward experiments to evaluate how the introduction of distortionary taxes affects the optimal environmental tax, and its relationship to MSD and MPD, as revenue requirements are raised to levels comparable to those in the U.S. economy.

A. Model specification

The model involves constant elasticity of substitution functions for utility and production, and is represented as a single period model rather than as a dynamic optimization problem. The model has *m* identical households who allocate their time between leisure (*l*) and labor supply (*y-l*). Utility is a function of consumption *u*=*U*(*x, l*) and leisure. Consumer goods are produced with two intermediate inputs, one using fossil fuels (*f*), and one using non-carbon inputs (*n*), such that *x = X(f, n*). We can therefore write utility as *u= U(x, (y-l))*.Production is assumed to be competitive, and labor is the only input used to produce the intermediate inputs *f* and *n*.

The preset model's structure has a more aggregated representation of production than the model used in Parry, Williams and Goulder (1999). Additional details of the model's structure and specification are presented in Appendix B.[4] Nested optimization models like our social planner's problem in (21) can be represented numerically as a single maximization problem by introducing the household's first-order conditions as constraints on social maximization. Setting *m*=1, and letting subscripts denote partial derivatives with respect to variable *j* (e.g., U_j and X_j), we write the social welfare maximization problem as

$$
\begin{aligned}
\underset{t_F,t_N}{\text{Max}}: \quad & m\left[\mathrm{u}(x(f,n),l,E)\right] \\
s.t. \quad & (\alpha) \quad (1+t_f)f+(1+t_x)n=(y-l)h+G \\
& (\mu) \quad t_f f+t_n n=G \\
& (\eta_1) \quad U_x X_f(1+t_n)=U_x X_n(1+t_f) \\
& (\eta_2) \quad U_l(1+t_f)=U_x X_f h \\
& (\phi) \quad E=\pi f
\end{aligned}
\qquad (26)
$$

In this model, the shadow value of the Lagrange multiplier on income, α, will reflect the social value of a unit of income because all optima in this model represent Pareto efficient states. Indeed, the private marginal utility of income, λ, does not appear directly in the model because it does not correspond to the Pareto efficient use of a marginal change in income. Rather, λ represents the value of a unit of income to households when taxes, *E* and *G* are held constant. If an incremental unit of income results in increased revenues or a change in environmental quality, the value of these changes is omitted when evaluating λ. Because of that, the private marginal utility of income will be less than the social marginal utility of income in an amount that reflects the marginal propensity to pay taxes. From society's perspective, one can also think of λ as reflecting a movement from a Pareto efficient state to a non-Pareto efficient state (with surplus, or deficit, revenues). That is, to the extent that a unit increase in income causes an increase in tax payments (assuming a positive marginal propensity to pay taxes), the value of λ does not afford any value to these added tax receipts. To evaluate λ at a particular optimum, we can fix t_n, t_f, *G* and *E*. The shadow prices on the income constraint will then reflect the private marginal utility of income since households take these parameters as given.

The three specifications being evaluated differ in that E enters the utility function only for the amenity externality. For the productivity externality h is a function *h*(*E*), and for the income externality *y* is a function *y*(*E*). Additional details are found in Appendix B.

B. Predictions

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[4] See Parry, Williams and Goulder (1999) for details of the source data and original calibration.

The tax interaction literature contains several central predictions about what happens as revenue requirements rise above those satisfied by a first-best Pigouvian tax for the three cases under investigation. In the case of the amenity externality, the tax interaction results suggest that the optimal environmental tax will decline below its first-best level (Bovenberg and de Mooij 1994, Bovenberg and Goulder 1996, Fullerton 1997). If utility and environmental damages are (approximately) linear over the relevant range (so that marginal damages are unchanged), we should expect that the optimal environmental tax will decline in dollar terms as revenue requirements increase. This prediction is said to be due to the presence of an additional distortionary cost, or "tax interaction effect" that lowers overall welfare.

The income externality case is similar to congestion pricing or health effects where an amount of endowed "time" is simply lost. The recent literature suggests that the adverse tax interaction effect is offset by "benefit-side tax interactions." In the congestion case, Parry and Bento (2002) find that the two effects are exactly offsetting, so that the optimal tax remains equal to the Pigouvian rate. In the health example, Williams (2002, p. 269) finds that the sign of this "benefit-side" tax interaction effect is ambiguous if medical expenses are involved, but that it will be positive if medical expenses are dominated by "time lost to illness." The present model does not consider medical expenses.

For the productivity externality case, Williams (2002) concludes that the optimal tax will equal the Pigouvian rate, because the two distinct tax interaction effects exactly offset each other. Thus, we expect no change in the optimal environmental tax if utility and environmental damages are approximately linear over the relevant range.

For these three models, then, as revenue requirements are raised, the tax interaction findings predict welfare to be higher for the productivity and income externalities, but substantially lower in the case of the amenity externality. Given the common starting point, the optimal environmental tax will also be higher for the productivity and income externality cases than for the amenity case.

One additional hypothesis can be tested with these simulations if we begin at a second-best starting point with equal taxes on all goods, and simulate revenue-neutral environmental tax reform which achieves optimality. The tax interaction literature predicts that the welfare gains for the productivity and income externalities will be significantly larger than for the amenity case.[5]

By contrast, the analysis above which relies on marginal social damage as a benchmark leads to quite different hypotheses. Based on comparisons between the optimal environmental tax and MSD, we expect that for all three externality types the optimal tax will rise and that the welfare changes will be similar. We further expect that the gains from environmental tax reform will be similar for all three models, and that those welfare gains will exceed the gains for the revenue-neutral introduction of an environmental tax equal to MSD.

C. Results

Beginning at a common first-best starting point, where the optimal tax equals MSD and MPD, we increase the revenue requirement above the levels that can be satisfied with the corrective tax alone. This is done for three levels, the highest level ($2 trillion) being comparable to revenue requirements and tax rates in the U.S. economy.

For each increase in revenue requirements, the optimal environmental tax rises above its first-best level for all three types of externalities, and the magnitude of the tax increase is essentially the same for all three as well (see Table 1). Beginning at a first-best tax of \$25.4, the environmental component of the optimal tax rises to as high as \$38 dollars per ton of carbon, or by 11%, 23%, and 50% for revenue requirements of \$500 billion, \$1 trillion, and \$2 trillion, respectively. These environmental components are in addition to the revenue-raising taxes on both *f* and *n*, of 0.13, 0.28, and 0.61 percent, respectively. The results for the productivity externality case are consistent with those in Jaeger (2002).

We can interpret these comparisons as being between a non-distorting lump-sum tax (for each revenue requirement, but where revenues are simply returned lump-sum as well), and a distortionary tax program to collect the same revenues. If revenues are collected and returned lump-sum, the outcome is the same as the first-best case. From this perspective we can also see that the shift from non-distorting to distorting taxation has a very small effect on MSD (due only to the non-linearities in utility), whereas in the case of MPD, the value of MPD makes a significant jump by about 1/3rd of its value when the tax program changes from non-distorting to distorting at levels similar to those in the US economy. Interpreting the effect of distortionary taxes on the relationship between τ^* and MPD when the value of MPD makes such a discrete shift is a manifestation of going from using a numeraire which includes the value of a full unit of income to one which includes only a portion of the value of a unit of income.

We can confirm that utility and environmental damages are approximately linear across these tax levels for the current models. Neither varies by more than three percent across

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[5] This change is predicted in concert with differences in the optimal environmental tax, of which evidence

tax levels for all types of externalities. A slight decline in MSD occurs over these tax scenarios for the amenity case (by 1.5%) owing to a slight rise in α due to the negative effect of the distortionary tax on utility. In the case of the productivity externality, there is a slight increase in MSD across tax scenarios (1%), owing to a slightly greater rise in ϕ compared to the increase in α. Given that the marginal values in both the utility function and production function vary only negligibly, these results are consistent with the expectation associated with the "double dividend hypothesis" that second-best optimal environmental taxes will exceed their first best levels.

The welfare changes from the first-best starting point for these second-best situations are also similar, declining to -$77 billion for the $2 trillion tax level. The welfare changes are negative because distortionary taxes have been introduced but without an explicit public sector or public good which would justify these taxes; the revenues are simply returned lump sum to households.[6]

The results for environmental tax reform at the $2 trillion revenue level indicate similar welfare gains for each type of externality, and the optimal environmental tax ends up being the same across all three externalities (Table 1). The gains differ slightly for the income and productivity externalities compared to the amenity case, but this is due to the small non-linearities in their environmental damage functions that give rise, at this level of revenue requirements, to slight differences in MSD. The differences in welfare gain from environmental tax reform are proportional to the differences in MDS.

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to the contrary has already been noted.

[6] A public good could be introduced separably into the utility function and calibrated to give rise to its optimal provision at each of the three levels indicated. In that case we would see equal welfare gains across all three types of externalities.

These results lead to the rejection of the predictions coming from the tax interaction literature: the optimal environmental tax does not decline for the amenity case, and the welfare changes do not differ significantly across types of externalities. The results are, however, consistent with the predictions made when using MSD as a benchmark measure of social valuations. Relative to MSD, the optimal tax rises about 50 percent at the G=\$2 trillion level. Welfare changes are invariant across types of externalities. Beginning with equal taxes for both goods, the optimum occurs with an environmental tax about 50 percent higher than MSD, indicating that the welfare gain is higher than it would have been had tax reform been halted at the Pigouvian rate, t*=MSD. This result supports the inference of the double dividend, and the result is invariant across types of externalities. The origins of the claims about tax interaction effects in the recent literature can be traced to the use of MPD as the benchmark for comparing to the optimal environmental tax. But in models like the ones used here where marginal utilities are approximately constant over the relevant range, that with a measure like MPD which values a unit of income as λ, that this value declines by 1/3rd between the first-best case and the \$2 trillion second-best case, even though consumption remains unchanged (the sum of f, n, and l is exactly the same for all scenarios since revenues are returned lump-sum to households). There is a slight decline in utility (less than 2 percent) due to the distortionary shifts in consumption among goods and leisure.

From society's perspective, the value of a unit of exogenous income is essentially unchanged. But because households will ignore the lump-sum return of revenues (or the provision of public goods), the private value of income declines in direct relation to the portion of incremental income that is taxed away. By valuing income from this private perspective rather than a social perspective, the marginal social damage no longer reflects society's value of environmental quality in terms of income.

When we look at the values for MPD, we see large variations in that measure of marginal damage both across revenue levels and for different types of externalities. Indeed, for these scenarios where the optimal environmental tax rises with regularity across externality types and revenue levels, we observe MPD to be rising by more than 50 percent for the amenity externality, declining by 10 percent for the productivity externality, and varying only slightly from the optimal tax in the case of the income externality. On closer examination, we see that these variations are primarily due to the decline in the value of λ relative to α as rising tax rates imply that a unit of income is only partially allocated to private consumption, with the other portion being allocated to public revenues. In the case of the amenity externality, this phenomenon appears to explain the sharp rise in MPD. For the other types of externalities, we also observe a decline in the sum of private marginal damages (in utility units) relative to social damages. This is because these two types of externalities have direct effects on taxable income, and a portion of the losses are therefore revenue losses not private losses.[7]

In the cases of the income and productivity externalities, Parry and Bento (2002) and Williams (2002) conclude that the optimal environmental tax remains equal to the Pigovian rate, and they argue that this is because a "benefit-side tax interaction effect" exactly offsets the "cost-side tax interaction effect." In these cases, however, they are defining marginal damage differently than they and others have done for the amenity externality case. Marginal environmental damage is being defined for the income and

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[7] For the income and productivity externalities, Parry and Bento (2002) and Williams (2002) conclude that the optimal environmental tax remains equal to MPD. In their definitions of MPD, however, they omit the third term from the numerator of MSD and the second and third terms from its denominator.

productivity externalities in terms of the gross change in income, without identifying how it is allocated between private consumption versus changes in public revenues. There would appear to be an inconsistency in this approach: when a change in income is due to environmental damage, the full unit of income is being recognized, but when valuing an exogenous change in income, only the change in private consumption is being recognized. Moreover, since the marginal damage is defined without considering how it will be allocated, the feedback effects on environmental quality is ignored (the third term in the numerator of (23p, 23y)). If this term is added to their measure of marginal damage in utility units, while still using λ as the numeraire unit of income, the relationship between this measure and the optimal environmental tax is identical to the relationship between τ^* and MPD in the amenity case.[8]

D. Discussion

Our theoretical expressions for optimal environmental taxes would be of little practical use without an estimable benchmark or standard against which policy objectives could be set and judged. Moreover, recent debate in the theoretical literature has relied heavily on comparisons of the optimal environmental tax and marginal private damages to make predictions about the benefits and costs of environmental policies, and changes in the levels of government revenues. For the two benchmarks considered above, the following observations are offered in regard to possible criteria.

First, does the benchmark have a theoretical basis for judging whether the welfare gains from environmental taxation with revenue recycling are higher or lower than marginal

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[8] This result can be anticipated by examining (24). We can substitute λ/λ for α/α to see that if the complete numerator from MSD, $\phi e'$, is used for all types of externalities, then the relationship between τ^* and $\phi' e/\lambda$ will be invariant across types of externalities.

social damages at a tax rate equal to MSD? The first-order conditions of the optimal tax problem includes $\phi e'$, plus other expressions pertaining to the private and social costs of taxation. If we define MSD using α as a numeraire, then we have maintained in these first-order conditions an expression which is equal to the Pigouvian rate. And if we then find that the optimum is reached at $t^* < MSD$, we can assume that other welfare changes represented in those first-order conditions offset the gains from reducing pollution short of the point where the optimal environmental tax equaled marginal social damage. The evidence presented above suggests the opposite, that at $\tau^* = MSD$, the net benefits from environmental taxation continued to justify further increases in τ to a point about 50 percent above MSD.

By contrast, if we introduce λ as a numeraire in these first-order conditions, we will have an expression for marginal damages with a socially valued numerator ($\phi e'$) and a privately valued denominator (λ). It becomes difficult to justify ignoring the two terms which cancel out at the first-best optimum in the denominator (as in (9)), while including two similar terms in the numerator. Whereas MSD does indeed reflect the social marginal rate of substitution between the environment and income, MPD does not reflect social valuations as a general proposition, nor do components of MPD emerge from the first-order conditions of the model, except as an expression which is equal to the optimal tax at the first-best optimum. The evidence presented above indicates that wide differences in τ^*/MPD do not correspond to differences in the welfare changes from revenue-motivated taxation or environmental tax reform. Moreover, the definitions of marginal damages used in the recent literature for the income and productivity cases raise additional questions of consistency across types of externalities and the theoretical justification behind the definitions being used.

Second, does the benchmark provide a basis for setting policy given the practical difficulties of empirical measurement? Although it may be the case that elements in the numerator and denominator of MSD add complications compared to estimating MPD, the optimal tax is ultimately a function of MSD, as evidenced by the single expression for τ^* which applies to all types of externalities. All the elements of MSD, μ, and α must be estimated to arrive at τ^*. Estimating MPD may be a simpler way to obtain a measure of damages in the amenity case, but this simply shifts the complications to an exercise in estimating how τ^* will diverge from MDP, which will depend on the type of externality and the differences between private and social values of income. Whereas τ^* is defined here succinctly in (24), the alternatives using MPD would appear to involve many more terms to evaluate the sources of divergence between τ^* and MPD (see, for example, Williams 2002, p. 266).

One may point to a number of reasons for preferring one measure of marginal damages over another, such as the ease of empirical measurement, or whether the economics profession is more accustomed to using one versus another. For present purposes of confirming or refuting predictions about the second-best welfare changes associated with environmental policy, however, there should be no dispute that the validity of the predictions should be the basis for using one approach over another.

V. Concluding comments

In the past few years the economic justification for environmental policy has been called into question by a theoretical literature relying on comparisons between the optimal environmental tax in a second-best setting and a benchmark measure of the Pigouvian rate, the sum of marginal private damages. Although this benchmark expression reflects society's marginal rate of substitution between the environment and income at the first-best optimum, it does not reflect social valuations either in the absence of corrective taxes, or in the presence of revenue-motivated taxes. Indeed, the presence of revenue-motivated taxes causes private valuations to diverge significantly and inconsistently from social valuations across different types of externalities. These differences mainly reflect the fact that in a second-best setting, an incremental unit of income will be allocated in part to private consumption and in part to government either for the provision of public goods or, in these stylized models, to be returned to households in lump sum payments. As a result, the private value of income is an inverse function of the tax level, but this does not reflect a decline in the social value of exogenous income. Using this private value as a social numeraire distorts this measure of marginal environmental damages relative to its social value.

The relationship between the optimal environmental tax and MSD is consistent across all types of externalities, and it is stable to the extent that the model's functions are nearly linear over the relevant range, so that social marginal valuations are relatively unchanged. Comparisons between the optimal environmental tax and MSD are consistent with our intuition and the results anticipated with the double dividend hypothesis: the optimal environmental tax generally exceeds MSD when a "revenue-recycling effect" lowers the cost of environmental policy. In this regard, the results are highly consistent with the classical literature: environmental waste disposal services, like other goods, should be priced according to their social cost in keeping with the Pigouvian Principle in a first-best setting, and in a second-best setting a Ramsey rule will generally add a tax premium on top of the Pigouvian rate.

Recent debate in the literature is reminiscent of Baumol (1972) concluding, "it is ironic that just at the moment when the Pigouvian tradition has some hope of acceptance in application it should find itself under a cloud in the theoretical literature." Although set in an earlier time, these sentiments seem valid again today. The implementation of large-scale emissions trading, congestion pricing, and discussions of national carbon taxes, has been juxtaposed with the suggestion that a heretofore unrecognized "tax interaction effect" castes doubt on the merits of pollution control policies, and implies that government's must choose between protection of the environment and financing expenditures on other public goods, but that doing more of one will raise the costs of doing the other.

One can, of course, compare optimal taxes to any kind of benchmark one wishes. The path taken recently, however, has led toward inconsistent and logically incongruous results across types of externalities, explanations that require the introduction of new distortionary phenomenon, newly defined measures of partial welfare changes called "gross cost," etc.. Most importantly, the predictions made based on the relative magnitude of optimal environmental taxes and this definition of marginal damages appear to reflect the inconsistency of the chosen benchmark rather than movement of the optimal tax in one direction or the other.

There is no doubt that both MSD and MPD can be shown to equal "the Pigouvian rate" at the first-best optimum, which raises ambiguity about which one should be used to make valid inferences and predictions about the benefits and costs of environmental policy in second-best setting. There is no evidence, however, that the authors of the recent tax interaction literature recognized that there were two possible definitions of marginal damages, or that the choice of one versus the other could lead to valid versus invalid inferences and predictions. The critical distinction between the social and private marginal utility of income appears to have been simply overlooked.

The analysis performed here finds that it is not the optimal environmental tax that behaves unexpectedly, but rather the benchmark of marginal private damages, which is found to have no consistent relationship with marginal social damage (defined from society's perspective), the optimal environmental tax, or the welfare changes from revenue-neutral environmental tax reform. In sum, the traditions in optimal tax theory begun by Pigou and Ramsey, and advanced further by Sandmo, Diamond, Baumol and others, appear to need no fundamental revision.

Table 1. Numerical model results for optimal environmental taxation in first-best, second-best settings and for "green tax reform"

Amenity externality	τ^*	MSD	$\frac{\tau^*}{MSD}$	α	$\phi e'$	t_n	μ	MPD	$\frac{\tau^*}{MPD}$	λ	$m\frac{dv}{dE}$	Welfare change from first-best ($ billions)	Welfare change fo “green tax reform” ($ billions)
First-best optimum	25.4	25.4	1.00	0.39	10.0	0.00	0.39	25.4	1.00	0.39	10.0		
Second-best:													
G = $0.5 trillion	28.2	25.4	1.11	0.39	10.0	0.13	0.40	28.3	1.00	0.35	10.0		
G = $1 trillion	31.2	25.3	1.23	0.40	10.0	0.28	0.41	31.5	0.99	0.31	10.0		
G = $2 trillion	37.5	25.0	1.50	0.40	10.0	0.61	0.43	38.2	0.98	0.26	10.0	-$76.7 billion	1.44
												(-1.9 %)	
Income externality													
First-best optimum	25.4	25.4	1.00	0.39	10.0	0.00	0.39	25.4	1.00	0.39	10.0		
Second-best:													
G = $0.5 trillion	28.3	25.4	1.11	0.39	10.0	0.13	0.40	25.2	1.12	0.35	8.9		
G = $1 trillion	31.5	25.5	1.24	0.40	10.1	0.29	0.41	25.3	1.25	0.32	8.0		
G = $2 trillion	38.3	25.7	1.49	0.40	10.2	0.62	0.43	25.3	1.51	0.26	6.6	-$77.2 billion	1.51
												(-1.9%)	
Productivity externality													
First-best optimum	25.4	25.4	1.00	0.39	10.0	0.00	0.39	25.4	1.00	0.39	10.0		
Second-best:													
G = $0.5 trillion	28.3	25.4	1.11	0.39	10.0	0.13	0.40	24.6	1.15	0.35	8.7		
G = $1 trillion	31.5	25.5	1.24	0.39	10.1	0.28	0.41	24.1	1.31	0.32	7.6		
G = $2 trillion	38.6	25.7	1.50	0.40	10.3	0.61	0.43	22.8	1.69	0.26	6.0	-$76.6 billion	1.52
												(-1.9%)	

Notes: Green tax reform compares welfare under uniform taxation with optimal taxation for a given revenue requirement.

Values for **τ^***, MSD, MPD, $\phi e'$, and $m\,(dv/dE)$ are in dollars per ton.

Tax levels at G = $2 trillion are equivalent to a marginal income tax of 38 percent.

Appendix A: Derivations of second-best optimal taxes

Optimal tax expressions are derived below for three types of externalities based on general models with n+1 goods. The general approach is similar to Sandmo (1975).

Amenity externality

For the case of an amenity externality, the problem can be formulated as one in which *m* identical individuals maximize utility $U = u(x_0, x_1, x_2, \ldots, x_Z, \ldots, x_n, E)$ for goods $j = 0, \ldots, n$, where leisure is x_0 and where labor supply is taken out of a time endowment, *y,* so that labor supply, $l = y - x_0$. Units are chosen for goods and income so that all pre-tax prices equal one, and where there are *n*-1 non-polluting *x* goods (excluding leisure) and one good x_z which produces an environmental externality. The consumption of x_z is assumed to erode the environment, *E*, where $E = e(mx_z)$ and where ${de}/{d(mx_Z)} < 0$.

In the amenity case, labor productivity, *h*, is constant, so that aggregate output is defined as $m(y-x_0)h = \Sigma m x_i$. Transfers of *mg* are financed by distortionary taxes, and *E* enters the utility function directly. Each household's maximization problem can be stated as

$$\underset{x_0 \ldots x_n}{Max} : \quad u(x_0, x_1, \ldots x_n, E)$$

$$s.t. \quad (y - x_0)h + g = \sum_{j=1}^{n} (1 + t_j) x_j$$

The Lagrangian expression for each household taking E and g as given is thus

$$\square = u(x_0, x_1, \ldots x_n, E) + \lambda \left[(y - x_0)h + g - \sum_{j=1} (1 + t_j) x_j \right] \text{ for } j = 1, \ldots, z, \ldots, n.$$

[A1]

Consumer prices are given as $p_j=1+t_j$ for j=1 to *n*, but where income is untaxed, so that $p_0=1$.

The first-order conditions for each household take the form

$$U_j = \lambda(1+t_j) \qquad j=1,\ldots,n$$

$$U_o = \lambda h$$

$j=x_0$.

Our social optimization problem can be stated as

$$\underset{t_1 \ldots t_n}{Max} : \quad m\left[u(x_0, x_1, \ldots x_n, E) \;\; s.t. \;\; (y - x_0)h + g = \sum_{j=1}^{n} (1+t_j)x_j \right]$$

$$\begin{aligned} s.t. \qquad & m\sum_{j=1}^{n} t_j x_j = mg \\ & E = e(mx_Z) \end{aligned}$$

[A2]

Taking the dual approach, we define the household's indirect utility function as $v(p_0, p_1, \ldots p_n, y, g, E) = u(x_1{}^*(p_0, p_1, \ldots p_n, y, g, E), x_2{}^*(p_0, p_1, \ldots p_n, y, g, E), \ldots x_n{}^*(p_0, p_1, \ldots p_n, y, g, E)$, so we can state the social optimization problem as the Lagrangian equation

$$\square = mv(p_0, p_1, \ldots p_n, y, g, E) + \mu\left[m\sum_{j=1}^{n} t_j x_j - mg \right] + \phi\left[e(mx_Z) - E\right].$$

The first-order conditions are

$$-\lambda x_j + \mu\left[\sum_i t_i \frac{\partial x_i}{\partial p_j} + x_j \right] + \phi^a e' \frac{\partial x_Z}{\partial p_j} = 0 \quad \forall \; j \neq 0 \cdot$$

[A3]

from which the term related to environmental damage in this expression, succinctly denoted as $\phi^a e'$, can be expressed as

$$\phi^a e' = -m\left[\frac{\partial U}{\partial E} + \mu \sum_i t_i \frac{\partial x_i}{\partial E} + \phi e' \frac{\partial x_Z}{\partial E}\right] e' \cdot$$

[A4]

From this expression we can see that the environmental component involves marginal social damage in utility units which includes the direct loss to households, the loss of revenues due to changes in consumption, and indirect losses to households from the environmental consequences of changes in consumption of the polluting good.[9]

Derivations of optimal tax rules often include substitution of the Slutsky equation in such a way that the social marginal utility of income, α, is represented along with the shadow cost of raising an additional dollar of revenue (Auerbach 1985). Diverging slightly from the approach taken by Sandmo, we rearrange the planner's first-order conditions and use the Slutsky equation to split the cross-price effects into compensated effects (superscript *U*) and effects on income, y, as $\frac{\partial x_Z}{\partial p_i} = \frac{\partial x_Z^U}{\partial p_i} - x_i \frac{\partial x_Z}{\partial y}$. We substitute α to obtain

$$-\alpha x_j + \mu \sum_i t_i \frac{\partial x_i^U}{\partial p_j} + \mu x_j + \phi^a e' \left(\frac{\partial x_Z^U}{\partial p_j} - x_j \frac{\partial x_Z}{\partial y} \right) = 0 \qquad \forall\, j \neq 0 \cdot \qquad \text{[A5]}$$

where for our *n* good model, the social marginal utility of income is expressed as

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[9] Sandmo does not explicitly consider the effect of changes in environmental quality on demands for goods, so the second and third terms on the right-hand side of [A14] is omitted in his analysis. However, given the highly stylized representation of an environmental externality, one may assume that Sandmo has assumed the effects to be incorporated as indirect components of the cross-price effects with respect to the polluting good.

$$\alpha = \lambda + \mu \sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial y} + \phi e' \frac{\partial x_Z}{\partial y} \cdot$$

We define **Š** as the determinant of the Slutsky matrix of compensated demands, so that **S_{ij}** is the cofactor of the element for the *jth* row (price) and *ith* column (quantity). Using Cramer's rule we can solve for the optimal taxes

$$t_j = \frac{(\mu - \alpha)}{\mu} \frac{\sum_{i=1}^{n} x_i S_{ij}}{\check{S}} - \frac{\phi^a e'}{\mu} \frac{\sum_{i=1}^{n} \left(\frac{\partial x_Z^U}{\partial p_i} - x_i \frac{\partial x_Z}{\partial y} \right) S_{ij}}{\check{S}}$$

[A6]

where the second term on the right-hand side is the environmental component of the tax. From theorems about the expansion of determinants, we know that

$$\sum_{i=1}^{n} \frac{\partial x_Z^U}{\partial p_i} S_{ij} = \begin{cases} 0 & \text{for } j \neq z \\ \check{S} & \text{for } j = z \end{cases} .$$

Let R denote the "Ramsey term" for compensated demands or $R \equiv \sum_{i=1}^{n} x_i S_{ij} \big/ p_j \check{S}$ reflecting the revenue generating potential for a marginal change in the tax on x_i due to the direct and indirect effects on consumption for all goods. Further simplify the notation by defining the income effect on the environment as $\sigma^a = \phi^a \sum_{i=1}^{n} x_i \frac{\partial x_Z}{\partial y}$. We can thus rearrange terms and simplify so that the optimal tax expressions can then be written as

$$\frac{t_j}{(1 + t_j)} = \frac{(\mu - \alpha + \sigma^a)}{\mu} R \qquad \forall j \neq z$$

[A7]

and

$$\frac{t_j}{(1+t_j)} = \frac{\left(\mu - \alpha + \sigma^a\right)}{\mu} R - \frac{\phi^a e'}{\mu(1+t_j)} \qquad j = z$$

[A8]

These implicit solutions are difficult to interpret by inspection, in part because of the lack of transparency in interpreting ***R***. Moreover, although the environmental component of the tax in [A8] appears to be separable from the standard formula, the independence is illusory both because of the denominator (1 +t_z) is endogenous and because the actual level of the externality depends on the actual equilibrium and hence the optimal tax rates; the same is true in the other direction (Sandmo 1975, Auerbach 1985).

The results differ from the expressions obtained by Sandmo involving uncompensated demands. Sandmo concluded that the environmental damages of x_z “does not enter the tax formulas for the other commodities, regardless of the pattern of complementarity and substitutability” (1975, p. 92). In this alternative derivation, we see that the numerator in the first term on the right-hand side includes σ, a term involving ϕ^a, indicating that the presence of an externality raises the optimal tax on all goods due to their income effect: by reducing real income, all taxes discourage consumption of the externality-producing good to some extent, and these optimal tax rates will be higher as a result. These two versions of the optimal tax results are not in conflict: in the model involving ordinary demands, the income effects are implicit.

In the sections below, optimal tax expressions are also derived for two other types of externalities, productivity externalities and income externalities. The resulting optimal tax expressions differ only in terms of the definition of marginal social damage, ϕ.

We are interested in the environmental component of the optimal tax on x_Z which can be taken as the differential between the optimal tax on x_z and the optimal tax on good x_j, or $\tau^* = t_Z^* - t_j^*$.

From the [A7] and [A8] we can express t_z^* as

$$t^*_Z = \frac{\left(1 - \frac{\alpha + \sigma}{\mu}\right)R}{\left(1 - \left(1 - \frac{\alpha + \sigma}{\mu}\right)R\right)} - \frac{\alpha}{\mu\left(1 - \left(1 - \frac{\alpha + \sigma}{\mu}\right)R\right)}\frac{\phi e'}{\alpha}$$

[A9]

where from [A7} we can express the Ramsey term as

$$R = \frac{\frac{t^*_j}{(1 + t^*_j)}}{\left(1 - \frac{\alpha + \sigma}{\mu}\right)}$$

[A10]

To evaluate the optimal tax t^*_Z relative to MSD, we substitute [A10] into the second term of [A9] and rearrange to get

$$t_Z^* = \frac{\left(1 - \frac{\alpha + \sigma}{\mu}\right)R}{\left(1 - \left(1 - \frac{\alpha + \sigma}{\mu}\right)R\right)} - \frac{\alpha\left(1 + t_j\right)}{\mu}\left[\frac{\phi e'}{\alpha}\right].$$

[A11]

We can evaluate the environmental component of the tax on x_z by evaluating the second term in [A11], or

$$\tau^*_Z = \frac{\alpha\left(1+t_j\right)}{\mu}\left[\frac{-\phi e'}{\alpha}\right]$$

where the term in brackets is MSD. Note that while the terms α in numerator and denominator could be replaced with λ, so that the optimal tax expression could involve the private marginal utility of income, the numerator involves ϕ rather than mU_z, so that the expression cannot be based on the sum of marginal private damages unless restrictions on preferences are assumed so that the second and third terms in ϕ can be dropped.

Productivity externality

We now consider a model where, rather than affecting utility directly, environmental quality affects labor productivity. Given the similarities with the derivation above, not all steps are repeated here.

In this model, labor productivity, *h*, is a function of environmental quality such that $h = h(E)$ where $E=e(mx_z)$. We define aggregate output as $m(y-x_0)h = \Sigma mx_i$, and where mg is financed through collection of tax revenues. Our maximization problem becomes

$$\underset{X_0 \ldots X_n}{Max}: \quad u(x_0, x_1, \ldots x_n)$$
$$s.t. \quad (y - x_0)h(E) + g = \sum_{j=1}^{n}(1+t_j)x_j \qquad \text{[A12]}$$

so that individuals maximize utility subject to their budget constraint while ignoring both the environmental consequences of their own consumption choices and government behavior. The Lagrangian expression for each household is thus

$$\square = u\left(x_0, x_1, ..x_n\right) + \lambda\left[(y - x_0)h(E) + g - \sum_{j=1}(1+t_j)x_j\right] \text{ for } j = 1, .., z, \ldots, n. \qquad [A13]$$

The social problem is then

$$\underset{t_1 \ldots t_n}{Max} : \quad m\left[u(x_0, x_1, \ldots x_n) \;\; s.t. \;\; (y - x_0)h(E) + g = \sum_{j=1}^{n}(1 + t_j)x_j\right]$$

$$s.t. \qquad m\sum_{j=1}^{n} t_j x_j = mg$$

$$E = e(mx_Z)$$

[A14]

As above, the dual approach gives us the household’s indirect utility function so we can state the social optimization problem as the Lagrangian equation

$$\square = mv(p_0, p_1, \ldots p_n, y, g, E) + \mu\left[m\sum_{j=1}^{n} t_j x_j - mg\right] + \phi\left[e(mx_Z) - E\right] \qquad [A15]$$

In the presence of environmental effects on labor productivity, the first-order conditions for the social optimization problem are

$$-\lambda x_j + \mu\left[\sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial p_j} + x_j\right] + \phi e' \frac{\partial x_Z}{\partial p_j} = 0 \qquad \forall\ j \neq 0$$

[A16]

where $\lambda = {dV}/{dh} = {\partial U^*}/{\partial h}$ is the household’s marginal utility of income. Let $\phi^p e'$ denote marginal social damages in utility units for the productivity externality case, or

$$\phi^p e' = m\left(\lambda(y - x_0) + \mu\sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial h} - \phi e' \frac{\partial x_Z}{\partial h}\right)h' e'$$

[A17]

Once again the marginal social damage includes the direct loss of income to households, the loss in revenues due to changes in consumption, and the indirect changes from the environmental consequences of changes in consumption of the polluting good.

The derivation of the optimal taxes proceeds from this point as indicated above. The optimal tax expressions are similar and can be written as

$$\frac{t_j}{(1+t_j)} = \frac{(\mu - \alpha + \sigma^p)}{\mu} R \qquad \forall j \neq z$$

[A18]

and

$$\frac{t_j}{(1+t_j)} = \frac{(\mu - \alpha + \sigma^p)}{\mu} R - \frac{\theta^p e'}{\mu(1+t_j)} \qquad j = z$$

[A19]

Income externality

We now consider a model where the quantity of income is a direct function of the environment. In our stylized model, *y*, the time endowment, is made a function of *E* such that $y= y(E)$ where $E=e(mx_z)$. We define aggregate output as $m(y(E)-x_0)h= \Sigma mx_i$, and where *mg* is financed through collection of tax revenues. Each household's maximization problem can be stated as

$$\underset{X_0 \dots X_n}{Max}: \quad u(x_0, x_1, \dots x_n)$$
$$s.t. \quad (y(E) - x_0)h + g = \sum_{j=1}^{n} (1 + t_j)x_j$$

[A20]

so that individuals maximize utility subject to their budget constraint while ignoring both the environmental consequences of their own consumption choices and government behavior. The Lagrangian expression for each household in this case is

$$\square = u(x_0, x_1, \dots x_n) + \lambda\left[(y(E) - x_0)h + g - \sum_{j=1} (1 + t_j)x_j\right] \text{ for } j = 1, .., z, \dots, n. \qquad [A21]$$

And the social problem is then

$$\underset{t_1 \dots t_n}{Max}: \quad m\left[u(x_0, x_1, \dots x_n) \;\; s.t. \;\; (y(E) - x_0)h + g = \sum_{j=1}^{n} (1 + t_j)x_j\right]$$
$$s.t. \qquad m\sum_{j=1}^{n} t_j x_j = mg$$
$$E = e(mx_Z)$$

[A22]

As above, the dual approach gives us the household's indirect utility function as $v(p_0, p_1, \dots p_n, y, g, E) = u(x_1^*(p_0, p_1, \dots p_n, y, g, E), x_2^*(p_0, p_1, \dots p_n, y, g, E), \dots X_n^*(p_0, p_1, \dots p_n, y, g, E)$, so we can state the social optimization problem as the Lagrangian equation

$$\square = mv(p_0, p_1, \dots p_n, y, g, E) + \mu\left[m\sum_{j=1}^{n} t_j x_j - mg\right] + \phi[e(mx_Z) - E]$$

In the presence of environmental effects on labor productivity, the first-order conditions for the social optimization problem are

$$-\lambda x_j + \mu\left[\sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial p_j} + x_j\right] + \phi^y e' \frac{\partial x_Z}{\partial p_j} = 0 \qquad \forall\ j \neq 0$$

[A23]

where $\lambda = {dV}\big/{d(yh)} = {\partial U^*}\big/{\partial(yh)}$ is the household's marginal utility of income. Let ϕ^R denote marginal social damages in utility units for the resource externality case, or

$$\phi^y e' = m\left(\lambda h + \mu\sum_{i=1}^{n} t_i \frac{\partial x_i}{\partial y} + \phi^y e' \frac{\partial x_Z}{\partial y}\right) y' e'$$

[A24]

where marginal social damage includes the direct loss of income to households, the loss in revenues due to changes in labor supply, and the indirect or secondary effect on environmental quality.

The resulting optimal tax expressions are nearly identical to those above, or

$$\frac{t_j}{(1+t_j)} = \frac{(\mu - \alpha + \sigma^y)}{\mu} R \qquad \forall j \neq z$$

[A25]

and

$$\frac{t_j}{(1+t_j)} = \frac{(\mu - \alpha + \sigma^y)}{\mu} R - \frac{\phi^y e'}{\mu(1+t_j)} \qquad j = z$$

[A26]

For all three types of externalities we obtain similar optimal tax expressions which differ only in terms of the expression for marginal social damage expressed in utility units, ϕ. It is worth noting that ϕ will differ from the sum of marginal private damages (in utility units) for each type of externality except for special cases involving restrictions on preferences and parameter values.

APPENDIX B: Specification of the numerical climate-economy model

The numerical models representing the US economy include a primary CES utility function, $u=U(x,l)$ given as

$$U = \left(\gamma x^{-\rho} + (1-\gamma)l^{-\rho}\right)^{-1/\rho}, \qquad \text{[B1]}$$

and a secondary CES production function defining substitutions between f and n in $x=X(f,n)$ as

$$x = \left(\beta f^{-\delta} + (1-\beta)n^{-\delta}\right)^{-1/\delta}. \qquad \text{[B2]}$$

This production function is a single CES function rather than the more disaggregated, nested CES structure of production in the Parry, Williams and Goulder model (1999). The functions and parameters have been calibrated to correspond to the second-best marginal abatement cost function from Parry, Williams and Goulder (1999).

Setting $\delta = -0.5$ implies that the elasticity of substitution between carbon emitting and non-carbon emitting consumption, σ_{nf}, equals $(1/1+\delta) = 2.0$. The value of $\rho = -0.167$, so that the elasticity of substitution between consumption and leisure, σ_{xl}, equals $(1/1+\rho) = 1.2$. In addition, $\gamma = 0.836$, $\beta = 0.667$, and $m=1$.

For the productivity externality, other than the constraints emerging directly from the household first-order conditions, we have the budget constraint

$$(1+t_f)f + (1+t_n)n = (y^0 - l)\left[1 + r(q-E)\right] + G \qquad \text{[B3]}$$

where $Y^0=4{,}101{,}535$, $r=0.0000072$ and $q=1448$, and the environmental constraint, $E=\pi f$ where $\pi=.00225$.

In the case of the income externality, labor productivity is instead fixed at h=1 and y is a function of but we have

$$(1+t_f)f+(1+t_n)n=\left[(y^0+w-sE)-l)\right]+G \qquad \text{[B4]}$$

where Y^0=4,101,535, w=1449, s=25.44. For this model, carbon content is slightly higher in E=πf where π =.002272.

In the case of the amenity externality the budget constraint is simplified since y is fixed at y^0 and h=1, so that

$$(1+t_f)f+(1+t_n)n=(y^0-l)+G\,. \qquad \text{[B5]}$$

The utility function, however, includes an additional term making environmental quality separable, or

$$U^A=\left(\gamma x^{-\rho}+(1-\gamma)l^{-\rho}\right)^{-1/\rho}+k(q-E) \qquad \text{[B6]}$$

where k=10 and q=1546. The pollution coefficient, π = 0.00225.

All three models produce a first-best optimum where the carbon tax is $25.4 per ton, and both MSD and MPD are also 25.4. The social, as well as the private, marginal utility of income is 0.39 at this optimum. Similarly, both the social and the private marginal damage in utility units equals 10. There are slight differences in household allocation between goods and leisure at the first-best optimum.

At the second-best optima where revenues and tax rates are similar to the U.S. economy (at G=$2 trillion), the uncompensated labor supply elasticity for each model is in the range of estimates for the U.S. economy (≅0.15).

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Comments on Carbon Taxes and Trades
EPA Conference on Market Mechanisms
and Incentives for Environmental Management, May 1-2,2003

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Introduction

The literature on environmental policy with pre-existing distortionary taxes addresses two important policy questions. First, how do pre-existing distortionary taxes affect the choice among different regulatory instruments: taxes, tradable permits, or various types of command-and-control? Second, how do pre-existing taxes affect the optimal degree of regulation? Each of the three papers in this session addresses some aspect of one or both of these questions.

I will begin with a very brief review of the important theoretical concepts from the prior literature on environmental policy with pre-existing taxes. I will then go on to comment specifically on each of the three papers presented in this session. Finally, I will return to the two policy questions I just mentioned, and attempt to draw some conclusions for policy based on the three papers.

The prior literature has identified two welfare effects that arise in the presence of pre-existing distortionary taxes. The first is the revenue-recycling effect: revenue raised by an environmental policy can be used to cut pre-existing distortionary taxes, producing a welfare gain. But this is offset by the tax-interaction effect: environmental regulation drives up the cost of production, thus reducing the real return to factors of production (ie, capital and labor), discouraging supply of these factors, thus exacerbating the pre-existing distortions in those factor markets and producing a welfare loss. The recent book edited by Larry Goulder (2002) provides a collection of the important papers from this literature.

Comments on the paper by Ian Parry

This paper provides a non-technical summary of several papers by Ian Parry (with a variety of co-authors, including myself). It addresses both of the policy questions mentioned earlier. On the issue of instrument choice, it points out that policies that raise revenue, such as a pollution tax or auctioned emissions permits, can generate a revenue-recycling effect. This gives such policies an important advantage over other regulatory instruments, such as grandfathered emissions permits, which do not generate revenue.

On the question of the optimal degree of regulation, the paper points out that the tax-interaction effect will typically exceed the revenue-recycling effect, thus implying that environmental regulation should be less stringent than it would be in the absence of pre-existing taxes. The intuition for this point is relatively simple; ignoring environmental considerations, broad-based factor taxes are generally more efficient means of raising revenue than are relatively narrow-based environmental taxes.

But, while this will be true for the typical case, that does not mean it will always be true. If the pre-existing tax system is suboptimal, and if the environmental tax offsets that, then pre-existing distortionary taxes may increase the optimal level of environmental regulation. In one example Parry cites, the US income tax favors certain kinds of consumption: medical care, owner-occupied housing, etc. If there is no legitimate reason for such preferences, then environmental taxes (which do tax such consumption) may well be more efficient–even on purely non-environmental grounds–than the income tax. Thus, the optimal level of an environmental tax could exceed marginal environmental damage.

I have no significant criticisms or suggestions for how to improve this work, both because it is based on research already published in good peer-reviewed journals, and because I was a co-author of several of the those papers. Therefore I will proceed on to the other two papers, which describe newer work.

Comments on the paper by Richard Howarth

Howarth's paper looks at optimal carbon taxation, using a simple dynamic computational general equilibrium model of the world economy. It makes two key points. First, the optimal carbon tax (and the welfare gain from implementing that tax) varies substantially based on how the tax revenues are used; using the revenue to cut capital taxes leads to a higher optimal carbon tax and larger welfare gain than if the revenue is used to cut labor taxes (which in turn yields a higher optimal tax than if the revenue is returned lump-sum). Second, pre-existing taxes on capital imply that the appropriate discount rate will generally differ from the marginal product of capital (which would be the appropriate rate in a first-best world). For a stock externality such as global climate change, where emissions today cause damage in the future, the discount rate plays an important role in determining optimal policy. The first point is not new–papers by Bovenberg, Goulder, and others have made this observation before. However, the second point–on the discount rate–is new, at least for this literature (the literature on discounting has been aware of this issue for a long time). Thus, I will focus my comments on this second point.

The point is relatively simple. Taxes on capital cause the after-tax rate of return on capital to be less than the pre-tax return. In this case, it is difficult to determine which rate to use as the discount rate; indeed, the discounting literature has shown that the appropriate rate will generally not be equal to either the pre-tax or after-tax rate of return. And for a long-lived pollutant such as carbon, even small changes in the discount rate can produce large changes in the present discounted value of a given stream of future damages. The prior literature has tended to focus on the cost side–typically assuming a particular value for discounted damages, rather than modeling damages explicitly–and thus has generally ignored this issue.

However, it is difficult to discern the importance of this issue from Howarth's current results. The second-best optimal carbon tax will differ from the first-best optimal tax for two reasons. First, as noted by the prior literature, the combination of revenue-recycling and tax-interaction effects implies that the second-best optimal tax will not equal discounted damages. Second, differences in the appropriate discount rate between the first-best and second-best imply that discounted damages will differ. Howarth's paper presents the first-best and second-best optimal tax rates, but does not distinguish how much of the difference between those rates is due to each of these two reasons.

It would be relatively easy to distinguish these two effects by comparing the results to those for the case of a flow pollutant–one for which emissions in a given time period cause damage only in that period. In such a case, the discount rate will not matter, which will make it possible to isolate the influence of the revenue-recycling and tax-interaction effects in Howarth's model. I would suggest that he introduce a flow pollutant into the model, and calibrate the marginal damage from the pollutant such that the optimal tax rate on the flow pollutant is equal to the optimal carbon tax in each period (which will generally require marginal damages to differ across periods). The marginal damage from the flow pollutant will then equal the discounted marginal damage from carbon emissions, making it straightforward to calculate the appropriate discount rate. I suspect that this will show that the divergence in discount rates between the first-best and second-best plays a significant role in determining the optimal carbon tax, but very little role in determining how that optimal tax varies based on how the revenue is used.

Comments on the paper by William Jaeger

This paper proposes a new definition for marginal damage in the presence of pre-existing distortionary taxes. It then notes that under this definition, there is a consistent relationship between marginal damages and the optimal tax across different externality types, and that the optimal pollution tax exceeds marginal damage. The paper also claims that under this definition of marginal damage, there is no tax interaction effect. The first two points strike me as correct– though I would disagree about the interpretation and the practical relevance of these points– while the third strikes me as likely to be incorrect.

The paper defines marginal damage as the ratio of the Lagrangian multiplier on environmental quality in the social planner's problem to the Lagrangian multiplier on gross income–or, more intuitively, as the social planner's marginal willingness to pay for improved environmental quality. This definition has the advantage that it is the same regardless of the type of externality, and that it yields the same relationship between marginal damage and the optimal tax.

In contrast, one of my recent papers (Williams, 2002) uses three different definitions of marginal damage for three different externality types. For an externality that directly affects utility, it defined marginal damage as the sum of individuals' willingness to pay. For an externality affecting productivity, it defined marginal damage as the value of lost production. And for a health externality, it defined marginal damage as the cost of additional medical care plus the value of time lost to illness. Furthermore, the relationship between the optimal tax and marginal damage is different for each type of externality.

Having three different definitions–and three different formulas for the optimal tax–may seem needlessly complex. But in practice, Jaeger's new definition isn't any simpler. The definitions I chose correspond to how environmental damage is measured empirically in each case. In contrast, Jaeger's new definition of damages cannot be directly measured in practice, and the relationship between his definition and empirical measures of marginal damage is different for each type of externality. Thus, the process of calculating the optimal tax from an empirical measure of damages is no simpler under his definition than under the definitions in my paper; it merely moves the complexity to a different step in the calculation.

Jaeger's new definition also implies that the optimal tax exceeds marginal damages, at least for typical parameter values. But one must be very careful in interpreting this result: it is not that his approach yields a higher optimal tax for a given economy than the prior literature would indicate, but rather that it yields a lower figure for marginal damage. The following example (drawn from Goodstein, 2003) makes it clear why the two approaches differ. Consider a case in which one unit of pollution leads to a 10 util reduction in utility, and the marginal utility of income is 6 utils/dollar. Under the prior literature's definition, marginal damages are \$1.67 per unit (the 10 util marginal damage converted into dollars by dividing by the marginal utility of income). Jaeger's definition differs in that it converts utility to dollars based on the social marginal utility of income–which differs from the private marginal utility of income because an additional dollar of pre-tax income also yields tax revenue for the government. Thus, if the social marginal utility of income is 10 utils/dollar, marginal damages equal \$1 (10 utils per unit of pollution divided by the social marginal utility of income) under his definition. If the optimal pollution tax is \$1.30 per unit, then the prior literature's definition implies that the tax is less than marginal damage (\$1.30<\$1.67), while Jaeger's definition implies that the tax exceeds marginal damage (\$1.30>\$1). But, for any given economy, both approaches yield exactly the same optimal pollution tax; the difference arises because the dollar figure for marginal damages differs between the two approaches.

The only way that one would get a different result for the optimal tax as a result of this paper is if one were to make a mistake and use an optimal tax formula based on one definition together with a measure of damages based on the other definition. For example, if one were to use an optimal tax formula based on Jaeger's definition of damages together with a figure for the marginal damage from a particular pollutant based on the prior literature's definition (which corresponds with most empirical measures of damage), the resulting "optimal" tax would in fact be much larger than the true optimal tax. Making the opposite mistake–combining the prior literature's formula for the optimal tax with a damage estimate based on Jaeger's definition–would yield too low a tax rate. Thus, while it strikes me that while this paper's results may be of theoretical interest, they have essentially no practical importance–as long as one does not make the mistake of using inconsistent definitions of marginal damage.

Finally, the paper suggests that under Jaeger's definition of marginal damage, there is no tax-interaction effect. I suspect that this is incorrect. What the paper has shown is that, under Jaeger's definition, the magnitude of the revenue-recycling effect exceeds that of the tax-interaction effect. That could imply that there is no tax-interaction effect under this definition, or it could imply that the tax interaction effect still exists, even under this definition, but is smaller than under the definition used by the prior literature. It would be relatively simple to check which explanation holds true. I would suggest modifying the model so that the pollution tax revenue is returned lump-sum, rather than being used to cut the labor tax. This will eliminate the revenue-recycling effect. If the optimal tax equals marginal damage in this case, then that would imply that there is no tax-interaction effect. If, as I suspect will be the case, the optimal tax does not equal marginal damage, then that would indicate that there is a tax-interaction effect, even under Jaeger's definition of damages.

Conclusions

Based on these three papers, what can we conclude about the two policy questions I mentioned earlier? First, on the question of instrument choice, it is clear that emissions taxes or auctioned permits will be more efficient than grandfathered permits, as Ian Parry's paper noted. Recycling revenues to cut other taxes produces a welfare gain, and this is not possible under a system of grandfathered permits. Second, as noted by both Parry's and Howarth's papers, the more distortionary a pre-existing tax is, the larger the gain from recycling pollution tax revenues to reduce the rate of that pre-existing tax. Third, as pointed out by Howarth's paper, pre-existing taxes affect the discount rate, and this will have potentially important implications for the taxation of a stock pollutant. Finally, as Jaeger's paper makes clear, the definition of damages matters. One should be very careful not to use an optimal tax formula based on one definition together with an estimate of damages based on a different definition. However, as long as one does not make that mistake, Jaeger's approach yields the same optimal tax as does the prior literature.

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May 1, 2003 4:45 PM

Question and Discussion Session

Q. Alex Farrell, University of California at Berkeley,
This question relates to auction to permits only. In addition to the things you have talked about with these macro economic efficiencies, there are at least two effects that can probably be achieved with grandfathered permits to some degree. The first is the efficiency of the allowance market itself. The way this occurs is by reducing uncertainty. Uncertainty would be reduced by making it easier for new participants to enter, and also through the provision of both earlier information and reliable information on the price of allowances. Participants in allowance markets are very concerned about the inability to obtain allowances at almost at any price in the future. An auction mechanism, even though it could be expensive, could reduce non-compliance. The second effect is an innovation effect which occurs from pricing all emissions more directly than a cap and trade program. Individuals have shown for an SO2 market, that if you have the ability to control emissions, not controlling them when the cost is actually lower than a current allowance price is money left on the table. These are two effects that might further improve the operation of the regulatory system given there are lots of second best activities.

A. Ian Perry
Point well taken. What we have been discussing has only been the static welfare effects of pollution control. Obviously in a broader analysis you would want to take into account impacts on induced innovation. Those are very important over time. Forty years from now what will matter is how much innovation we did to develop cleaner technologies in the transportation sector and electricity sector. It is very important when choosing amongst different policies to consider how they might have different effects on incentives to innovate.

A. Richard Howarth
I agree with that comment as well. I haven't done it yet, but something that I want to do actually with this model that I have been working with is to put in the technical changes and then see how having ITC in the dynamic model, like what I have, how that changes what a second best tax looks like.

Q.
This question is about permits in general whether auctioned or grandfathered. It's clear from the discussion that if you have a tax you have revenue and you have to dispose of the revenue and this is offset someplace with distortionary taxes elsewhere in the economy. If you auction off permits again you are also raising revenue. If you grandfather permits and let the market operate only within the private sector so that the revenue remains in the private sector, then revenue still needs to be disposed. In these circumstances, I have never heard anybody say 'How are the folks in the private sector, where the funds never leave, going to use their returns and sales and so on.' What are the efficiency effects and the income generating effects and how that might they be compared to the efficiency gains by revenue recycling?

A. Roberton Williams,

Essentially the key with recycling through tax cuts you is that you get both a substitution and an income effect. If you cut taxes or allow the private sector to retain the revenues you get income effects. Income effects are going to go the other direction, so labor and investment decrease, and current consumption increases. If you have pre-existing tax distortion, these effects are going to create a situation where you don't have enough savings, don't have enough investment, don't have enough labor supply. Income effects worsen those distortions. Substitution effects reduce those distortions. That's why those two effects are going to go in opposite directions.

Q. Skip Laitner, US EPA, Office of Atmospheric Programs
I want to build a question on the issue of second best. We've suggested that revenue recycling could have some benefits because of reducing distortionary effects of some pre existing taxes and taking advantage of the market mechanism. What if the market itself isn't all that efficient? I'll give you an example. I'll use the ethylene industry which produces a lot of basic goods for our economy. We might have one average plant in the ethylene industry that might use 8K Btu per pound of ethylene for example but a very bad plant might use 8K, 9K, 10K Btu, and a very good plant might use 6K. So if we are using a representative agent to capture the dynamic of an overage plant there is a huge disparity among the performance of individual firms within individual sectors. In fact a good bit of work suggests a lot of work and a lot of little inefficiencies at all levels whether things are technologically based or managerial based. So I am wondering how this discussion will emerge if we begin to think more in terms of an agent based representation of these issues rather than a representative agent. That might uncover other market efficiencies that might further amplify this kind of discussion.

A. Richard Howarth
I guess there are inefficiencies in energy market and there is slack. And there are a lot of cost effective energy efficient technologies which the market is not taking advantage of because of various market failures. Policy makers need to focus on both getting the prices right, which is what we are discussing here, and on finding ways to make markets work more efficiently at the prices they see. In some of these models I guess energy efficiency programs for example would increase the decarbonization rate of the economy in a model like mine. So I guess we haven't address that question in this set of talks but clearly that's also a part of the big picture.

A. Roberton Williams,
I think Dallas Burtraw has also done some work that has firm level heterogeneity including tax interactions with Matt Cannon.

A. Richard Howarth
Also in a theoretical plan, my impression is that evolutionary economics offer some tools that are useful in looking at questions of technology adoption. Although how ideas from that research get integrated with ideas from the policy optimization models that we talk about it is of course a big task although something that ultimately needs to be done.

Q. June Taylor, Journalist,

When talking about recycling the carbon tax revenues to reduce labor taxes, payroll taxes and income taxes seemed to be lumped together. I wanted to know if you have ever separated any of them out because income taxes are nominally progressive and payroll taxes are regressive. Payroll taxes are split by those who are paid by employer and those paid by us working folks. So how do you tease out the economic stimulus benefits of reducing labor taxes when labor taxes are different? Also, as you look at the long run how do you take into account the change in demographics and the decreasing labor supply we foresee in the industrialized countries?

A. Ian Perry

The models we have been dealing with are highly aggregated - they just take the labor market as a whole. It would be good in future work to disaggregate that labor market and break out different income groups who place different rates of income tax. The problem is we have pretty good estimates of how economy wide labor supply would respond to changes of average wage for the economy. As far as I know we don't have good estimates of how labor supply elasticity might differ across different income groups. It's not obvious because this labor supply captures the decision regarding how many workers with in the family are deciding to go into the labor force. It's capturing whether a spouse in a poor family verses a rich family is likely to be in the labor force or not. And it's capturing how much extra over time individuals are likely to work. It's not obvious necessarily whether high income families are more responsive in their labor supply decisions to changes in tax rates than low income families. But in principle that's a good point. I think that we should take a more careful look at this revenue recycling effect in an analysis that breaks out different income groups and tries to asses how people facing different tax rates would vary in their labor supply response. It might alter the results somewhat. That would be a good research agenda if we had some evidence of how good labor supply elasticity's differ across different income groups. As regards to payroll tax, it's standard in economics to assume it doesn't really matter whether the payroll tax is levied on workers or on firms. Because when the labor markets are competitive, the firms have to pay the tax and firms are competitive, they would just tend to off set that by lowering the nominal wage to compensate. It's a standard assumption in tax theory that it doesn't matter who bears the tax. If you abolish payroll taxes for workers then shift them on to firms then they would be roughly compensating wage adjustments that would offset that tax change so not much would really happen to labor supply. That's a conventional assumption that if labor markets are working well it doesn't really matter whether the taxes are levied on the worker or the firm you get the same result.

A. Roberton Williams,

I am doing work with Sarah West at Macalester College where we are actually trying to break out different households by income class, and look at both efficiency and distribution in a tax interaction model and get out some of the issues. Ian's right it's complicated and very much a work in progress.

Q. Richard Woodward, Texas A&M University,

I don't have a question but since it was sort of two on one I'd like to make sure Bill Jaeger has an opportunity to rebut.

A. William Jaeger,

Let me respond to a couple of things Rob Williams said. This is a complicated issue. He indicated that I am coming up with a new definition of marginal damages. That sounds to me like suggesting that marginal damages were first defined in 1994. Peter Diamond talked about the social margin utility of income long before. It's not a new concept that the social margin utility of income is different than the private margin utility of income. I'm not creating new definitions. With different definitions we can say that one marginal utility is higher and one is lower. That is exactly my point. What's important in choosing a definition of marginal damages is that if you are going to make inferences by comparing the optimal tax to marginal damages, those inferences give you acute predictions about what's going on in terms benefits and costs and accurate predictions about what's going to happen if you raise the revenue requirement.

Market Mechanisms and Incentives: Applications to Environmental Policy

PROCEEDINGS
SESSION FOUR

SO_x/NO_x TRADES

A WORKSHOP SPONSORED BY THE US ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS AND NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH

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Session IV Proceedings

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A Comparison of the Effects of the Distribution of Emission Allowances for Sulfur Dioxide, Nitrogen Oxides and Carbon Dioxide

Dallas Burtraw and Karen Palmer

May 2, 2003

Abstract

Emissions cap and trade programs have gained wide acceptance as a cost-effective method for reducing air pollution arising from the electricity sector. One of the biggest issues in designing a cap and trade program is how to initially distribute the emission allowances. Three approaches, grandfathering to current emitters, distributing on the basis of recent generation and auctioning allowances to the highest bidder, have been proposed. The choice among these three approaches has tremendous effects on the distribution of costs and on the level of overall costs of a trading program. This paper summarizes the findings of a body of recent research on this issue and presents some new preliminary findings on how these effects can vary depending on the pollutant or mix of pollutants being regulated.

Key Words: emission trading, cap and trade, air pollution, cost-benefit analysis, electricity, sulfur dioxide, SO_2, nitrogen oxides, NO_X, carbon dioxide, CO_2, distributional effects

JEL Classification Numbers: Q25, Q4, Q28, L11, L94

A Comparison of the Effects of the Distribution of Emission Allowances for Sulfur Dioxide, Nitrogen Oxides and Carbon Dioxide

A Comparison of the Effects of the Distribution of Emission Allowances for Sulfur Dioxide, Nitrogen Oxides and Carbon Dioxide

Dallas Burtraw and Karen Palmer[Ψ]

April 28, 2003

1. Introduction

For the first time since 1990, Congress may be poised to enact major clean air legislation. Proposals now before Congress would impose dramatic reductions in emissions on electricity generators and large industrial facilities. They address multiple pollutants including sulfur dioxide (SO_2), nitrogen oxides (NO_X), mercury (Hg), and some proposals address carbon dioxide (CO_2) as well. The level and timing of emission reductions dominate the political debate. But one of the most controversial issues in 1990 – the question of whether to use emission trading - has fallen off the table. All of the current proposals embrace a cap and trade program for most, if not all, of the emission reductions that would be achieved. This represents a tremendous reversal of thinking from prevailing thought just over a decade ago when trading was a controversial idea. However, in spite of its widespread acceptance as a concept, the future generation of trading programs may ultimately raise a din of controversy that outdoes earlier debates about trading.

One of the biggest issues in designing a market-based pollution policy is how to initially distribute the emission allowances. The choice has tremendous effects on the distribution of costs of a trading program. Just as importantly, how allowances are distributed can have dramatic effects on the efficiency and overall cost of a trading program, a point that is not widely appreciated.

Three basic approaches to distributing emission allowances have been proposed. Under grandfathering, the most popular approach, allowances are distributed for free to incumbent pollution-emitting firms based on generation at each plant during a base year period. Grandfathering is the main approach that has been used in cap and trade programs, including the Title IV acid rain program, to date. An alternative method of free distribution gives allowances to firms including recent entrants based on generation in a recent year or recent set of years and

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allocations are updated over time. This approach, known as output-based allocation or OBA, provides firms with an incentive to increase their generation in order to increase their share of the total pool of allowances. An analogous price based approach in the form of a revenue-neutral emissions tax that refunds pollution tax revenues based on production is currently being used to reduce NO_X emissions from electricity generators and other sources in Sweden (Hoglund 2002, Sterner and Hoglund 2000). A third approach is for the government to auction the allowances to firms.

Distributional questions related to initial allowance distribution tend to be at the crux of political debates about this issue. Environmental regulations can impose large costs on regulated firms and getting allowances for free provides some compensation for bearing those costs. The fairness of a cap and trade approach from the viewpoint of electricity generators or consumers, and specifically the fairness of free distribution of emission allowances, would seem to many observers to hinge on the comparison of the value of emission allowances and the costs of emission reductions.

In general, economists overwhelmingly prefer an allowance auction to approaches that distribute allowance for free because of its generally positive implications for economic efficiency. These efficiency benefits come primarily in two forms.

First, whether electricity price is set by regulators or by the market, the value of allowances would be reflected in electricity price under an allowance auction, at least to a large degree. Using an auction prevents a potentially tremendous distortion in electricity price between regions of the country depending on the nature of regulation. Also, when electricity price reflects the full opportunity cost of emission allowances, it leads to more efficient decisions. For example, an auction provides a signal to consumers about the opportunity cost of using electricity, giving them the incentive to make investments in efficient refrigerators, etc., in a way that takes full social costs into account.

The second reason why auctions tend to be more efficient is more technical. Emission cap and trade programs raise costs in an industry just as does a new tax; in fact, these regulatory costs can be thought of as a virtual tax. Taxes have the unfortunate property of promoting inefficiency in the economy because, as a result of a tax, the willingness to pay for a good or service will necessarily differ from its opportunity cost. The size of this difference is the magnitude of the tax. A new virtual tax in the form of an environmental regulation magnifies this inefficiency, and the inefficiency grows at an accelerating rate with the magnitude of taxes in the aggregate, including the virtual tax. The virtue of an auction, in this context, is that it raises revenues that at least in principal can be used to reduce preexisting taxes.

While an auction is generally preferred on efficiency grounds, other approaches that distribute allowances for free tend to be more popular politically. One reason is that the auction will raise electricity prices at least as much as any other approach to distributing allowances. Also, when allowances are distributed for free under grandfathering or output based allocation, they endow a constituency with a valuable asset, and this constituency will speak up in favor of the given approach. The potential efficiency benefits of an auction are much more diffuse and may not benefit a specific constituency.

Within the context of the electricity sector, the relative attractiveness of different approaches to distributing allowances will vary depending on whether electricity is subject to price regulation or not. It will also vary across pollutants. In some contexts, allowance distribution could be used as a tool by states to achieve economic, fiscal or political goals. Furthermore, all these factors exert a different influence depending on the pollutant that is regulated. This is because the technologies that are affected vary by pollutant, and the technologies vary by their mix of capital and fuel costs and their place in the schedule of marginal costs for electricity generation.

This paper summarizes the research on the interaction of allocation approaches with pre-existing taxes in the context of different approaches to regulating emissions of NO_X and SO_2 from electricity generators. We avoid discussion of CO_2 in this context because the tax interaction effects of regulating CO_2 has spawned a vast literature that has been reviewed elsewhere. Then we focus on the efficiency and distributional effects of allowance distribution within the electricity sector and how these effects vary across pollutants, including CO_2, and according to how electricity prices are set.

2. The Evolution of Cap and Trade Programs for Air Pollution

The 1990 Clean Air Amendments initiated the first grand experiment in emissions trading in the regulation of SO_2 from power plants. The SO_2 program established a cap on the distribution of emission allowances each year representing about a 50% reduction in aggregate emissions. Individual firms have flexibility to decide how to comply. Firms can buy or sell allowances, or bank them for use in a future year.

Under the SO_2 program in 1990, there was a keen awareness that the allowances were valuable, but there was relatively little squabbling over their distribution. The vast majority of allowances were grandfathered to incumbent firms based on generation at each plant during a base year period.

A key difference between 1990 and today is the change in the regulation of the electricity industry. In 1990 the entire industry was subject to regulation, with prices determined by regulators and set roughly equal to average cost of providing service. Today about 17 states have committed to competitive pricing of electricity. The way that prices are set makes a huge difference in the performance of the program, and the issues are complicated. Literally billions of dollars are at stake each year in potential transfers of wealth among industry, consumers and the government.

The federal creation of emission allowances for SO_2 represented a new intangible property right with an asset value – that is, the value of allowances being given away for free – equal to roughly $2 billion per year. Under cost of service regulation, however, because firms paid nothing to acquire the allowances initially, the allowances were included in the firms' calculations of total and average cost at zero original cost. Hence, under cost of service regulation firms were prevented from charging customers for something they received for free. Firms were expected to pass along to customers through regulated prices only the cost of reducing emissions and the net cost of allowance sales or acquisitions that supplemented their free endowment.

However, under competitive pricing the relationship between price and costs is quite different. The guiding principle under competitive pricing is that electricity price is set equal to the marginal cost of providing electricity. Since the marginal cost varies significantly over the time of day and season of the year, in general marginal cost is quite different from average cost.

In competitive electricity markets allowances would be valued at their market price, or opportunity cost, without regard to how they were acquired initially. For each kilowatthour of generation, the opportunity cost of electricity would include costs such as fuel and labor costs, and in addition it would include the cost of emission allowances used to generate electricity. Firms that wake up to discover they have been endowed with emission allowances for free are not going to give them away for free. Instead, under competitive electricity pricing, firms will charge customers for using allowances at the value they would receive were the allowances instead sold in the allowance market.

However, firms may not come out ahead under competitive pricing depending on the cost of reducing emissions. Under regulated pricing, firms could expect to see their compliance cost reflected automatically in electricity price. But under competitive pricing this might not be the case. The firm might come out a loser, if its increment in revenues is less than its increment in costs. But the scenario could be reversed. Imagine a firm that operates a nuclear facility with no emissions. This facility has no costs associated with emission reductions or emission allowances, but under competitive pricing it will benefit from the increase in electricity prices due to costs borne at other facilities.

Whether or not emission allowance allocations are sufficient, or more than sufficient, to compensate firms for the cost of emission reductions is an empirical question. Whether allocations should be sufficient to do so is a political one. However, one result from economic models is clear. It is possible that the value of emission allowances could dramatically overcompensate firms for the cost of reducing emissions if all allowances are given away for free, by grandfathering, as was done under the SO_2 program.[1] Whether this is true depends on the pollutants that are regulated, especially on whether CO_2 is included, and on the portfolio of generation technologies owned by individual firms.

The second grand experiment in emission trading is the summertime NO_X cap and trade program to take effect in 19 eastern states and the District of Columbia. It will take effect for 8 northeastern states in May of 2003, and for the remaining states in June 2004.

The NO_X program is different from the SO_2 program because the distribution of emission allowances was not specified in statute or decided by the Environmental Protection Agency (EPA). Rather, the EPA established allocations to each state and those states in turn are responsible for determining the method of allocation to affected sources. Nonetheless, almost all emission allowances will be distributed for free to incumbent producers, as was done for the SO_2 program.

In times of severe budget challenges facing state governments, the value of the NO_X emission allowances has attracted the attention of some state officials, and for good reason. The annual value of the NO_X emission allowances depends on the market price of the allowances. If emission allowances trade at \$2,500 per ton, the value of all the allowances will approximate \$1 billion. Currently, NO_X emission allowances for use in 2005 are trading at well over twice that price, suggesting an aggregate asset value of \$2 billion per year. In Kentucky, for example, the value of NO_X allowances at a price of about \$5,000 per ton is over \$180 million per year. In Indiana the value is around \$240 million per year.

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[1] In the case of the SO_2 program, Carlson et al. (2000) estimate that the annual cost of compliance with the SO_2 cap ones the program is fully implemented and the accumulated bank of allowances is drawn down to be approximately \$1 billion per year, roughly half the total annual value of the allowances. As noted, the program was originally designed when electricity generators operated under cost of service based regulation, and regulators were expected to safeguard the recovery of costs. However, with the advent of competition in many states the question of the proper amount of compensation has become much more meaningful.

To return to the theme above, how these allowances are reflected in electricity price will depend on the nature of regulation in each state. In regulated regions, allowances would be reflected in electricity price at their original cost of zero, but firms would recover their cost of reducing emissions directly in electricity price, if regulators behave according to the textbook. However, in competitive regions, firms would be expected to gain from the value of allowances through higher electricity prices even if allowances are obtained for free, although they could not automatically recover the cost of emission reductions.

After the SO_2 and regional NO_X programs take effect, the next grand experiment could be the implementation of cap and trade programs being debated currently in Washington. If these programs include just SO_2, NO_X and Hg, as the Bush administration's Clear Skies Initiative would do, then the value of emission allowances may be somewhat proximate to costs. Even in this instance, however, the value could be greater than costs, especially for some firms, which is part of the reason the Clear Skies Initiative does not give all of the allowances away for free. Instead, the Initiative would institute a revenue raising auction for a small share of the allowance pie. That share starts out at 1% but ends up at 100% after about fifty years. In net present value terms, this represents about 15% of the aggregate value of allowances.

However, if CO_2 is included in the legislation, as it is in separate proposals by Senator Jeffords and by Senator Carper, the financial landscape would look entirely different. In this case it is certain that the value of emission allowances would dramatically outweigh the cost of reducing emission reductions. The primary reason is that only a small percentage of emissions will be reduced. The value of emission allowances is the allowance price multiplied by the quantity of remaining emissions. It may take a little geometry to make this point convincingly, but for a five percent reduction in emissions, the value of emission allowances could be expected to be 20 times greater than the cost of emission reductions, and probably more. Further, for CO_2, the asset value of allowances may easily exceed $30 billion per year, even under modest emission cap targets.

This poses an conundrum. What should be done with emission allowance revenues? The preference of industry is pretty clear. Grandfathering to incumbent firms has billions of dollars worth of appeal.[2] On the other hand, senators and governors may sense the appeal of this potential source of revenue to fund programs such as education, especially when it appears that grandfathering is unjustified based on costs. The Jeffords bill suggests yet another approach. The

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[2] For an analysis of the effects of different allocation approaches on the asset values of firms see Burtraw et al. (2002).

bill would auction allowances, and return most of the revenue directly to households as a rebate and the federal government would not see any of it.

In public policy schools and law schools, and indeed in most economics departments, the decision about how to distribute emission allowances within a pollution trading program has been viewed as largely a distributional one. But the biggest surprise may be that this decision has tremendous efficiency implications as well. The likely outcome on this issue is not clear. It probably is clear that in the future at least some portion of emission allowances will be auctioned in one form or another, especially if society decides to use a cap and trade approach to regulate CO_2. The importance of this issue can hardly be exaggerated. Resolving this will require that policymakers address both fairness and efficiency. This body of research provides several insights that can help address the issue from both of these perspectives.

3. The Economy-wide Perspective on Efficiency

The relative efficiency of different approaches to distributing emission allowances always stems from the influence the policy has on the relationship between price and marginal cost throughout the economy. The general equilibrium literature has focused on prices in factor markets, especially the labor market, but also the capital market.[3]

The general equilibrium literature has focused on the fact that new regulations raise the costs of goods and services, and thereby lower the real wage of workers – that is, the bundle of goods and services that workers can purchase for an hour of labor. In so doing, new regulations appear similar to taxes on labor income. Both have the effect of inserting a wedge between the price of labor (the opportunity cost of a worker's time) and the value of labor to the firm (value of marginal product of labor). Hence, it is conjectured that new regulations that raise product prices potentially imposes a hidden cost on the economy by further lowering the real wage of workers. This can be viewed as a "virtual tax" magnifying the significance of previous taxes, with losses in productivity as a consequence.[4] This effect is commonly referred to in the literature as the tax interaction effect.

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[3] Bovenberg and de Mooij, 1994; Parry, 1995; Bovenberg and Goulder, 1996. Parry, Williams, and Goulder (1998) estimate that due to pre-existing distortionary labor taxes, efforts to reduce carbon emissions through free distribution of tradable carbon permits will be efficiency-reducing unless the marginal benefits from carbon abatement exceed $18 per ton. However, the authors find an emission tax (or revenue-raising auction) can be efficiency-enhancing at any level of marginal benefits from carbon abatement if revenues are used to decrease preexisting distortionary labor taxes.

[4] A complementary issue is the effect on the measure of benefits. Williams (2002) demonstrates that the improvement in labor productivity from reducing pollution can have sizable positive effects when measured in an general equilibrium framework.

Economic instruments are likely to impose a greater cost through the tax interaction effect than prescriptive approaches because they have a greater effect on product prices, and this tends to offset some of the reduction in compliance costs. The reason economic instruments have a greater effect on product prices is that when economic instruments are used, firms must not only comply with environmental standards but also internalize the opportunity cost of the remaining emissions. In a cap and trade program, this occurs through the cost of emission allowances.

The virtue of an auction is that it raises revenues that can, in principle, be used to reduce pre-existing taxes. Two papers have examined this question in the context of conventional pollutants. One addresses SO_2 and the other NO_X.

3.1 SO_2 General Equilibrium Costs

Goulder et al. (1997) investigated the magnitude of the tax-interaction effect in the context of the SO_2 program using both analytical and numerical general equilibrium models. They find that this effect will cost the economy about $1.06 billion per year ($1995) in Phase II of the program, adding an additional 70% to their estimated compliance costs for the program. That estimate would pertain in the long run if the entire electricity sector sets prices in the market rather than bases them on cost of service. If price is based on cost of service, then the regulatory burden is much lower because allowances under Title IV were distributed at zero original cost. The hidden cost of the tax-interaction effect would be reduced substantially, but not entirely, if the government auctioned the permits and used the revenues from the auction to reduce preexisting distortionary taxes. However, under grandfathering, no revenue is available for this purpose.

If the entire industry is deregulated, the cost of the tax interaction effect could be substantial. Table 1 illustrates the relative potential cost savings from allowance trading and the hidden costs of the use of grandfathered emission allowances, compared with the costs under a command-and-control approach. The values in this table are expressed in percentage terms, normalized around the values in the first cell. This value in the first cell in the first row represents the least-cost estimate of compliance in 2010, or partial equilibrium cost, estimated by Carlson et al. (2000). The second cell in the first row represents the ratio of compliance (partial equilibrium) costs under the command-and-control scenario modeled in that study to costs under the least-cost approach, about 135% of the least-cost outcome.

The remaining rows reflect estimates of cost in a general equilibrium context. The first column summarizes the Goulder et al. (1997) finding that the general equilibrium costs of a market-based policy (emission tax or auctioned permit system) are about 129% of the partial equilibrium measure of costs in the least-cost solution. The bottom row indicates that the cost of a permit system that fails to raise revenues is about 171% of the least-cost partial equilibrium estimate.

The last cell in the bottom row of the table yields an estimate of the relative cost of command-and-control policies in a general equilibrium setting. We find that the type of policies modeled in the context of the SO_2 program, a uniform emissions standard applied to all sources, would result in general equilibrium costs that were 178% of those measured in the least-cost solution in a partial equilibrium framework.[5] In other words, the general equilibrium cost of the tradable permit program with grandfathering (171) is only slightly less than the general equilibrium cost of a command-and-control program (178). The example suggests that the failure to raise revenue and to use that revenue to offset distorting taxes may squander much of the savings in compliance costs that can be achieved by a flexible tradable permit system. As the electricity industry has moved away from cost-of-service (regulated) prices to market-based (deregulated) prices for electricity in many regions, this failure has greater relevance in the context of the SO_2 program because the opportunity cost of using grandfathered permits has a greater effect on electricity prices in deregulated regions.

3.2 NO_X General Equilibrium Costs

A similar analysis has been applied to regulation of NO_X. Goulder et al. (1999) find that the presence of distortionary taxes raises the costs of pollution abatement under all types of approaches to distributing emission allowances. This extra cost is an increasing function of the magnitude of pre-existing tax rates. For plausible values of pre-existing tax rates and other parameters, the cost increase for all policies is substantial (35 percent or more).

The impact of pre-existing taxes is particularly large for non-auctioned emissions quotas (tradable permits). Here the cost increase potentially multiple-fold. Earlier work on the design of regulatory policy emphasized the potential reduction in compliance cost achievable by converting fixed emissions standards (quotas) into tradable emissions permits. Goulder et al. indicates that the regulator's decision whether to auction or grandfather emissions rights can have equally important cost impacts. Similarly, the choice as to how to recycle revenues from

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[5] The number 1.78 (178%) is the product of 1.29 times 1.35 times 1.02. The number 1.29 is the ratio of general equilibrium to partial equilibrium cost from Goulder et al. (1997) for a policy that raises revenue, such as an emissions tax. The number 1.35 is the ratio of command-and-control to efficient least-cost from Carlson et al. (2000). The number 1.02 is the ratio of general equilibrium costs for a performance standard relative to an emissions tax identified in Goulder et al. (1997).

environmentally motivated taxes can be as important to cost as the decision whether the tax takes the form of an emissions tax or fuel tax. This choice involves whether to return the revenues in lump-sum fashion or via cuts in marginal tax rates. The use of funds to reduce marginal tax rates is much more efficient, and this is particularly important when only modest emissions reductions are involved.

The difference in costs when different approaches are used to distribute allowances depends importantly on the extent of pollution abatement under consideration. Total abatement costs differ markedly at low levels of abatement, and then less so as the level of emissions is reduced. Strikingly, Goulder et al. find that for all instruments except the fuel tax these costs converge to the same value as abatement levels approach 100 percent. However, this finding appears to be the result of assumptions about the shape of the cost functions for pollution abatement. Using a detailed simulation model of the electricity sector, Banzhaf et al. (2002) find that the amount of potential tax revenues begins to decline, but then begins to increase dramatically, as the emission cap is lowered.[6] This is illustrated in Figure 2 for a range of emission targets for SO_2 and NO_X in the electricity sector.

4. Efficiency Perspective in the Electricity Market

The previous section addressed the effect on efficiency from the perspective of the entire economy. As noted already, the relative efficiency of different approaches to distributing emission allowances always stems from the influence the policy has on the relationship between price and marginal cost throughout the economy. While the general equilibrium literature has focused on prices in factor markets, in this section we discuss the effect within the product market subject to environmental regulation. The findings are again surprising and significant. The way that emission allowances are distributed can dramatically affect the cost of achieving emission reductions within a cap and trade system.

The method of distributing allowances matters to the social cost of reducing emissions within the electricity sector because the distribution of allowances can have a direct effect on the price of electricity, and more importantly, on the relationship between electricity price and marginal cost. In most time periods, in most regions of the country, electricity price differs from marginal cost leading to important deviations from economic efficiency. In this "second-best" setting, the effect of emissions trading on electricity price can modify or amplify the efficiency

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[6] These simulations are done using the Haiku model. For more information about this model see Paul and Burtraw (2002).

cost stemming from the difference between price and marginal cost. A central component, therefore, is the way in which prices are determined in the electricity industry.

4.1 Institutions Setting Electricity Price

For the purpose of this discussion, let us assume the transmission and distribution parts of retail electricity price are set according to average cost and are not affected by allowance distribution. We focus attention on the cost of generation, which is more than two-thirds of electricity price and the most important part with respect to environmental policy.

How the distribution of allowances affects electricity price and the difference between price and marginal cost will depend on the institution in place for determining electricity price. The marginal cost of electricity generation varies by season and time of day. Typically, however, the price that consumers face is much less variable, meaning that generation price differs systematically from marginal cost. The method of distributing emission allowances can amplify or diminish the difference between willingness to pay (price) and marginal cost, thereby affecting economic efficiency.

In regulated regions, we assume regulators provide an incentive or otherwise require firms to utilize their facilities in a manner that minimizes the total cost of meeting the obligation to serve electricity customers at a regulated price equal to the average cost of service. Equation 1 illustrates the total annual cost of electricity generation for technology *i* as the sum of capital, fixed operation and maintenance (O&M), fuel, variable O&M and emission allowance costs. Total cost includes the opportunity cost for emission allowances associated with using technology *i* regardless of how allowances are distributed initially, as long as there is a liquid market providing the firm an opportunity to sell allowances. In this equation we suppress the change in variable costs over season and time of day and do not address the provision of reserve services, although these considerations are included in the simulation exercise.

$$T_i\left(q_i\right) = K_i + FOM_i + \left(F_i + VOM_i\right)q_i + e_i q_i p_A \qquad (1)$$

where:

T= total cost (\$/yr),
q=megawatt-hours (MWh/yr),
K = capital cost (\$/yr),
FOM = fixed O&M (\$/yr),
F = fuel (\$/MWh),
VOM = variable O&M (\$/MWh),
e=emission rate (tons/MWh), and
p_A=price of allowances (\$).

In regulated regions electricity price depends on the firm's total cost summed over all technologies and price is set equal to the firm's average cost. Costs and consequently electricity price depend on how allowances are distributed initially, as long as the regulator follows standard practice of recognizing the original cost of acquiring allowances, rather than economic cost (market value), when determining costs that are recoverable through electricity prices. If allowances are acquired for zero cost through grandfathering or output-based allocation, then only the difference between the cost of emissions and the value of the free allocation would be a recoverable cost: $\left(\sum_i e_i q_i - D\right) p_A$, where D is the number (tons) of free allowances distributed to the firm.

Equation 2 represents how allowance costs are reflected in price in regulated regions based on how allowances are distributed. Under an auction *D=0*, and electricity price is higher than if allowances are distributed for free.

$$RP = \frac{\sum_i T_i\left(q_i\right) - Dp_A}{Q\left(RP\right)} = \frac{TC}{Q\left(RP\right)} \tag{2}$$

where:

RP = regulated price for the firm (\$/MWh),
$Q\left(RP\right)$ = electricity demand (MWh/yr); $Q' < 0$,
TC = total cost (\$/yr).

We assume electricity demand equals supply, $Q = \sum_i q_i$.

In competitive regions price is set not by average cost but by marginal cost. Under perfect competition the generation component of electricity price is determined by the variable cost of the marginal facility in the wholesale power market at each moment in time. The variable cost for each technology *i,* and specifically for the marginal technology *m,* is indicated by equation 3.

Identification of the marginal technology depends on aggregate demand (*Q*). Again time subscripts are suppressed for convenience.

$$CP(Q) = v_m = f_m + vom_m + (e_m - s)\, p_A \tag{3}$$

where:

CP = competitive price (\$/MWh),
v = variable cost (\$/MWh),
f = fuel (\$/MWh),
vom = variable O&M (\$/MWh), and
s = output based allocation rate (tons/MWh).

The output-based allocation rate (*s*) is the rate at which allowances are distributed based on generation. Incremental generation earns a share of the emissions cap equal to 1/*Q*; and *s* equals the aggregate emission cap $(\overline{E})$ measured in tons, divided by total generation: $s = \overline{E}/Q$. Under grandfathering or an auction, the output-based allocation rate is zero $(s = 0)$. Therefore, the variable cost for each technology and consequently the price under output-based allocation is less than under grandfathering or an auction because of the output subsidy associated with the distribution of allowances.

Note also that if all technologies are eligible to receive allowances on the basis of their output, the output-based allocation is uniform for each unit of generation and it reduces the variable cost of every kWh produced by all facilities that qualify for allowances in an equal manner. Hence, the output-based allocation does not alter the relative ordering by variable cost of generation units. Also, the lower price is expected to lead to greater electricity demand. However, we will see that when different groups of generators are eligible for output based allocations, and when multiple pollutants are regulated simultaneously, then the relative ordering by variable cost of generating units can be affected.

In summary, in regulated regions the electricity price under an auction is expected to be greater than the price with grandfathering or output-based allocations, and the price with grandfathering and output-based allocation would be equal. Under perfect competition, the electricity price under output-based allocation is expected to be less than the price under an auction and grandfathering, which would be approximately equal.[7] This is summarized in by:

$$RP[au] > RP[gf] \cong RP[oba] \quad \text{and} \quad CP[au] \cong CP[gf] > CP[oba], \tag{4}$$

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[7] The relative effects of grandfathering versus an output-based approach are confirmed in Beamon et al.'s (2001) simulation analysis comparing these two approaches to allocating carbon emissions within the electricity sector.

where *au* designates an auction, *gf* designates grandfathering, and *oba* designates output-based allocation.

In practice and in our simulation exercise the equations above do not hold precisely, especially in competitive regions because most customers do not see an electricity price that is equal to variable costs on a real-time basis. Rather, they see the average of variable costs over some period of time, which means the electricity price differs from variable cost but typically not by as much as in regulated regions. Also, features of regulation such as stranded cost recovery may affect price differently under different approaches to allowance distribution. In regulated regions firms may have the opportunity to export power from unused facilities to outside the region and regulators may capture some of those profits to reduce price within the region. Also, if only certain technologies are eligible for allowances under the output-based allocation, then it will affect the cost ordering of technologies which will, in turn, lead to differences between the price under grandfathering and output-based allocation. However, the inequalities in expression (4) are expected to hold throughout.

4.2 The Magnitude of Inefficiencies in Electricity Price

The loss in economic surplus from inefficient pricing of electricity, at the margin, is measured by the difference between willingness to pay (electricity price) and marginal cost. We ignore marginal social cost, inclusive of social costs of environmental damage, and focus just on marginal private cost roughly equivalent to the cost components reported in equations 1-4.

Electricity price is expected to increase under any policy to reduce emissions due to the increase in resource costs that include changes in fuel use and capital investment required for compliance. However, as noted the magnitude of the effect differs across different methods of distributing allowances. If one policy does more to close the gap between price and marginal cost, it will do more to reduce deadweight loss and offset some of the increase in resource cost.[8]

In our simulation model in the absence of a cap and trade policy we find that price is less than marginal cost for 36% of the MWh of electricity sold for the nation, and price is greater than marginal cost for 54% of electricity sales. Even in regions with competitive pricing, we assume prices to residential and commercial customers do not reflect real-time marginal costs but rather the average of marginal costs over the season. Only 9% of electricity sales is priced

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[8] See Oates and Strassman (1984) for a discussion of the role that market structure plays in determining the cost of environmental policy.

efficiently, and this occurs in regions that price electricity competitively and provide real-time pricing for industrial customers.

Even though the share of generation with price less than marginal cost is 36%, in the example illustrated in Figure 1, this negative difference has the greatest effect on economic welfare. This is because marginal cost is bounded by zero from below, so when price is greater than marginal cost the potential difference is bounded also. The upper limit on marginal cost is unbounded, so the potential difference when marginal cost is greater than price is also unbounded. Figure 1 illustrates that virtually all of the time when price is greater than marginal cost, the difference is less than \$25/MWh. However, when marginal cost is greater than price the difference can be as great as \$1,000/MWh.

The magnitude of the difference when price is less than marginal cost matters because the loss in welfare from inefficient pricing grows at a geometric rate with the size of the difference. This can be illustrated by considering linear aggregate inverse demand $P(Q)=w-\alpha Q$ and aggregate marginal cost $C(Q)=x+\beta Q$, where w, α, x, and $\beta>0$. Surplus is maximized where demand and marginal cost are equal at $Q*=(w-x)/(\alpha+\beta)$, that is, where price equals marginal cost. At any other quantity the deadweight loss (L) is measured by:

$$L=(w-x)(Q-Q*)-\frac{(\alpha+\beta)}{2}\left(Q^2-Q*^2\right)=\frac{-(w-x)^2}{2(\alpha+\beta)}+(w-x)Q-\frac{(\alpha+\beta)}{2}Q^2 \qquad (5)$$

The loss in welfare grows at an increasing rate as the difference between Q and $Q*$ grows. Moreover, in reality the marginal cost curve is not linear. It may be very convex in some ranges when expensive units for peak generation are brought into service, typically in ranges where marginal cost is greater than price. Thus magnitude of the welfare loss is most sensitive in ranges where marginal cost is greater than price.

Hence, the methods of distributing allowances that increase electricity price the most can therefore have the least cost in terms of loss of producer and consumer surplus from the carbon policy because these methods are most effective at closing the gap between price and marginal cost. The inequalities in expression (4) indicate that in regulated regions the auction raises electricity price the most. In competitive regions the auction and grandfathering raise prices similarly and more than the output-based approach. On the other hand, output-based allocation leads to a lower price in competitive regions because it lowers the variable costs of all generating units including the marginal generating unit and therefore it lowers electricity price. Lower electricity price also leads to greater electricity demand, thereby exacerbating the difference between price and marginal cost, and increasing the economic cost of the emissions trading policy.

4.3 Magnitude of Efficiency Effect of Allocation

The potential magnitude of the effect of different approaches to distributing emission allowances on economic efficiency in the electricity market is most dramatically illustrated by considering a cap and trade policy for CO_2 (Burtraw et al. 2002). The main finding is that allocation through the auction (labeled AU on the graph) approach is roughly one-half the cost to society of allocation through grandfathering (labeled GF on the graph) or output-based allocation (labeled OBA on the graph) when viewed over a range of emission targets. This finding is illustrated in Figure 3 in a snapshot for the year 2012. The horizontal axis indicates reductions from the baseline emissions absent any carbon policy in 2012, which are estimated to be 626 million metric tons of carbon (mtC). The vertical dotted line anchors a point equivalent to 1990 emissions in the electricity sector, which were about 150 million mtC less than in the baseline for 2012. The vertical axis reports the average social cost in 1997 dollars per mtC of emission reduction.

Average social cost is calculated as the ratio of economic cost divided by tons of emission reduction. Economic cost is measured as the sum of the changes in consumer and producer surplus in the electricity sector. We measure consumer surplus using the Marshalian demand curve and producer surplus is equivalent to producer profits. A critical issue, as we will see below, is how revenues collected under the auction are used. In the results illustrated in Figure 3, we assume revenues are redistributed to households.

For moderate emission reduction targets, the cost under the auction approach is closer to one-third the cost of grandfathering and output-based allocation, and it is somewhat greater than one-half for ambitious reduction targets. However, the comparison of social cost and cost-effectiveness of different distribution mechanisms is of growing importance under the more ambitious targets because the overall level of costs incurred and the absolute value of the cost savings under an auction grow substantially.

Figure 4 provides a partial explanation for why social cost differs among the distribution methods by illustrating the price of an emission allowance commensurate with achieving various emission reduction targets in 2012. Over the range of emission targets we examine, an auction generates the most emission reductions for a given allowance price. Although grandfathering and output-based allocation achieve comparable reductions at lower permit prices (i.e., less than $60 per mtC), grandfathering results in more reductions at higher permit prices.

4.4 Distribution of allowances can create substantial price differences between regulated and unregulated regions

The difference in methods of distribution of allowances can have a sizable effect on the difference in electricity price among regions based on the way prices are determined in each region. The relationships in expression (4) indicate that electricity prices are always expected to be highest under an auction. They are expected to be similar under different regulatory regimes but they may not be the same because under competition the technology that is at the margin will determine the degree to which costs can be passed through to consumers. For example, if the marginal technology does not have emissions, then there will be no pass through, in that time period.

The potential differences in electricity price and the interaction of regulation and the method of allocating allowances is especially evident in comparing policies for CO_2 emission reductions. This is illustrated in Figure 5, which shows the change electricity price in a scenario that includes roughly 10% emission reductions from baseline for 2012. The figure requires some caveats. A competitive baseline will have greater CO_2 emission within the simulation model, so it will require greater emission reductions to achieve a comparable emissions cap. This picture does not compare equal emissions reductions or equal emissions. Rather, the change in electricity price is normalized for the two data series indicating regulation and competition for the case of an auction. The interesting aspect is the relative change in electricity price under alternative approaches to regulation. Under competition, grandfathering affects electricity price in almost the same way as the auction, but under regulation the result is very different.

The role of output based allocation varies among regimes because under competition the subsidy to electricity generation that is implicit leads to a decline in electricity price, because that price is equivalent to variable costs inclusive of the subsidy. However, under regulation, the price is set so as to recover the full resource costs of reducing emissions and therefore it is comparable to the grandfathering approach.

The important aspect of this picture is that the choice of how to allocate emission allowances can provide as great of incentives for choosing a regulatory regime as other usual justifications in support of competition or regulation. The way in which emission allowances are allocated could conceivably be the most important factor in determination of the best approach to setting electricity prices, from the perspective of producers and consumers in a given region.

4.5 Nature of pollutant and regulation

The potential magnitude of the efficiency effect is much less for the conventional pollutants SO_2 and NO_X, but as a share of program costs they could be important. To explore this we model a policy for reduction of NO_X and SO_2. We focus on the SIP Call region. To do so we construct two pollution control regions. The SIP Call region involves a cap and trade program for both NO_X and SO_2. The long-run emission reduction target is 1.25 million tons for annual NO_X emissions and 2.1 million tons for annual SO_2 emissions in the SIP Call region. Emission allowances were distributed to NERC regions for NO_X in proportion to their share of allocations under the NO_X SIP Call. For SO_2, they were distributed in proportion to emissions in the baseline, which assumes compliance with Title IV. Outside the SIP Call region we model a separate cap and trade policy comparable to emission rates equal to Title IV. The policy is implemented in the year 2005.

To explore this scenario we redefine competition so that differences from regulation are attributable strictly to greater use of marginal cost pricing. We assume regulation and competition have equivalent rates of technological change and we assume no time of day pricing under competition. We calculate changes in economic cost is measured as the sum of the changes in consumer and producer surplus in the electricity sector. We measure consumer surplus using the Marshalian demand curve and producer surplus is equivalent to producer profits.

Our preliminary results indicate that within the conventional pollutant scenario the ordering of methods of allocations is different, from an efficiency perspective, from that under the CO_2 policy. This is illustrated in Table 2, looking across the methods of allocation under limited restructuring. The results are net present values through 2020. All results are from a current year perspective 1999, with values in 1999$. With the conventional pollutants we find the auction to be more efficient than either grandfathering or output based allocation, as was the case with CO_2. However, the ordering of grandfathering and output based differs somewhat. We find output based to be more efficient than grandfathering, although it is less efficient than an auction. Also, the difference among all the conventional pollutant policies is less, relative to the total regulatory cost, than is the case for CO_2. This is primarily because the amount of potential revenue raised under the conventional pollutant policies is less relative to the resource costs necessary for compliance.

This different result is robust across the method of regulation for the electricity industry. As in the regulation of CO_2, the auction is the least cost method across the types of regulatory regimes in the electricity industry.

As mentioned, one way that the conventional pollutant scenario differs from the analysis of CO_2 is the magnitude of revenues.[9] In relative terms, the revenues collected under an auction of CO_2 allowances always measure greater than the loss in consumer surplus and there exist revenues that can be used in principle to offset all of the consumer surplus losses and some of the producer surplus losses.

However, under the scenario we model for NO_X and SO_2, revenues under the auction are roughly 80% of the loss in consumer surplus under the auction. This results from the fact that the emission reductions targets significantly exceed fifty percent of the baseline target. Consequently we are on the portion of the total revenue curve under the auction where revenues are declining (but not to the point where revenues begin to climb again, indicated on Figure 2).

Another outcome that varies across pollutants is the effect of cap and trade programs on merit order of plants. SO_2 has the biggest effect on baseload and virtually no effect on peak since gas units do not emit SO_2, and as a result SO_2 caps are unlikely to affect electricity price as much under competition (even with an auction). NO_X caps should have a more uniformly distributed effect throughout the dispatch order since both gas units and coal units have NO_X emission rates but total costs of new NOX caps are small so price effects likely to be low. Carbon emission caps will also raise generation costs across entire dispatch order.

The third difference between the CO_2 analysis and the analysis of conventional pollutants is the focus on the SIP Call region, and the particular features about that region of the country. The region generates just under 60% of the nation's electricity. The region emits 64% of the CO_2 for the nation. In contrast, the SIP Call region is responsible for over80% of the nations emissions of SO_2 and even after implementation of the SIP Call NO_X trading program in 2004 it will emit over 50% of the NO_X for the nation's electricity sector. Consequently the focus on this region will yield results that differ from those for the nation.

Even more particular is the relationship between price and marginal cost in the region, and especially in the ECAR subregion. ECAR accounts for 31% of the nation's SO_2 emissions, and about 26% of the nation's generation. Moreover, in the relationship between price and marginal cost, Figure 6 illustrates that, given the special assumptions about competition that are maintained in this analysis, ECAR has three-quarters of its generation sold at price greater than marginal cost.

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[9] An important issue is how revenues collected under the auction are used. We assume that they are available to society on a dollar-per-dollar basis, and contribute to net economic surplus.

One of the most important reasons that an auction proves cost effective in the regulation of CO_2 is that for the nation price is less than marginal cost an important portion of the time periods. The auction internalizes a price signal about the opportunity cost of CO_2 emissions and the cost of the emission reductions is somewhat offset by closing the gap between price and marginal cost. But in ECAR, the internalization of a price signal through an auction amplifies the difference between price and marginal cost by increasing price. Rather than diminishing the cost of the auction as was the case for CO_2, in the analysis of conventional pollutants the price signal amplifies the cost of the auction.

5. Distributional Perspectives

The similarity between regulated and competitive regions under an auction will depend on the degree to which changes in costs can be passed through to consumers in competitive regions. In principle, given that costs of the marginal generator determine prices, producers who own a portfolio of generation facilities may be under-compensated, or over-compensated, for their costs.

In the case of CO_2 regulation there is an opportunity to potentially dramatically over-compensate firms for the costs imposed by the regulation. Figure 7 illustrates the change in the value of generation assets under a CO_2 policy that reduces emissions by 6% from a forecast baseline for the year 2012. The effect on three representative firms are illustrated. For example, Firm B is a firm with a large coal-fired portfolio. The value of its portfolio is diminished under any of the methods to distribute allowances.

In all cases, grandfathering is the most beneficial for the firms that are illustrated. The surprising result illustrated in this figure is that for all three firms the auction is at least as beneficial as output based allocation.

This result is only somewhat different in the analysis of conventional pollutants. As indicated in Table 2, in our preliminary results we find that producers favor grandfathering by a substantial margin over other approaches to distribution. Second, producers favor output based allocation and third they prefer an auction, but the difference between these options is small. As in the case of the CO_2 policy, the reason output based allocation yields greater losses in producer surplus is that the output subsidy erodes electricity price and the value of existing generation assets.

6. Conclusion

This paper reviews several pieces of research on the efficiency and distributional aspects to distributing emission allowances in the electricity sector. We briefly discuss results from the general equilibrium literature, and then discuss in greater detail results using a detailed simulation model of the electricity sector.

An important finding is that the performance of methods to distribute allowances varies significantly based on the nature of the pollutant and the amount of reductions to be achieved. In the case of CO_2 policies, there is substantial evidence that an auction approach is the most efficient. Furthermore, in the case of CO_2 an auction generates sufficient revenue to offset entirely the loss in consumer surplus and to offset partially the reduction in producer surplus due to the policy.

In the case of the scenario constructed for analysis of conventional pollutants SO_2 and NO_X, the auction again performs best in terms of overall efficiency. However, the difference between the auction and the other policies is less dramatic than is the case for CO_2 policy. There appear to be several contributing reasons for this. Perhaps foremost is the fact that the CO_2 policy potentially generates substantially more revenue, especially relative to the resource costs of compliance, than does the conventional pollutant policy. The substantial portion of emission reductions compared to baseline put the policy on the declining portion of the total revenue curve for the auction, meaning that there are not significant revenues collected compared to the case for CO_2.

Secondly, the ECAR region, an important component of the modeling domain, exhibits a different relationship between price and marginal cost than characterizes the rest of the nation. In ECAR one finds price more significantly greater than marginal cost than elsewhere. Hence, the apparent efficiency virtue of the auction in the context of national CO_2 policy – that it internalizes in price the opportunity cost of emission reductions – becomes a liability within the ECAR region.

Another finding is the important role of the structure of electricity regulation on the efficiency and distribution effects of the pollution policy. Regulation in the electricity industry causes the auction and grandfathering to behave very differently for regulation of both CO_2 and the conventional pollutants. Depending on the package of pollutants that are regulated in the electricity industry, the way in which emission allowances are allocated could conceivably be the most important factor in determination of the best approach to regulation of the electricity sector, at least from the perspective of producers and consumers in a given region.

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Table 1. General Equilibrium Cost of SO_2 Allowance Trading as Percentage of Partial Equilibrium Least-Cost Compliance

Percentage values normalized around first cell	*Least-cost compliance (%)*	*Command-and-control performance standard (%)*
Partial equilibrium measure	100	135
General equilibrium measure		
with revenue	129	*n/a*
without revenue	171 (Title IV)	178

Table 2. Net present value of the change in economic surplus in the SIP Call region, from current year perspective of 1999, with analysis through 2020. (billion 1999 $)

	Au	**GF**	**OBA emitters**	**OBA all except hydro and nuclear**
Consumer Surplus	-43.8	-27.4	-10.9	-11.6
Producer Surplus	-22.3	-7.0	-20.4	-21.1
Sum	*-66.1*	*-34.4*	*-31.3*	*-32.7*
Revenue to Government	35.6	0	0	0
Net Direct Surplus	*-30.5*	*-34.4*	*-31.3*	*-32.7*

Figure 1. Cumulative distribution of electricity sales (MWh) according to the difference between price and marginal cost (P-MC)

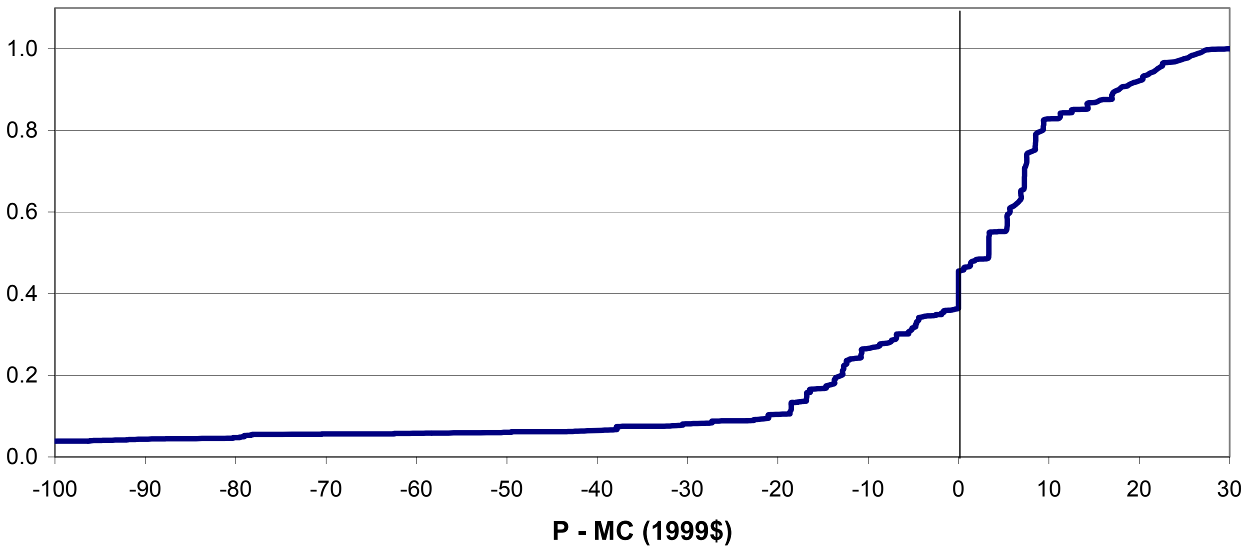
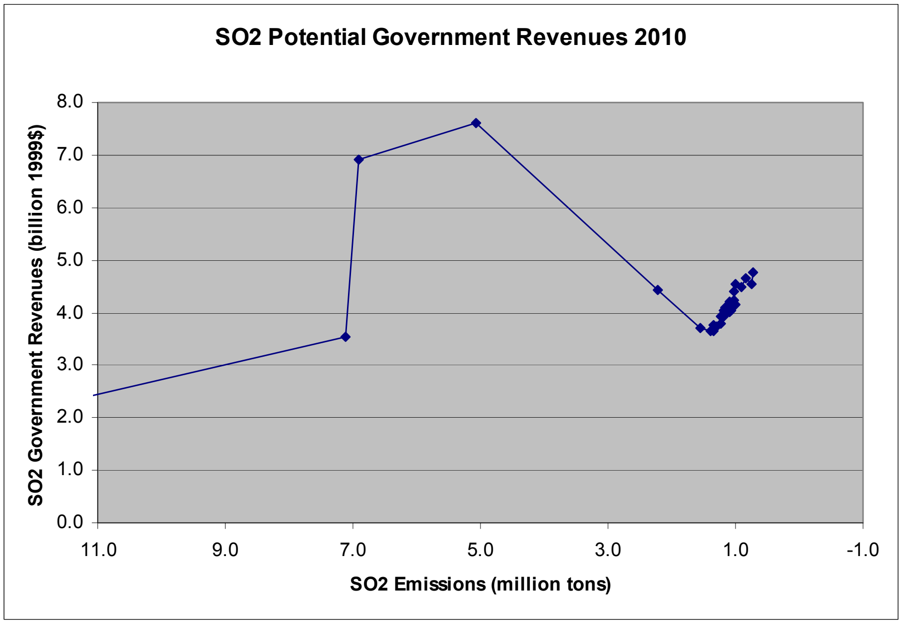


Figure 2. Potential Government Revenues from Auctioning SO2 and NOX Allowances as a Function of the Respective Emissions Caps



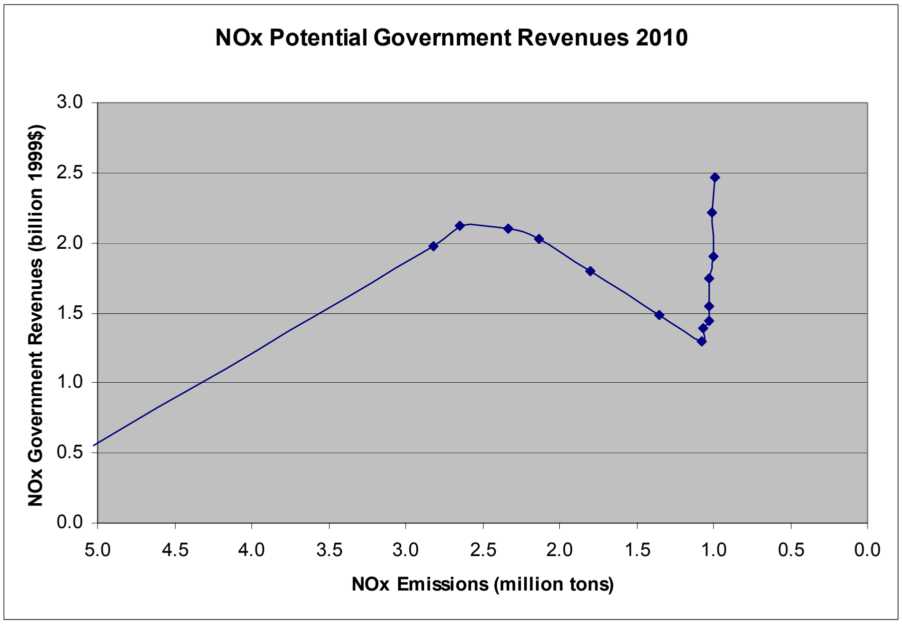


Figure 3. Social cost of allocation approaches over a range of emission targets.

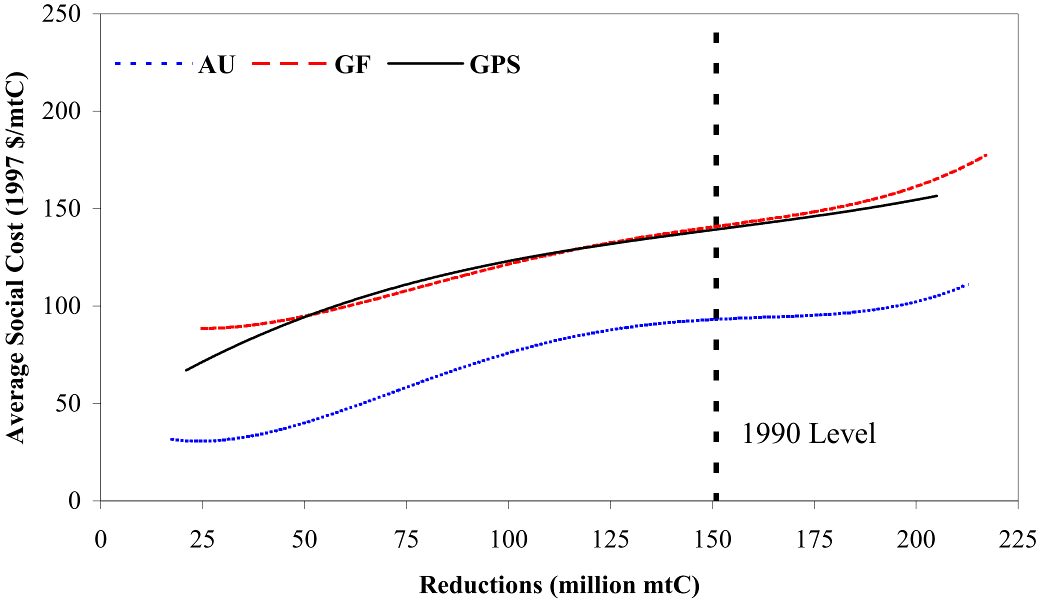


Figure 4. Allowance price for different allocation approaches over a range of emission targets.

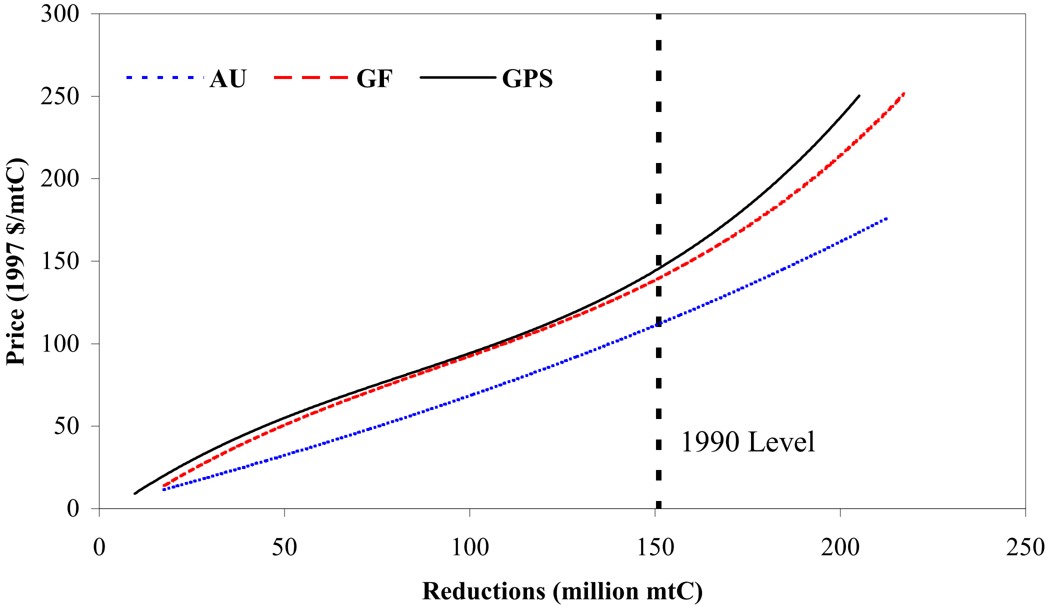


Figure 5: Percent Change in Electricity Price for Carbon Emission Reductions under Different Approaches to Electricity Regulation

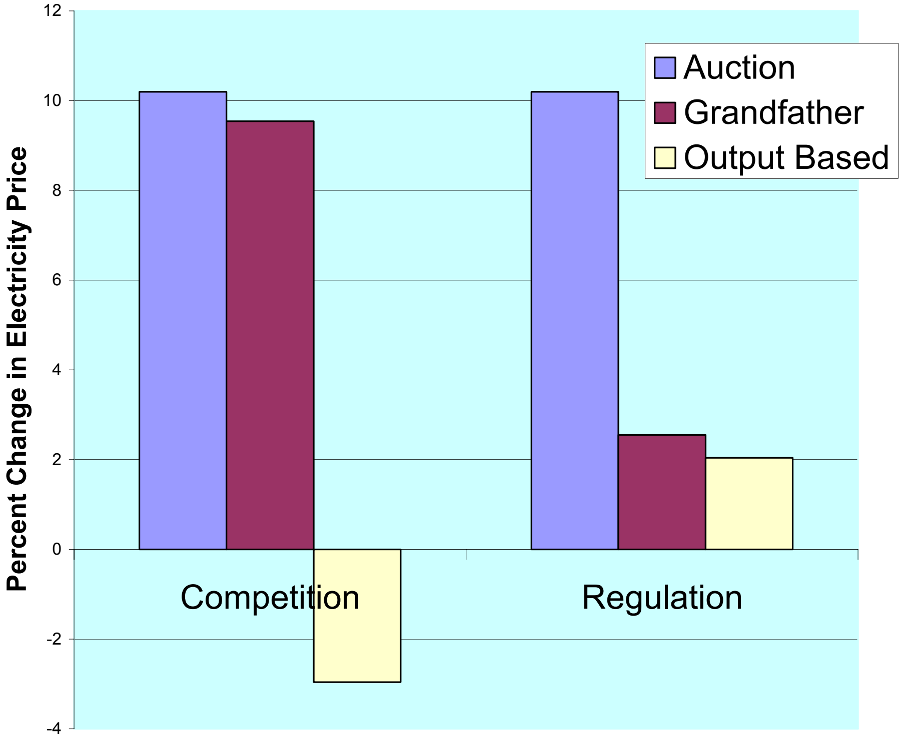
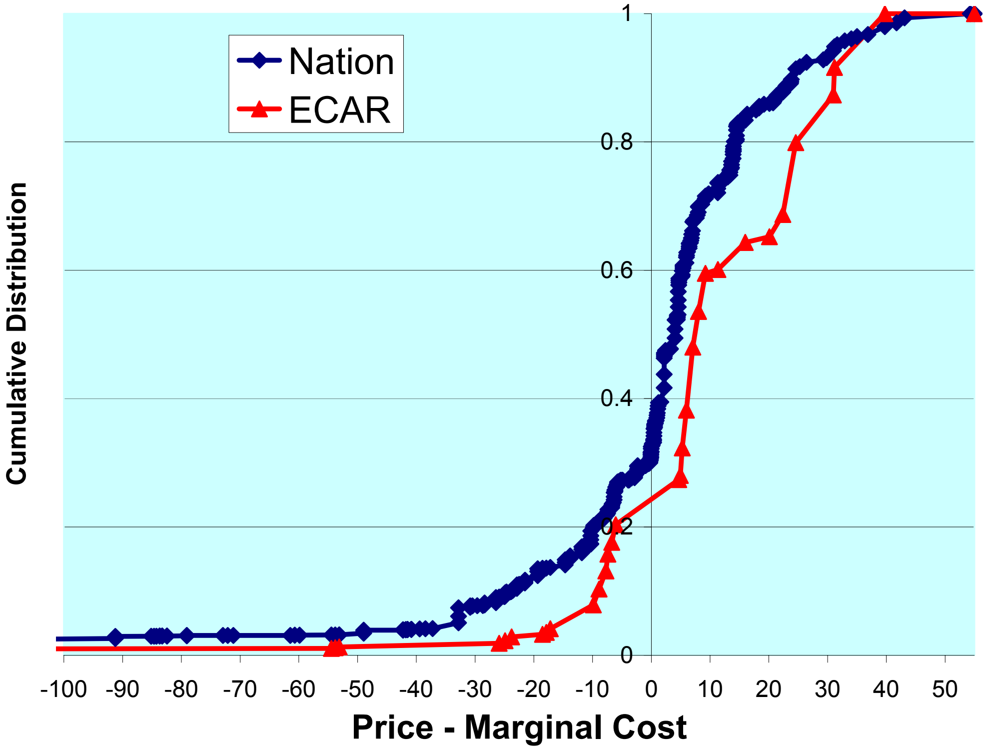
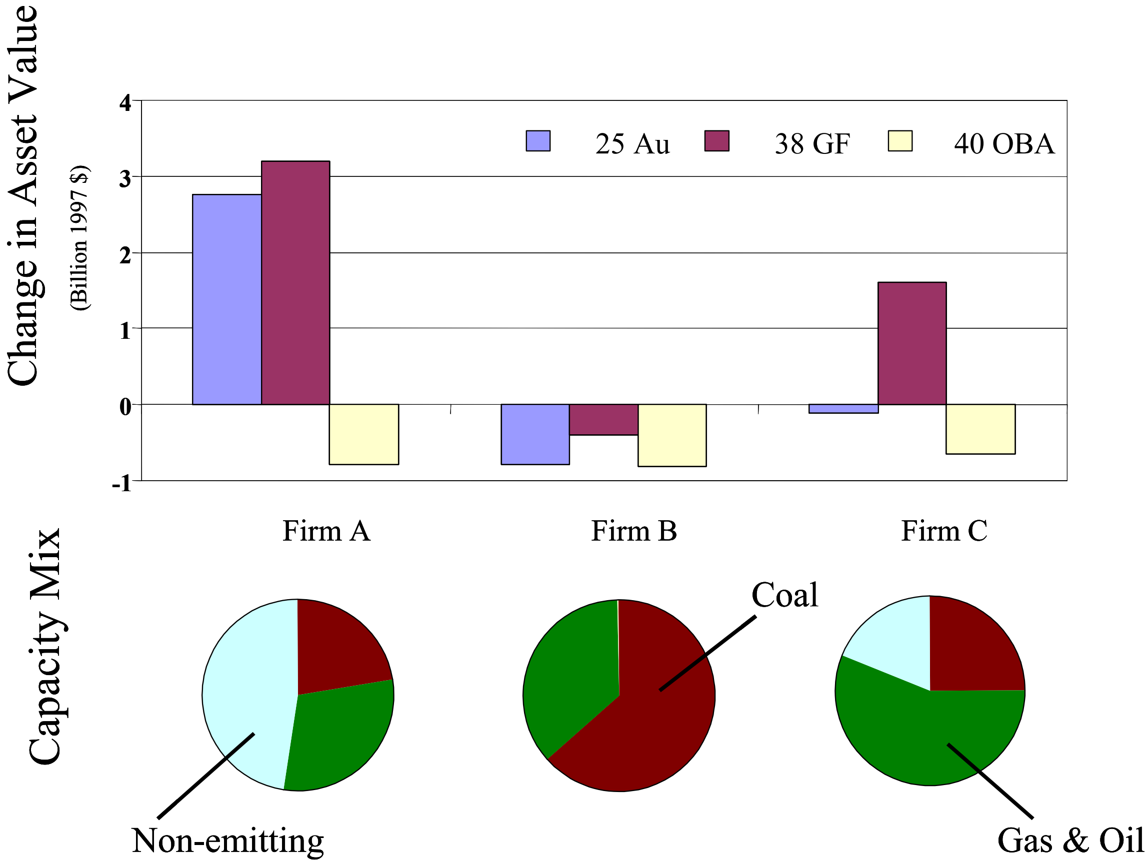


Figure 6: For Conventional Pollutant Scenario, Cumulative Distribution of Electricity Consumption Measured by Difference between Price and Marginal Cost for the Nation



and for ECAR.

Figure 7: The Change in Value of Generation Assets under a Carbon Policy, and the Effect on Three Representative Firms



Efficiency and Distributional Consequences of the Allocation of Emission Allowances in the Electricity Sector

Dallas Burtraw and Karen Palmer
Resources for the Future

"Market Mechanisms in Environmental Policy"
EPA / National Center for Environmental Research
May 2, 2003

Cap and trade approaches have gained wide acceptance because of demonstrated cost-effectiveness.

One of the biggest issues in designing a program is how to initially distribute allowances.

Distribution affects fairness and has unanticipated and large effects on efficiency.

Three Allocation Schemes

- (Au) Auction
- (GF) Grandfathering
- (OBA) Output Based Allocation (updating)

When Does Allocation Matter to Efficiency?

…When prices of goods and services differ from opportunity costs.

The allocation can amplify or diminish these distortions away from economic efficiency.

Why Does Allocation Matter?

1. Interactions with factor markets in the general economy.
   (so-called "Tax-Interaction Effect")
2. Inefficient pricing in the product market that is the subject of environmental regulation.

General Equilibrium Perspective

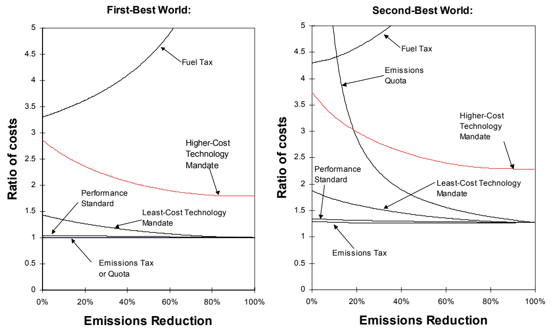
- Models assume perfect competition, constant returns to scale.
- Internally consistent linkages between all factor markets.
- Two articles examined SO_2 and NO_x. Both found substantial costs from grandfathered permits relative to other policy approaches.

SO_2 General Equilibrium Costs

Percentage values normalized around first cell	**Least Cost Compliance (%)**	**Command and Control Performance Standard (%)**
Partial Eqm Measure	100	135
General Eqm Measure		
• with revenue	129	*n/a*
• w/o revenue	171 (Title IV)	178

Table draws on Goulder, Parry and Burtraw, 1998, *Rand Journal* and Carlson, Burtraw, Cropper and Palmer, 1998, *J.Pol.Econ.*

NO_X General Equilibrium Costs:
Ratio of policy to first-best emissions tax



Citation: Goulder, Parry, Williams and Burtraw, 1999, *J. Public Econ.*.

Electricity Sector Perspective

Different from CGE approach, because…

- Heterogeneous technologies represented with non-constant returns to scale, long-lived capital
- Able to capture important institutions
- Price not necessarily equal to MC
- Comparable to NEMS or IPM approach

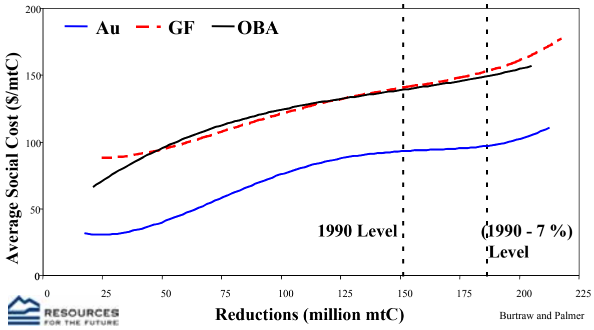
Results for Carbon Appear to Reinforce CGE Findings

- Allocation through an Auction is roughly one-half the cost to society of Grandfathering or OBA.

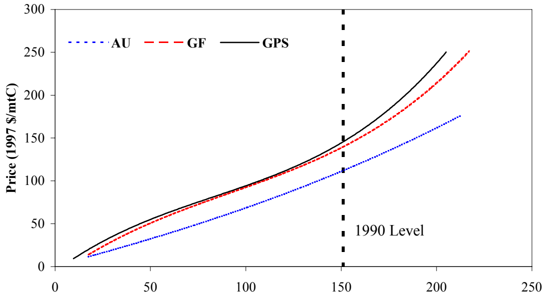
Also…

- Auction preserves **asset values** better than OBA.
- However, Auction raises **prices** to consumers.

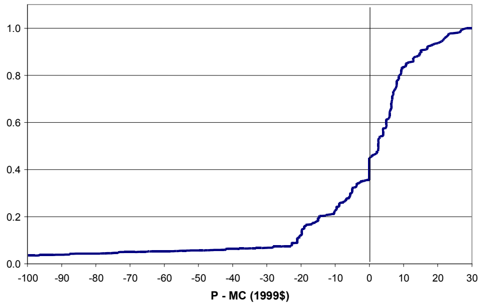
Social Cost Within Electricity Sector Varies Importantly with Choice of Policy



Carbon Permit Price Varies According to Choice of Policy



Inefficiency from $P \neq MC$



Determining Electricity Price

Regulated Price = Average Cost = (Total Cost ÷ Production)

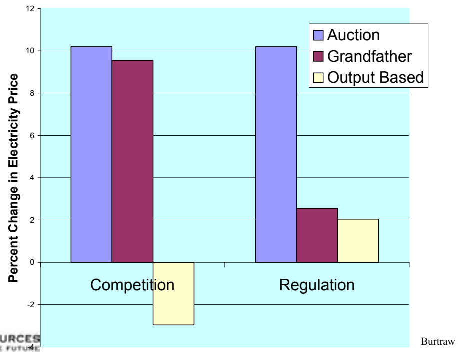
=> Price [Au] > Price [GF, OBA]

Competitive Price = Variable Cost of Marginal Unit

=> Price [Au, GF] > Price [OBA]

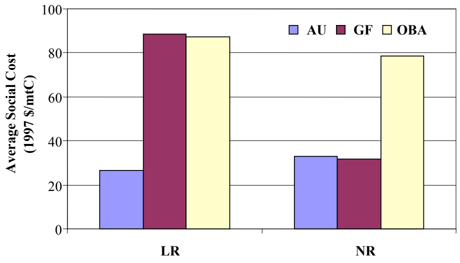
Price Effects Vary by Interaction of Regional Electricity Regulation and Choice of Carbon Policy

(2012, normalized to change under competition)



Social Cost under Limited & Nationwide Restructuring

(1997 $ in 2012; required carbon reductions vary to achieve same target)



Three Reasons Why SO_2/NO_x May Behave Differently

1. Declining revenues from additional emission reductions
2. Regional differences in “price – marginal cost”
3. Different technology

=> How important is each feature?

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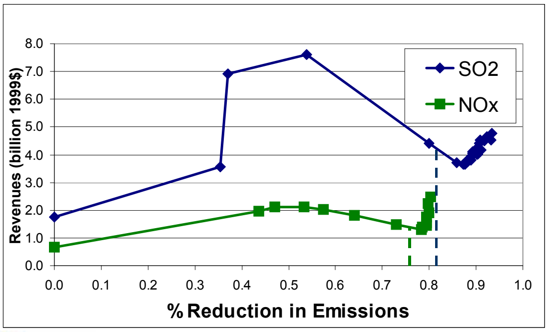
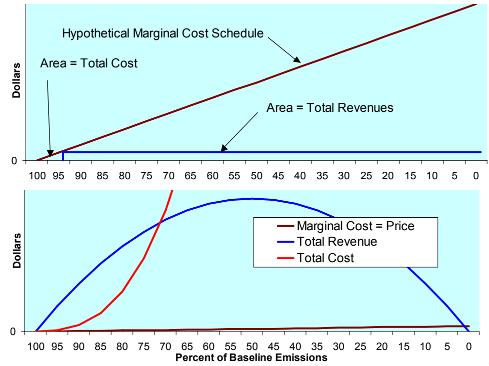
1. Emission Targets Are On the Declining Portion of the Total Revenue Function



Likely Targets for Carbon Are On Increasing Part of Revenue Schedule



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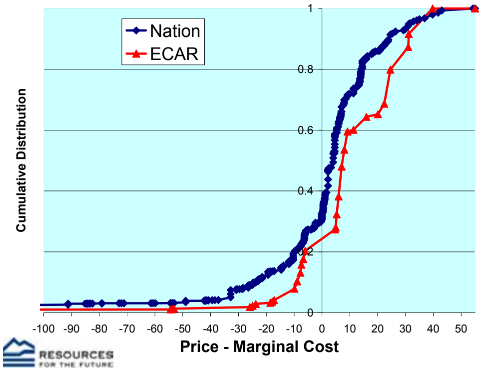
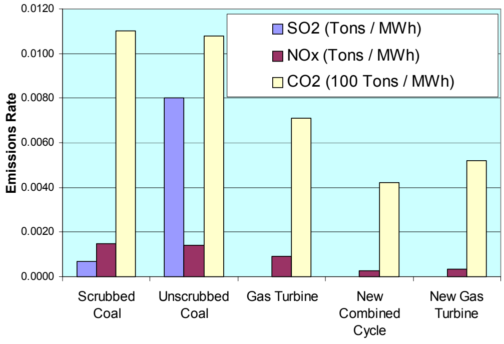
2. Price Differs from Marginal Cost Depending on Regulation, Technology

(artificial characterization of competition)



3. Effect on Price Varies with Technology of Marginal Generator



RESOURCES FOR THE FUTURE

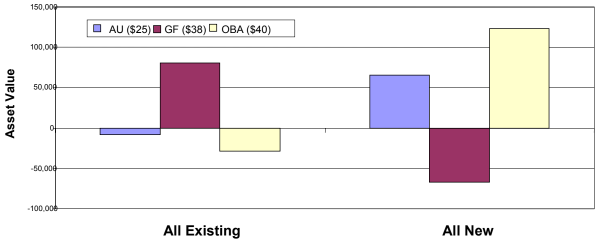
Distributional Perspectives

- To varying degrees, the free allocation of permits can potentially over-compensate firms at the expense of consumers.
- The effect on firms varies with their technology portfolio, and with regulation of prices.

RESOURCES FOR THE FUTURE

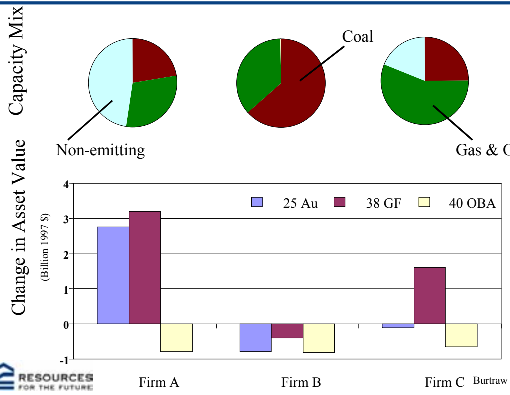
Change in Asset Values and Compensation Under Moderate Carbon Policy

(1997 $/MW in 2001; 35 million mtc carbon)



RESOURCES FOR THE FUTURE

Illustrative Effects on Three Firms of Modest Carbon Cap



RESOURCES FOR THE FUTURE

Conclusion

- Society’s cost of emission cap programs can vary dramatically with method of distributing allowances.
- For carbon, an auction is dramatically more efficient. Output-based allocation undermines asset values and harms many firms.
- Free allocation (grandfathering) of carbon permits also can dramatically over-compensate firms.
- The story may be different for conventional pollutants; output based allocation may be less inefficient.
- The effects on firms and consumers may vary widely based on electricity regulation and technology portfolio.

Temporal Hotspots in Emission Trading Programs:

Evidence From The Ozone Transport Commission's NO_X Budget

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Market Mechanisms and Incentives:
Applications to Environmental Policy

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Washington, DC 20005

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Introduction

The use of Market Mechanisms and Incentives (MM&I) for environmental protection has increased over the last several years, and proposals for new MM&I policies are increasing. Notable (perhaps even principal) among these proposals are cap-and-trade (C/T) systems, which as the name implies, create a permanent limit on total emissions yet provide firms with flexibility in compliance. Several concerns have been raised about the environmental and economic outcomes of C/T systems, in particular about the potential for "hot spots" and about the viability of markets in emission allowances. Environmentalists are concerned that C/T systems may allow for localized pollution problems while industry is concerned that there be a large, stable enough market in allowances so that they can count on being able to buy or sell allowances at reasonable and predictable prices (Dudek and Goffman 1992; Solomon and Rose 1992; Campbell and Holmes 1993; Chinn 1999). The results so far have been mixed on both counts, some emission trading programs have had problems with hot spots and environmental justice issues and others have not (Drury 1999; Swift 2001). Similarly, some emission allowance markets have been successful and others have not (Foster and Hahn 1995; Carlson *et al.* 2000; Israels *et al.* 2002).

This paper examines several key aspects of an early multi-state C/T system designed to control oxides of nitrogen (NO_X) in nine Northeastern States, the Ozone Transport Commission's (OTC) NO_X Budget. Several earlier papers have examined the political economy of the OTC NO_X Budget (Farrell 2001; Farrell and Morgan 2003). Electricity generating plants, including co-generators, dominate regulated facilities in the OTC NO_X Budget (representing more than 90% of seasonal NO_X emissions) and will have a key role in the upcoming NO_X SIP Call, so this paper focuses on the electric power sector (U.S. Environmental Protection Agency 1998).

The OTC NO_X Budget is a cap-and-trade (C/T) system[1] operated jointly by the nine states shown in green in Figure 1: CT, DE, MD, MA, NH, NJ, NY, PA, RI, plus the District of Columbia. Three states in the OTC chose not to participate in the NO_X Budget Program (ME, VA, VT), shown in yellow. Maryland did not participate in 1999 due to a lawsuit. The NO_x Budget applies to electrical generating units 25 megawatts or larger and similar-sized industrial facilities (such as process boilers and refineries), and covers a 5-month control period from May through September. The NO_x budget has uses a C/T system to reduce emissions by 55-65 percent for 1999–2002 and 65-75 percent starting in 2003.

The OTC NO_x Budget has some important and distinctive features. First, there were no early auctions or other methods for price discovery before the year it actually went into effect, and no method to build up a bank of allowances before the start of the program. These have proved important in other markets (Ellerman *et al.* 2000 pp. 161-5, 174-6). Second, the NO_X Budget is operative only during the 'ozone season' of May through June. Third, and most unusually, banked allowances can be discounted through provisions called 'progressive flow control' (PFC). Under these rules, several months after the true-up date for the relevant control period, regulators determine the discount factor for all banked allowances for the upcoming year. Although a relatively straightforward formula is used to determine the discount factor, it is based

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[1] This paper assumes the reader has a general familiarity with MM&I policies. For a more detailed description of emission trading programs, see Farrell, A. E. (2003). Clean Air Markets. In Encyclopedia of Energy. C. Clevelenad, Ed.: Academic Press. pp. forthcoming..

on aggregate behavior of all firms that hold allowances, so individual firms do not know what (if any) discount will be applied to their allowances until after they have made decisions about banking allowances. This adds an element of uncertainty to the allowance market.

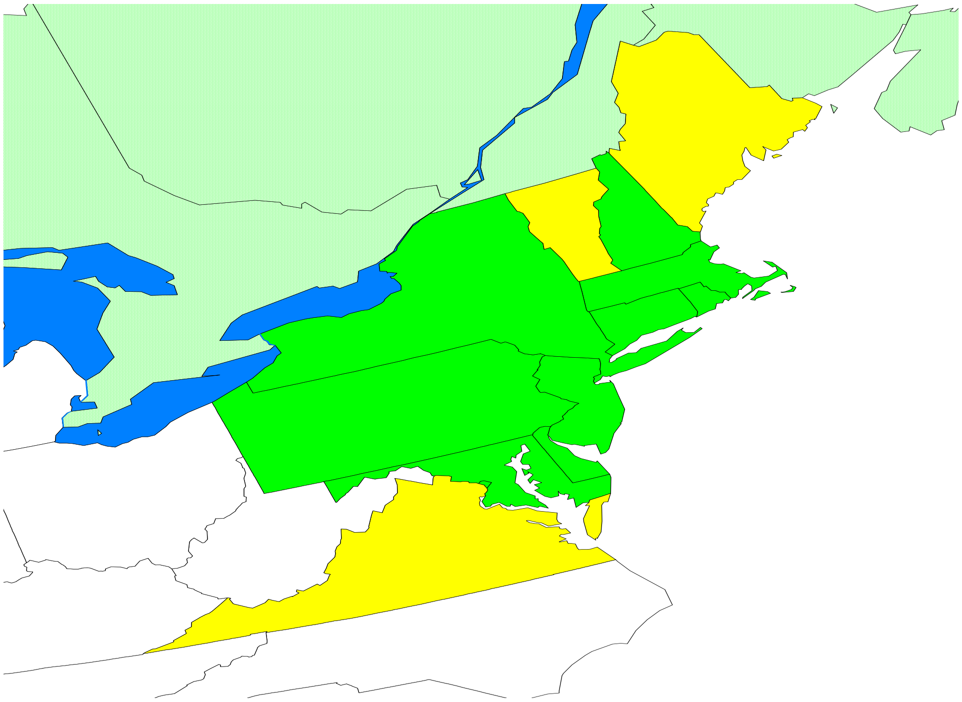

Figure 1: Sates in the Ozone Transport Region.
Green: States in the OTC NO_X Budget Program.
Yellow: States not the NO_X Budget Program

The intent of PFC is to deal with the episodic nature of photochemical smog (commonly measured in terms of ozone concentrations) in the northeastern United States (Possiel and Cox 1993). Smog is a secondary pollutant, formed from precursor compounds, of which NO_X is the most important in the OTC region (Milford *et al.* 1994). Unhealthful smog levels occur in the OTC region on only a limited number of days (usually <20 per year), which occur when meteorological conditions are most favorable for smog formation and accumulation. These are typically hot summer days when anthropogenic NO_X emissions also tend to rise as electric power plants increase generation to meet air conditioning demand. PFC was implemented to limit the use of banked allowances out of concern that if one or two cool summers was followed by a hot summer, firms would build up a significant number of allowances that could allow them to emit more NO_X than the capped level, possibly allowing firms to comply with the requirements of the program without achieving its goals.

However, it is not clear that progressive flow control adequately addresses this problem of a mismatch between the time period of the environmental problem (2-5 day episodes) and the control period (5 months). Even small differences may be important because ozone concentrations are highly non-linear functions of local NO_X concentrations. This is potential problem may be exacerbated by the fact that power plant operation and several NO_X control technologies can be easily adjusted in near real-time and because restructuring has led to higher power prices when demand is greatest (Zhou *et al.* 2001; Blumsack *et al.* 2002).

NO_X control technologies can be divided into three rough categories: combustion controls, selective catalytic reduction (SCR) and non-selective catalytic reduction (SNCR). Combustion controls (e.g. low-NO_X burners, overfire air, etc.) are used to change the shape, temperature profile and air/fuel ratio of the flames in the boiler in order to minimize the amount of fuel and atmospheric nitrogen (NO_2) that is oxidized. The other two technologies are used to chemically reduce NO_X into molecular nitrogen (N_2) and water (H_2O) by spraying a nitrogen-based chemical reagent, usually urea (CH_4N_2O) or ammonia (NH_3) into the flue gas.

In the case of SNCR, reagent is introduced close to the boiler because the greatest NO_X reduction is achieved at temperatures between1, 600-2,200°F. Multiple injection locations may be required to permit adequate control during partial load conditions. Typical SNCR technologies can lower NO_X emissions 30-50% from coal-fired power plants, although more recent advances may give better performance. The capital costs for SNCR units are about 10-20$/kW for retrofits and half that for new construction, the difference being the need to modify boilers and flues in during a retrofit. Operating costs associated with reagent, maintenance and power requirements usually amount to 1-2$/MWh.

SCR controls are very similar, except that they contain beds of catalyst, usually made of a vanadium/titanium formulation (V_2O_5 stabilized in a TiO_2 base) and zeolite materials. The flue gas flows around and through these catalyst beds, speeding up the reduction reactions and allowing for much lower temperatures, 650-720°F. SCR technologies can lower NO_X emissions 70-95% from coal-fired power plants. The capital costs for SCR units are about 50-150$/kW for retrofits and less for new construction, although very unit-specific difficulties in fitting an SCR unit into (or next to, or on top of) an existing power plant can drive those costs up. Operating costs associated with reagent, catalyst cost, maintenance and power requirements usually amount to 4-8$/kWh, largely dependent on the catalyst's life.

Two important potential are problems associated with SCR and SNCR controls. The first is the buildup of ammonium bisulfate on the pre-heater or other downstream components. These buildups can reduce plant efficiency and may require maintenance to remove them. The second problem is that ammonia may contaminate the fly ash, which may make it difficult or unsafe to handle and thus hard to sell to concrete makers or other buyers. Thus, careful, controlled operation of these technologies is required to maximize plant operation and revenue.

Under these conditions, power plant operators may respond to economic incentives in the both the production of electric power and the management of NO_X emissions, possibly turning NO_X controls down when electricity prices are highest in order to increase electricity production (and therefore revenue), or possibly shifting from one plant to another as fuel prices change, thus changing the rate and mass of NO_X emissions during hot summer days. Such actions could lead to higher levels of air pollution than would be expected under a command-and-control approach, and raises the question of whether the periodicity of the NO_X Budget gives firms too much temporal flexibility even with progressive flow control (Farrell *et al.* 1999).

Concern about spatial hotspots is more common than about temporal hotspots. Here the question is: Does emission trading result in a geographic pattern of emissions that is undesirable, even if total mass emissions are limited by a cap? This concern is sometimes associated with the term 'wrong-way trades', suggesting that an emission trade may in effect move pollution from a relatively clean area to a relatively dirtier area. This concern also forms the basis of environmental justice claims of disparate impacts on minority communities.

Concerns about these temporal and spatial effects have been an important part of the policy landscape. For instance, the RECLAIM program had two trading zones as well as a policy that did not allow banking from one year to another, features that addressed each of these issues (Fromm and Hansjurgens 1996). Some local emission reduction credit programs feature sunset provisions for credits. The debate about the Clean Air Act's Acid Rain Program for SO_2 featured a spatial limitation almost to the end and the current Clear Skies Initiative features spatial limitations (Nash and Revesz 2001 pp. 589-593; Bush 2002). Some experts feel this is an inherent problem of C/T systems and several solutions have been proposed, including trading zones, markets in units of environmental degradation or health impacts, offset ratios in emissions markets, and a web-based analysis for quick pre-approval of proposed emission trades (Atkinson and Tietenberg 1987; Raufer 1998; Nash and Revesz 2001). Others who have looked at such restrictions are skeptical (Bernstein *et al.* 1994; Stavins 1997).

Several studies on the potential existence and importance of hot spots have been conducted. Some simulation-based analyses so far of the Acid Rain SO_2 program have shown benefits from trading (Burtraw and Mansur 1999). Simulations of NO_X emission trading systems in the eastern part of the United States and in California showed no significant effect due to directionality (i.e. no significant net 'wrong way' trades and no significant hot spots), but that limiting trading to avoid even the potential problems imposed a cost increase for a C/T system of several percent (Johnson and Pekelney 1996; Dorris *et al.* 1999). Several simulations by Nobel and others of NO_X C/T system in the Houston-Galveston area have shown that spatial and temporal variability can produce only small changes in outcomes, compared to the average benefit, and that these changes may be slight improvements (Nobel *et al.* 2001; Nobel *et al.* 2002). However, these studies have all been simulations of one sort or another. One of the goals of this paper is to examine data based on the actual outcomes of a C/T system to gain insights into the potential for hot spots to be a problem in practice.

The overall effects of the NO_X Budget Program are described in the Environmental Protection Agency's (EPA) annual compliance reports for the OTC NO_X Budget program, which provide aggregate results, including the number of units regulated, ozone season emissions and allowance allocations (by state and total), the number of banked allowances (total), noncompliance issues and the progressive flow control ratios.[2] This analysis goes somewhat deeper by examining data at a much more fine level of temporal detail (hourly).

Data and Methods

Qualitative data used in this study was gathered from interviews with participants in the NO_X Budget Program, including regulators, managers in regulated firms, and brokers. Electric power plant and other plant configuration information were compiled from several sources, including EPA's *E-GRID* database, several EIA reports and publicly available material provided by firms with facilities regulated by the NO_X Budget. Unit-specific, hourly NO_X emissions data for all sources in the OTC NO_X Budget for 1998-2001 were obtained from Resource Data International (RDI). Weekly NO_X allowance prices were obtained from several brokers and industry trade publications, especially *Air Daily*, for 1998-2003. Hourly electricity data (demand, generation,

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[2] http://www.epa.gov/airmarkets/cmprpt/index.html

imports, and prices) were obtained from the Independent System Operators (ISO) for the New England (NE), New York (NY), and Pennsylvania-New Jersey-Maryland (PJM) interconnects. Fuel prices were obtained from RDI and the New York Mercantile Exchange.[3]

Insights from the interviews and literature review were used to guide the several quantitative analyses that followed. There are 907 'sources' in the OTC NO_X Budget Program, which, in 2000 had emissions of 952,049,548 lbs. This study focused on 'large' (>100MW_e) electric power plants and co-generators, which accounted for 773,530,680 emissions in 2000, or 81% of all regulated emissions. This data set contained 476 units combined in 137 plants. A part of this analysis considered only power plants and not co-generators and part considered only plants in PJM, due to data availability. Data from 1998-2000 was used. Table 1 shows some of the details of large power plants in the OTC states and post-combustion NO_X controls.

Table 1: Large (>100MW) power plants (not co-generators) in the OTC States

	Number of Units	**Capacity (MW)**	**Post-Combustion NO_X Controls (2002)**	
			SCR	**SNCR**
CT	26	3767	1	2
DC	2	550	-	-
DE	13	2149	--	1
MA	27	6891	3	1
MD	48	8386	2	1
NH	9	1034	2	-
NJ	67	8157	2	2
NY	153	16519	4	-
PA	64	15962	3	-
RI	6	1127	4	-
Total	415	64542	21	7

The first quantitative analysis compared key values in terms of emissions and emissions rates for various periods. Because power plant emissions are closely associated with generation, comparisons to control for the effect of changes in demand were made. In addition, because emissions during ozone periods are of greatest importance in terms of human health, these periods were identified and compared as well. The second quantitative analysis consisted of a series of Ordinary Least Squares (OLS) regressions designed to more rigorously investigate possible reasons for observed changes in NO_X emissions during the course of the year. Again, greatest focus was given to the periods during which NO_X emissions have the greatest potential impact on human health – ozone episodes.

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[3] Relevant URLs include: http://www.epa.gov/airmarkets/egrid/, http://www.eia.doe.gov/fuelelectric.html, http://www.emissions.org/, http://www.energyargus.com/, http://www.epa.gov/airmarkets/tracking, http://www.iso-ne.com/, http://www.nyiso.com/, and http://www.pjm.com/

Results

The interviews with the participants in the OTC NO_X Budget Program indicated a wide variety of opinion. The early years of this market (1997-2000) occurred in a very different world – this was while the dot.com stock market bubble and electricity industry restructuring were underway, and before the financial scandals associated with Enron and some electric power markets. A key finding of this study was that virtually every firm with a requirement to reduce emissions took a conservative approach to the trading of emissions allowances. They traded relatively infrequently and generally did not rely on the market very much for compliance.

Reluctance to rely on the NO_X Allowance market came from several sources. Perhaps most importantly, market participants perceived very large uncertainties in the market, especially over the ability to purchase allowances. The relatively small number of potential participants in the NO_X market and, over time, the observation that relatively few transactions occurred during most weeks, meant both buyers and sellers were concerned that their own participation in the market could change market prices, generally in an unfavorable direction. The slow pace of the allowance market may have been enhanced by a somewhat hurried start of the program in 1999 and the lack of mechanisms for early price discovery, such as allowance auctions (Farrell 2000). Uncertainties were also introduced by the PFC provisions, and lawsuits (especially in Maryland) in 1998-99.

Another reason for reluctance to rely on the market was that most firms thought of the NO_X Budget program as a regulatory issue for which the most appropriate concept is compliance, rather than a market opportunity for which the most appropriate concept would be profitability. The relatively low cost of the program relative to electricity markets at the time may also have contributed. For instance, using average values for the 2000 ozone season, NO_X emission allowances were priced at 0.40$/MWh, while electricity prices averaged 42$/MWh and peaked at over 1,500$/MW in at least one market. Given these incentives, it is likely that power plant operators would focus on reliability in generating electricity over making slight changes to the emissions control equipment to optimize NO_X control costs. The structure of contracts in electricity markets would tend to reinforce this effect, since they punish both over- and under-generation relative to the amount promised in day-ahead markets. Interviews with market participants and power plant operators supported these arguments. Thus, many firms with regulated sources participated in the NO_X market only occasionally, whenever their total environmental compliance plan was modified, which might happen only once or twice per year.

An exception to this observation of low participation can be found in speculators in the NO_X Allowance Market, including Enron, Arizona Power System, and individual trading desks at some regulated firms. Speculative activities were not uncommon in the first few years of the market but became more rare after 2001, as many markets slowed down.

The results of the first set of quantitative analyses are discussed next. Table 2 shows a variety of emissions values as well as generation for the ozone seasons (May-September) in 1998-2001. This information is shown in graphical form in Figure 2. The data has been normalized in the tables to allow all the relevant values to be shown on the same figure. Total emissions over the NO_X season (tons) declines in each year, and declines substantially (by almost 25%) in the first year of the program from the pervious year. Similarly, the average emission rate (lb/hr) declines every year. However, the peak emission rate recorded over any single hour during the ozone season at first declines by about 15% from 1998 to 1999 and then rises again, although never rising higher than pre-program levels. The peak emission rate may be a better indicator of the impact of the OTC NO_X Budget program than the seasonal values because of the episodic nature of the ozone problem. This suggests that there may be a problem with temporal hotspots. However, it should be noted that even the 1998 emissions were lower than the baseline used for the OTC NO_X Budget program, which was 1990. In addition, it is hard to know what the counter-factual condition would be (i.e. if there was no NO_X Budget, what regulatory program would exist?) and what the resulting emissions profile would be.

Table 2: Ozone Season NO_X emissions and generation

Year	Emissions (tons)	Avg. NO_X rate (lb./hr)	Peak NO_X rate (lb./hr)	Avg. NO_X rate (lb./MWh)	Peak NO_X rate (lb./MWh)	Generation (GWh)
1998	156,484	83,310	134,947	2.9	20.0	108,799
1999	120,048	63,082	115,628	2.1	8.2	118,107
2000	117,025	60,640	124,125	1.2	5.5	134,390
2001	111,043	57,223	126,556	1.1	3.0	131,521

Note: These data are for all power plants, including those in Maryland that only participated in the 2000 and 2001 NO_X Budget program.

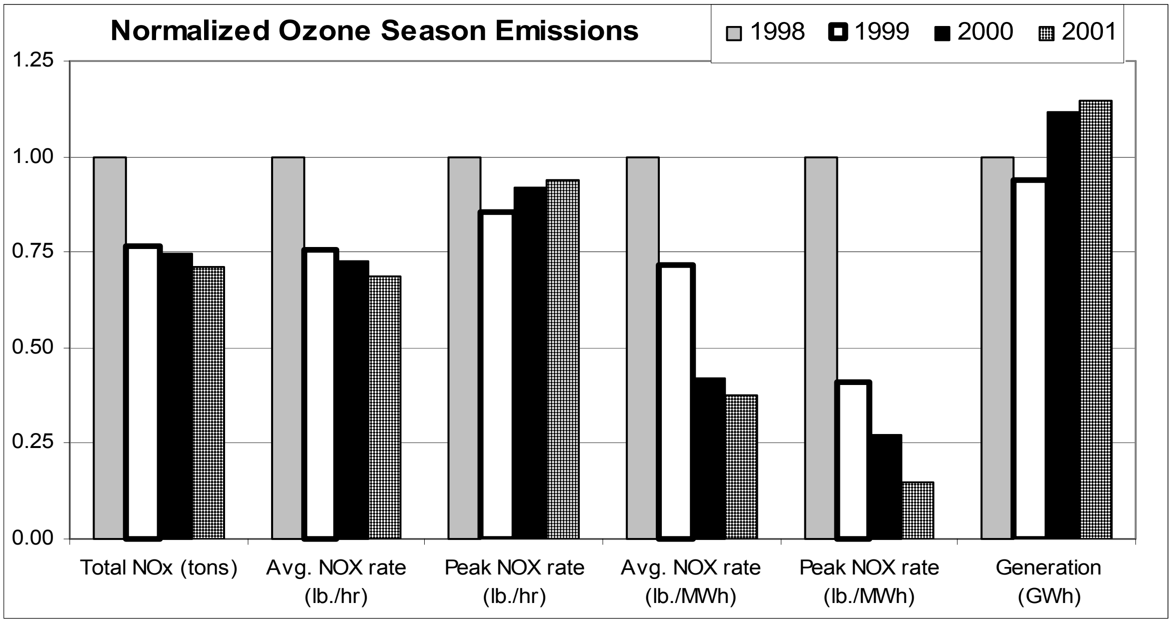

Figure 2: Normalized Emissions during the ozone season

Also significant are the very substantial declines in emissions per unit of output (lb./MWh, or emission factor), which is a result of both declining emissions and rising generation. This analysis shows that the large (>100MW) power plants in the OTC NO_X Budget controlled emissions, on aggregate, more each of the first three years of the program. Similar but less strong trends are seen in annual emissions data (not shown here).

Table 3 and Figure 3 present emissions and generation for the worst ozone episode in each year, as measured in New York City (which is roughly in the center of the OTC states). Peak ozone concentrations ranged from 0.142-0.171 parts per million (ppm), compared to the health standard of 0.120ppm. Two episodes lasted three days (2000 and 2001), and two lasted four days (1998 and 1999), making the total tons and total generation results less easily comparable.

Table 3: Ozone episode NO_X emissions and generation

Year	Emissions (tons)	Avg. NO_X rate (lb./hr)	Peak NO_X rate (lb./hr)	Avg. NO_X rate (lb./MWh)	Peak NO_X rate (lb./MWh)	Generation (GWh)
1998	5,670	91,996	121,570	3.0	4.9	3,374
1999	4,238	85,038	110,573	2.8	5.5	2,980
2000	2,483	65,658	83,643	1.2	1.7	2,135
2001	3,801	100,976	126,556	1.8	3.0	3,177

Notes: These data are for the worst ozone episode in each year, which were of different lengths.

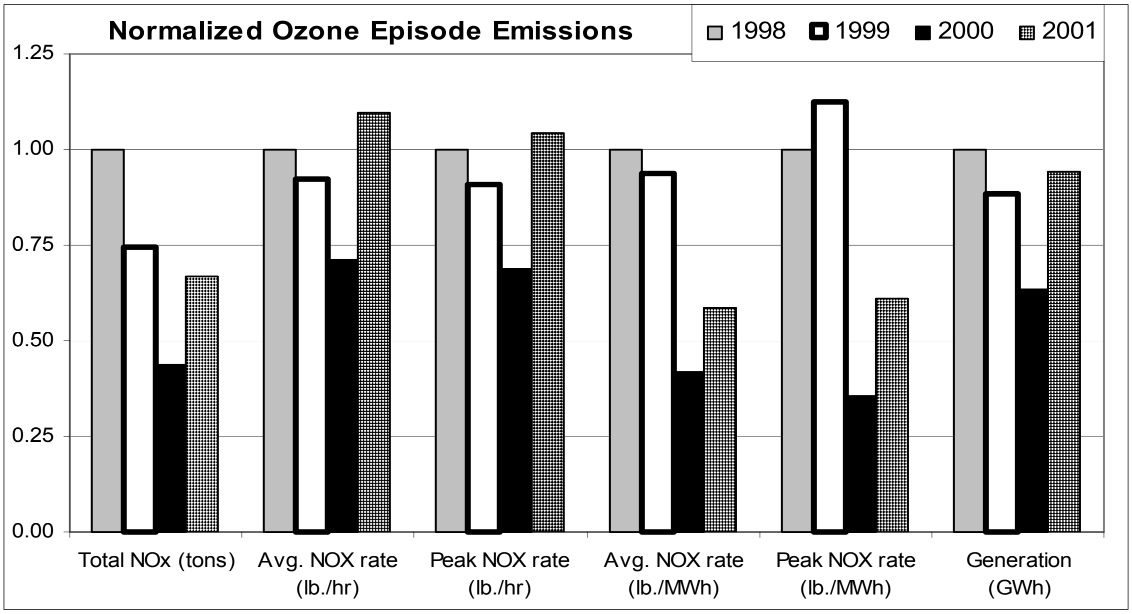

Figure 3: Emissions and generation for the worst ozone episodes in four years

As with the ozone season analysis, total emissions during ozone episodes periods decreased with the NO_X Budget, but they have not declined each year since 1998. However, the average and peak NO_X emission rates (lb/hr) are highest in 2001, while the peak emission factor (lb/MWh) is highest in 1998. More tellingly, average generation (in MW, not shown) during these episodes is considerably (12%-80%) higher than during the ozone season as a whole. Further, comparing between Tables 1 and 2, it can be seen that the absolute magnitudes of the average NO_X emission rates (lb/hr) are substantially (8% to 77%) higher during the ozone episodes than during the entire ozone season they occur in. Thus, temporal hotspots do occur under the OTC NO_X Budget program, however it is not yet clear if this is due to the C/T system.

One reason for the high emission rate in 2001 is that electricity demand for this period (8/7-8/9) was extremely high. Total generation for these three days was greater than that for the four-day long ozone episode of 1998 (3.18GWh compared to 2.98 GWh), while peak generation was even more exceptional (52GW compared to 37-39GW for the other three episodes). At the same time, the 2001 ozone episode was the least severe, with a peak concentration of 0.142ppm.

This analysis suggests two things. First, NO_X emissions under a C/T system are strongly correlated with electricity generation. This is particularly important because the same is true of traditional command-and-control regulation, the most reasonable counter-factual regulatory situation. Second power plant NO_X emissions in the Northeast are not always determinative of the level of smog problems in the area. This may be important because it suggests that even if there is a temporal hotspot problem for all seasonal NO_X C/T trade systems designed to combat regional photochemical smog, relatively modest-sized hotspots may not matter.

While an increase in emission rates due to increased electricity demand (and thus increased generation) would occur under both C/T and traditional command-and-control regulation, it may still be the case that plants take advantage of the temporal flexibility and change their operations during ozone episodes or other periods (such as when electric power prices are higher. Aggregate comparisons here are difficult in particular because to a significant degree, NO_X emissions depend on which specific power generators are operating at any give time. One approach would be to look at periods with similar total power generation, when the units operating would be roughly similar.

This approach is taken with Table 4 and Figure 4, which present data for four three-day periods with generation close to the three-day period containing the worst ozone episode in 2000 (00e). The first two are also taken from 2000, one period during the ozone season (00s) and one period is not during the ozone season (00n). The second two are from the ozone seasons in 1999 and 2001 (99 and 01, respectively). While not a perfect control, this should reduce the differences due to having different generators running for any given period, assuming dispatch order does not change appreciably.

Table 4: Emissions and generation for periods comparable to a 2000 ozone episode

Period	Emissions (tons)	Avg. NO_X rate (lb./hr)	Peak NO_X rate (lb./hr)	Avg. NO_X rate (lb./MWh)	Peak NO_X rate (lb./MWh)	Generation (GWh)
00e	2,483	65,658	83,643	1.2	1.7	2,135
00s	2,236	59,217	87,471	1.2	1.4	1,916
00n	3,613	95,527	113,253	2.6	3.6	2,315
99s	2,766	74,117	101,968	2.6	3.2	1,880
01s	2,008	52,917	82,768	1.1	1.6	1,820

Note: Table contains data for four three-day periods with total generation close to the worst ozone episode in 2000, 6/9-6/11, labeled 00e. Period 00s occurred during the 2000 ozone season. Period 00n occurred during 2000 but not during the ozone season. Period 99s and 01s occurred during the 1999 and 2001 ozone seasons.

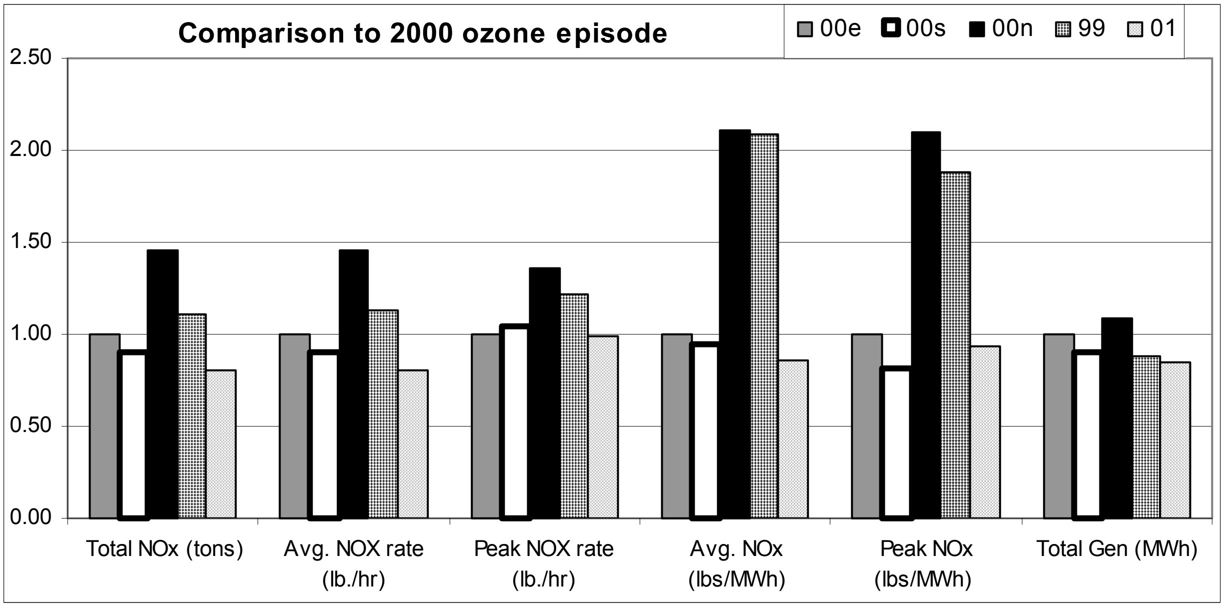

Figure 4: Emissions and generation for periods comparable to a 2000 ozone episode

Emissions in the non-ozone season comparison period (00n) are substantially higher than those, during the season, which is expected. Differences in terms of the emission factor (lb/MWh) are greatest, which is important because this metric reflects changes in dispatch and plant operation and is independent of amount of electricity generated. The emissions of the other two comparison periods (00s and 01s) suggest, on the contrary, very similar dispatch and plant operation. This suggests that the NO_X Budget Program does not tend to change the propensity for temporal hotspots. To test this definitely, however, a more rigorous approach is needed.

A set of OLS regression models were developed to test for the effect of the OTC NO_X Budget program on temporal hotspots by looking for evidence of changes in the behavior of large (>100MW) power plants. Data for 2000 was used. This analysis proceeded in three steps.

First, several models were estimated using data for all the large plants in the OTC region. The second step consisted of using the same models with data from large plants in PJM and specifying additional models were specified with variables for electricity prices, which were available for the entire year only for PJM. Power plants in the PJM interconnect account for a majority of electricity capacity in the entire OTC region (55%), so these results are reasonably representative of the overall outcomes.

The results from the first two steps are presented in Tables 5 and 6 below. The models are specified to use generation, fuel prices, electricity prices, and the OTC NO_X Budget to explain hourly ozone emissions. Various specifications were used; those shown here demonstrate the results best. All of the coefficients are significant at the 0.001 level, and all have the expected sign, save two minor exceptions.

Model 1 consists only of a variable for electricity generation at power plants (excluding co-generators for the OTC data) and a constant. Even this simple model achieves high explanatory power (R^2 values of 0.64 for the OTC and 0.78 for PJM). This confirms the earlier assumption that electricity generation would be a good predictor for emissions. Model 2 adds a dummy variable that takes a value of one for hours during the ozone season and a value of zero otherwise. The predictive power of these models is significantly stronger (R^2 values of 0.84 for the OTC and 0.96 for PJM). These results strongly suggest that the OTC NO_X Budget has had a very strong affect on emissions from large power plants, which is unsurprising.

More importantly, models 3-6 add fuel and electricity prices (and co-generators for the OTC data) to models 1 and 2. While the coefficients for these specifications are significant, and they improve the predictive power of the regression models without the ozone season dummy variable (models 3 and 5), they have very little or no effect with the dummy *is* in the model (models 4 and 6). This strongly suggests that fuel and electricity prices have little or no effect on NO_X emissions of large power plants in the OTC NO_X Budget program relative to the requirements of the program itself. Very similar results are obtained with a variety of specifications and when allowance prices are included.

Table 5: Regression models for large OTC plants for all of 2000

Model 1-OTC					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.10	175	0	N	8,760
Constant	5,100	13	0	R^2	0.78
				Adj. R^2	0.78

Model 2-OTC					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.37	373	0	N	8,760
D_SEASON	-16,600	-162	0	R^2	0.94
Constant	6,400	34	0	Adj. R^2	0.94

Model 3-OTC					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	2.94	234	0	N	8,760
COGEN	3.79	66.0	0	R^2	0.90
COALPRICE	192,000	29.6	0	Adj. R^2	0.90
GASPRICE	-5050	-18.0	0		
Constant	-243,000	-27.0	0		

Model 4-OTC					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.33	381	0	N	8,760
COGEN	-.427	-8.05	0	R^2	0.96
COALPRICE	104,000	24.5	0	Adj. R^2	0.96
GASPRICE	-1,870	-10.3	0		
D_SEASON	-16,900	-111	0		
Constant	-35,200	-9.36	0		

Table 6: Regression models for large PJM plants for all of 2000

Model 1-PJM					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.00	125	0	N	8,760
Constant	-27,800	-40	0	R^2	0.64
				Adj. R^2	0.64
Model 2-PJM					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.24	200	0	N	8,760
D_SEASON	-14,400	-104	0	R^2	0.84
Constant	-287,00	-61	0	Adj. R^2	0.84
Model 5-PJM					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.07	108	0	N	8,760
ELECTPRICE	-16.3	-4.2	0	R^2	0.64
Constant	-29,200	-37.9	0	Adj. R^2	0.64
Model 6-PJM					
Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.18	167	0	N	8,760
ELECTPRICE	15.6	5.98	0	R^2	0.84
D_SEASON	-14,500	-104	0	Adj. R^2	0.84
Constant	-27,400	-53	0		

The third step in the regression analysis applied model 3 to data from the worst ozone episode in 2000 and two other periods in that year of the same duration with very similar total electricity generation, one during the ozone season and one not during the ozone season. . This analysis parallels the analysis above associated with Table 4 and Figure 4. The key regression results are presented below in Table 7. The R^2 values for these models are extremely high, but the sign and significance of most of the variables change from one model to another. Only the coefficient for electricity generation is significant and has the expected sign in all three models. This suggests that generation can be an extremely good predictor of NO$_X$ emissions over short periods of time, and that some of the residuals in other (annual) models applied to annual data may be associated with the operation of different power plants over the course of the year due to scheduled (and unscheduled) maintenance. If it is assumed that within each of the three-day periods that the same power plants are operated, the results in Table 7 indicate extremely stable operation. The idea that power plant operators might change plant operation as electricity prices change over the course of the day (power prices often have a diurnal pattern) is not supported by this analysis.

Interesting but less obvious are the values taken by the generation coefficient in the three models shown in Table 7. For comparison, the coefficient found using annual data is 2.94 (see Table 5). The coefficient for the ozone episode (00c) is lower, while the coefficient for the in-season comparison (00d) is close to the annual value and the coefficient for the non-season (00e) value is higher. (The coefficient for generation when model 3 is applied to October-December data is similar to the non-season value.) A higher value for the non-season coefficient is expected since this implies that power plants in the OTC produce more NO_X when the NO_X Budget program is not in force, which was observed in models 2, 4, and 6. However, it is not so clear why the value for the ozone episode itself should be so low. Investigating more ozone season comparisons or using a disaggregated analysis may be needed to resolve this issue.

Nonetheless, this third step of the regression analysis provides no support for the idea that the NO_X Budget program has led to increased emissions during ozone episodes, undercutting concerns about temporal hotspots.

Table 7: Regression models for large PJM plants for 2000

Model 3-00e: ozone episode

Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	2.27	12.6	0	N	72
COGEN	2.71	1.94	0.057	R^2	0.98
COALPRICE	-12,800	-0.877	0.384	Adj. R^2	0.98
GASPRICE	-205	-0.230	0.818		
Constant	213,000	38.7	0.228		

Model 3-00s: comparison during ozone season

Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	3.01	19.1	0	N	72
COGEN	1.74	1.47	0.240	R^2	0.99
COALPRICE	37,900	4.30	0.0001	Adj. R^2	0.99
GASPRICE	114	4.59	0		
Constant	-517,000	-4.37	0		

Model 3-00n: comparison not in the ozone season

Variable	Coefficient	*t* – statistic	*p* – value		
POWERGEN	4.02	23.6	0	N	72
COGEN	-2.81	-2.82	0.0062	R^2	0.96
COALPRICE	-2,830	-0.208	0.836	Adj. R^2	0.96
GASPRICE	41.4	0.195	0.846		
Constant	58,100	0.339	0.736		

Discussion

The analysis presented here supports the idea that temporal variations in NO_X emissions occur during the ozone season in the Northeast, with higher than average emissions occurring during ozone episodes. However, these 'hotspots' are very closely associated with increases in electricity generation, and would likely occur even with rate-based command and control regulation. The statistical analysis showed that while generation is by far the most important driver of NO_X emissions in the OTC NO_X Budget, the effect of the program is very significant as well.

More importantly, this research discovered no interview or statistical evidence for the 2000 ozone season that operators of large power plants respond to fuel or electricity prices by adjusting (in aggregate) plant operation to change NO_X emissions. This result is further supported by the comparison of a specific ozone episode with periods similar from an electric generation standpoint. Power plants appear to operate the same during high ozone periods as other periods of the year.

Policies, both proposed and adopted, for dealing with hotspots in emission trading systems have tended to introduce uncertainty and inflexibility into the markets. These have (or would have) reduced the efficiency of the market and thus limited the cost savings available, and in the case of RECLAIM they probably contributed to the failure of the program. While there is no doubt that emission trading systems may hypothetically increase the likelihood of hotspots, concern for this problem may be over-stated. A better policy may be to avoid provisions that limit trading or banking in the hopes of limiting temporal hotspots, but institute a regular system of review that would impose such limits if the potential for such a problem arose. These policies should be prospective, not retrospective, in order to minimize the uncertainty they introduce into the market.

Nonetheless, while this research has turned up no evidence that emission trading enhances any tendency towards greater temporal hotspots, it is undeniable that the flexibility built into such systems plus the mismatch between the phenomenon of concern and the regulatory period makes such a problem possible. Further, this study has some limitations. Most important is probably the fact that the OTC NO_X market is relatively small and illiquid, which limited participation and possibly limited the opportunity for firms to vary plant operation to optimize revenues associated with NO_X controls and allowance purchases. This would be accentuated by the fact that only the first three years of the program are evaluated and for the first, at least, there was very little familiarity with the program and no bank of allowances saved up. The relatively low prices for NO_X allowances (compared to the prices for power) may also be a factor – things may change as the cap decreases.

This paper suggests a number of areas for further research. One obvious issue would be to continue to look for temporal hotspot problems in C/T systems as the caps become tighter. A second would be to conduct a more detailed and disaggregated analysis of plant dispatch and utilization to verify the underlying causes of the residuals in the regressions above and the values that the coefficients take. Third, an analysis of the NO_X Budget program for spatial hotspots is clearly needed. Finally, air quality modeling may be needed to determine if any spatial and temporal differences in *emissions* caused by the OTC NO_X Budget have a significant effect on pollution concentrations or on health.

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Lessons from Phase 2 Compliance with the U.S. Acid Rain Program

A. Denny Ellerman[1]

INTRODUCTION

The acid rain provisions of the 1990 Clean Air Act Amendments, included in Title IV, required fossil-fuel-fired electricity generating units to reduce sulfur dioxide (SO_2) emissions by 50% in two phases. In the first, known as Phase I and extending from 1995 through 1999, generating units of 100 MW^e of capacity and larger, having an SO_2 emission rate in 1985 of 2.5 lbs. per million Btu (#/mmBtu) or higher, were required to take a first step and to reduce SO_2 emissions to an average of 2.5 #/mmBtu during these transitional years. Phase II, which began in 2000 and continues indefinitely, expanded the scope of the program by including all fossil-fuel-fired generating units greater than 25 MW^e and increased its stringency by requiring affected units to reduce emissions to an average emission rate that would be approximately 1.2 #/mmBtu at average annual heat or Btu input in 1985-87, and that would be proportionately lower for increased total fossil-fuel fired heat input.[2]

The behavior of affected units in Phase I has provided the answers to many questions about how tradable permit systems would work in practice: for instance, how electric utilities would use allowances and whether reasonably efficient allowance markets would develop. It has also been possible to answer questions about environmental effectiveness, patterns of abatement, opt-in behavior, cost savings, and

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[2] The nation-wide Phase II cap on SO_2 emissions is 8.9 million tons, which is approximately the product of total baseline (average 1985-87) heat input and the emission rate target of 1.2 #/mmBtu. Since the cap is fixed, higher total heat input necessarily implies a lower average emission rate, and vice versa.

innovative activity associated with cap-and-trade programs.[3] Yet, the answers to some of these questions were necessarily incomplete, while other questions could not be addressed until Phase II began, such as: How much additional abatement would be provided by the four-fold increase in coverage and the tighter cap? How would the allowances banked in Phase I be used during Phase II? Was the degree of over-compliance in Phase I, which led to the accumulation of a large allowance bank, even reasonably optimal? Do new generating units, who receive no allowances, face any barriers to entry caused by the need to acquire allowances in the market? And finally, what will it all cost when the Phase II cap is fully phased in? This paper provides tentative answers to these questions based on the analysis of data from the first two years of Phase II.

THE DISTRIBUTION OF ABATEMENT

Phase 1 and Phase II units

Any analysis of abatement and compliance must distinguish between those units for which 2000 was only the sixth year of being subject to the requirements of Title IV and those for which 2000 was the first year.[4] Table 1 shows the relevant statistics for these two groups of units for the year 2001.

Table 1. Title IV Compliance Behavior, 2001

	Phase I Units (374 Units)	Significant Phase II Units (1,420 Units)	Total (1,794 Units)
Heat Input (trillion Btu)	6,007 (24%)	18,730	24,737
Emissions (000 tons SO_2)	4,041 (38%)	6,571	10,612
Emission Rate (lbs SO_2/mmBtu)	1.35	0.70	0.86
CF Emissions (000 tons SO_2)	9,304 (55%)	7,622	16,926
Abatement (000 tons SO_2)	5,263 (83%)	1,051	6,314
Allowances (000 tons SO_2)	2,914 (32%)	6,199	9,113
Banking (000 tons SO_2)	(1,127) (75%)	(372)	(1,499)

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[3] The principal works evaluating compliance behavior in Phase I are Burtraw (1996), Carlson et al. (2000), Ellerman et al. (2000), Joskow et al. (1998), Montero (1999), Popp (2001), Schmalensee et al. (1998), Swift (2000), and Swift (2001). Ellerman (2003) provides an update that includes the first years of Phase II and Ellerman et al. (2003) provide a more general treatment that includes other emissions trading programs.

[4] About 100 of the Phase II units opted into and out of Title IV in one or more years of Phase I, but none of these units were continuously affected until 2000.

Three hundred seventy-four electrical generating units were subject to Title IV during all five years of Phase I, including 263 units that were mandated to be subject to Title IV beginning in 1995 and another 111 units that voluntarily opted into Phase I for all five years. A total of nearly 4,000 unit accounts were subject to Title IV requirements in 2000 and 2001, but many of these were for units that were yet to be built and about 1200 generated little electricity and virtually no emissions. For the purpose of analyzing the Phase II response, inclusion of these units provides little information about compliance behavior since they account for less than 2% of fossil-fuel heat input and less than 0.2% of emissions.[5] Instead, and unless otherwise stated the analysis below is based on the 374 Phase I units and 1420 Phase II units that can be considered significant either because of their generation or their emissions. By definition, the Phase II units are smaller and lower emitting units, but they accounted for approximately 45% of 2001 counterfactual emissions and they received 68% of the allowances.

While the Phase II units account for the majority of allowances and heat input (and therefore generation), they account for a relative small part of the abatement that can be attributed to Title IV. The reduction of SO_2 emissions in 2001 due to Title IV is 6.3 million tons of which five-sixths occurred at the Phase I units. As a group, these units have reduced emissions by 57%, while the comparable percentage for the Phase II units is 14%. As a result, the share of emissions attributable to the Phase I units, the "big dirties," has declined from approximately 55% of the national total to 38%.

As of 2001, both Phase I and Phase II units are relying upon the accumulated Phase I bank of allowances to cover emissions that are higher in the aggregate than the 2001 allowances allocated to these two categories. The use of the bank is however much greater for the Phase I units; their emissions are about 39% higher than the aggregate allowance allocation for the Phase I units while the comparable number for the Phase II units is 6%.

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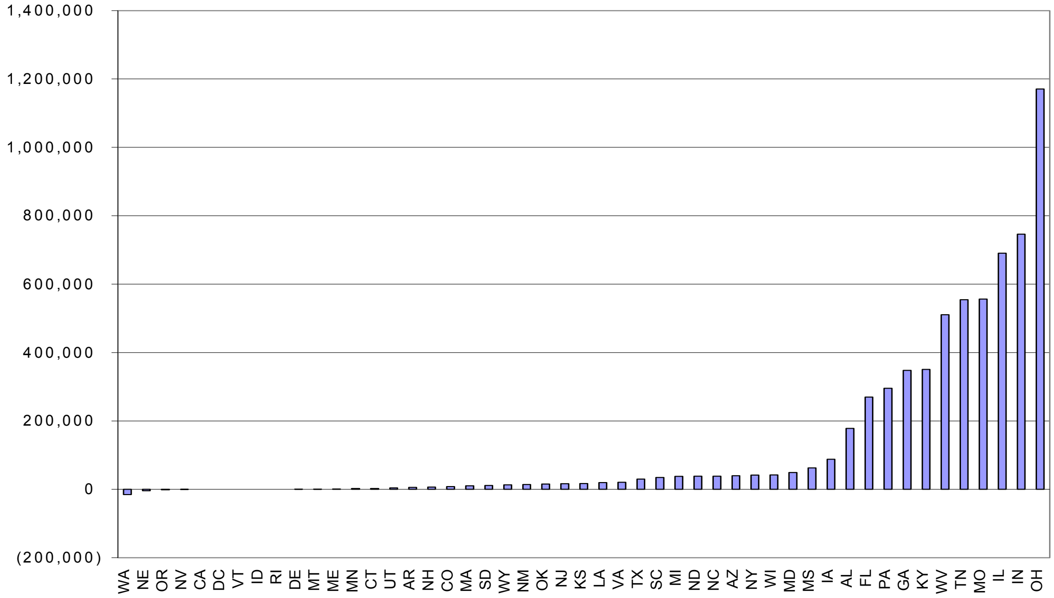
[5] Technically, the criteria for inclusion as a significant unit was having heat input greater than 1×10^{12} Btu in two of the seven years, 1995-2001, or heat input greater than 5×10^{12} Btu in any one of those years. For a unit with a heat rate of 10,000 Btu/kwh, heat input of 1×10^{12} Btu would generate approximately 100,000 Mwh in a year, which would imply a 11% capacity factor for a 100 MW unit.

The Geographic Distribution of Abatement

Figure 1 show the geographical distribution of abatement in 2000.

Figure 1. Title IV Emission Reduction by State, 2000 (tons SO_2)



Eleven states (OH, IN, IL, MO, TN, WV, KY, GA, PA, FL, and AL) account for 90% of national abatement. Excluding the three southeastern states of GA, FL, and AL, 77% of the abatement is occurring in the Mid-west. This geographic concentration of abatement in the Mid-west reflects the predominance of the Phase I units in this region. Virtually all of the Phase I units are located east of the Mississippi River and the heaviest concentration of emissions prior to enactment of Title IV was in the Mid-west.

Since Title IV did not require abatement in any specific geographic location, one might ask: Why did the abatement occur where it was desired? The increased availability and attractiveness of lower sulfur coals in the Midwest provides part of the answer, but an equally important cause is the changed incentive structure of cap-and-trade programs. Deep abatement technologies, such as scrubbers, are more economic at units where a lot of sulfur can be removed, that is, at large units burning high sulfur coal, which in this instance were located in the Midwest. When the owners of affected units must pay a price (in the form of an allowance surrendered) for every ton of emissions, these large and high emitting units will offer the most attractive locations for scrubbers. In fact, 23 of the 30 retrofitted scrubbers installed in response to Title IV are located in the Midwest.

By Abatement Technique

Table 2 provides a breakout of emissions reductions in 2001 by abatement technique, that is, whether by scrubbing or switching to lower sulfur fuels.

Table 2: 2001 Emission Reduction by Technique and Fuel

000 tons	Phase I Units	Phase II Units	Total
Scrubbing	2,048	263	2,311
Fuel Switching	3,215	788	4,003
Total	5,263	1,051	6,314

Scrubbing accounts for approximately 37% of the abatement in 2001 and virtually all of this abatement (1,993,000 tons) comes from new scrubbers installed on 30 Phase I units as a result of Title IV.[6] These thirty units, located primarily in the Midwest and constituting 3% of the generating capacity and 4% of the 2001 heat input at Title IV units, accounted for 32% of total abatement. The remaining reductions attributed to scrubbing are reductions in excess of the percentage reduction required of scrubbers under non-Title IV regulation, which is typically 70% to 90%. Switching to lower sulfur fuels occurred almost exclusively (99.9%) at coal-fired units and it consisted entirely of switching to lower sulfur coals. The remaining 0.1% of the emission reduction by switching occurred at oil-fired units, which were switched either to lower sulfur petroleum products or to natural gas. No coal units have been switched to natural gas because the price of natural gas is too high to justify abatement by this means.

First Year Effect

One of the most interesting phenomena of both Phase I and Phase II is that the largest reduction of emissions was made in the first year that units were subject to Title IV, which is to say, the first year in which they were required to pay a price for every ton of SO_2 emissions. Figures 2 and 3 show this effect for the 374 Phase I units that first

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[6] 27 of these units were installed at the beginning of Phase I. Since 1998, when allowance prices first exceeded $200/ton, at least eight new retrofit scrubbers have been announced and three of these were on-line in 2001.

became subject to Title IV in 1995 (by law or through opting-in voluntarily) and have been so continuously since then and the Phase II units that became subject to Title IV in 2000.

Figure 2. Phase I unit emissions, allowances and counterfactual emissions

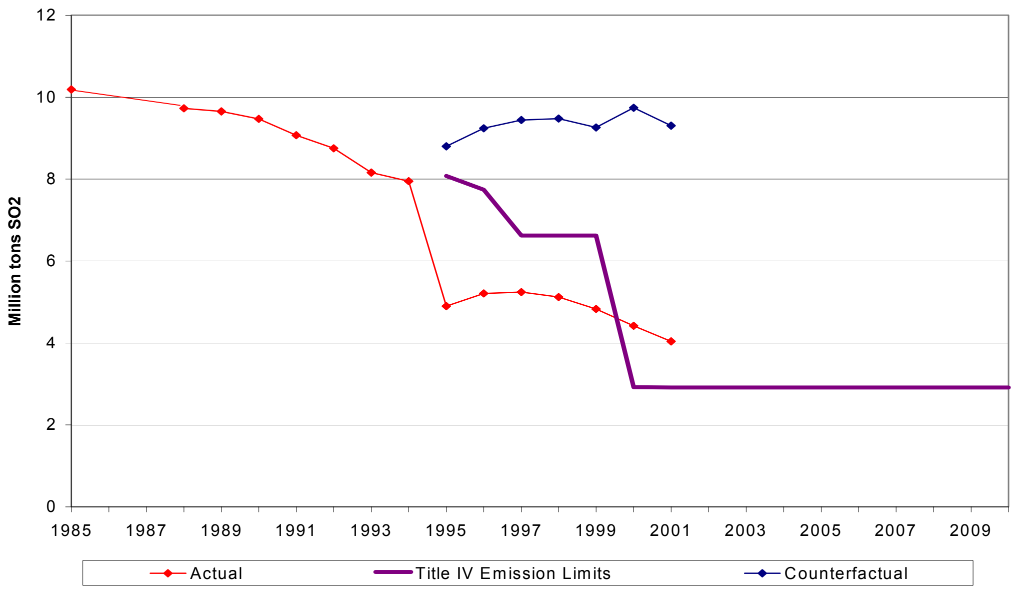
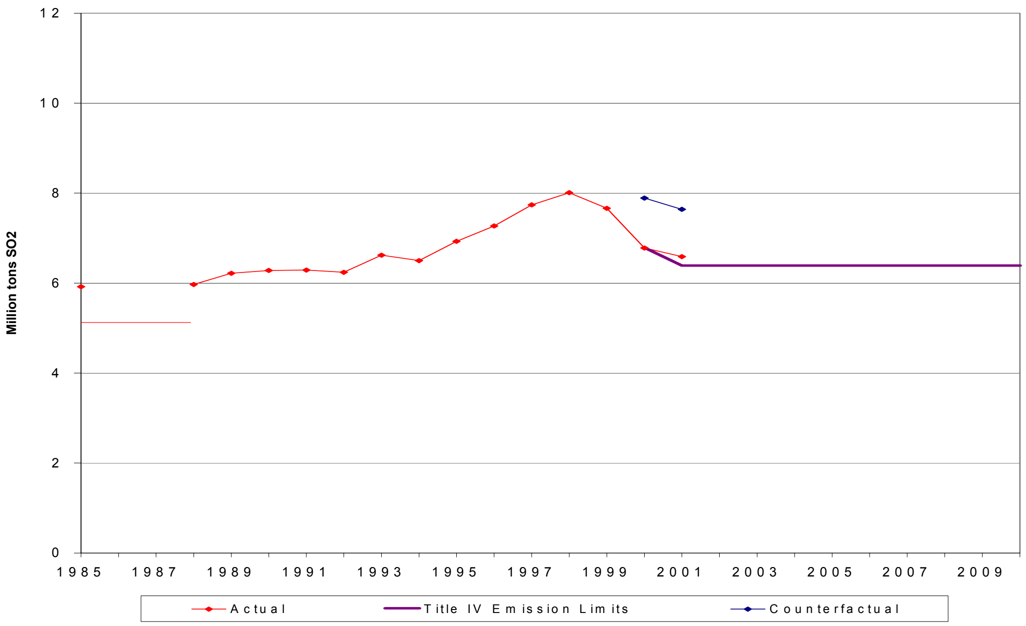


Figure 3. Phase II unit emissions, allowances, and counterfactual emissions



In both of these figures, the red line beginning in 1985 and continuing through 2001 depicts the evolution of actual SO_2 emissions; the lines beginning in 1995 in Figure 2 and in 2000 in Figure 3 and continuing to the right-hand side of each figure represents the total number of allowances issued to these units for each year; and the shorter line consisting of seven points in Figure 2 and two points in Figure 3 provides an estimate of counterfactual emissions, what emissions would have been for these units if Title IV had not been in force. The notable feature for each subset of generating units is the large reduction in emissions that is observed in the first year that Title IV took effect.

This first-year effect is particularly striking for the Phase I units. A steady decline in the trend of emissions can be observed in the late 1980s and early 1990s, but the reduction from 1994 to 1995 was much greater than any year-to-year decline observed before.[7] Title IV occasioned this sharp one-year decline; there simply is no other explanation. It is the more remarkable in that it can be seen as completely voluntary, at least with respect to the timing of the emission reduction since the total number of allowances issued for 1995 was in fact not very constraining.

The first-year effect is not as large in absolute or percentage terms for the Phase II units because these relatively low emission units contribute less to the aggregate emissions, but it is still noticeable. The start of Phase II broke what had been a steady upward trend in SO_2 emissions for these units that contrasts with the pre-Title IV trend for the Phase I units. In 2000, aggregate emissions for Phase II units were virtually the same as the number of allowances issued to these units, but the pattern beneath the aggregate is highly variable. Approximately 60% of the Phase II units receive more allowances than needed to cover calculate counterfactual (and generally actual) emissions; the surplus is effectively transferred to other Phase II units, generally located east of the Mississippi, that received fewer allowances than those unit's pre-Title IV and estimated 2000 counterfactual, emissions.[8]

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[7] Ellerman and Montero (1998) the declining trend in SO_2 emission prior to the onset of Phase I to the deregulation of railroads which made low sulfur western coal cheap in the Midwest. The appendix by Schennach in Ellerman et al. (2000) provides an econometric estimate that separates the amount of pre-1995 decline due to railroad deregulation and to anticipation of Title IV.

[8] Counterfactual emissions are calculated as the product of the observed, pre-Title IV emission rate and actual heat input for the year in question. For instance, 2000 counterfactual emissions for any given unit is

BANKING

One of the prominent features of Phase I was the accumulation of a bank of allowances that totaled 11.65 million tons at the end of 1999. Although most observers believed that these allowances would be used during the first decade of Phase II, it was never clear whether the amount of banking in Phase I was the result of reasonably rational banking programs implemented by the owners of Phase I affected units, which is to say, whether the level of banking was economically justified..

The effect of Phase II on Phase I unit emissions

One important sign that the owners of Phase I affected units have been engaging in reasonably rational banking behavior is provided by the change in total emissions from these units between 1999 and 2000, when the allocation of allowances for these units was reduced by about 50%. Economic agents who engage in reasonably efficient banking programs would ignore year-to-year changes in the number of allowances allocated and abate according to a banking program based on the cumulative required emission reduction over the relevant economic horizon—essentially smoothing abatement over time.

Figure 2 shows that the 56% reduction in allowances from 1999 to 2000 had little effect on emissions, which declined by 8% between the two years. The only change from 1999 to 2000 was the change in the banking position of these units; in 1999 they continued to bank allowances and in 2000 they started to draw down the accumulated Phase I bank.. The general shape in the trajectory of emissions, and in the net changes to the bank, is what would be predicted by economic theory when agents are able to redistribute emissions over time in a cost-minimizing fashion and they are faced with a sharp discontinuity in the temporal allocation of allowances (Schennach, 2000).

Optimality of Banking

The smooth path of aggregate emissions from Phase I units and the concomitant start of the draw down of the accumulated allowance bank does not imply that banking

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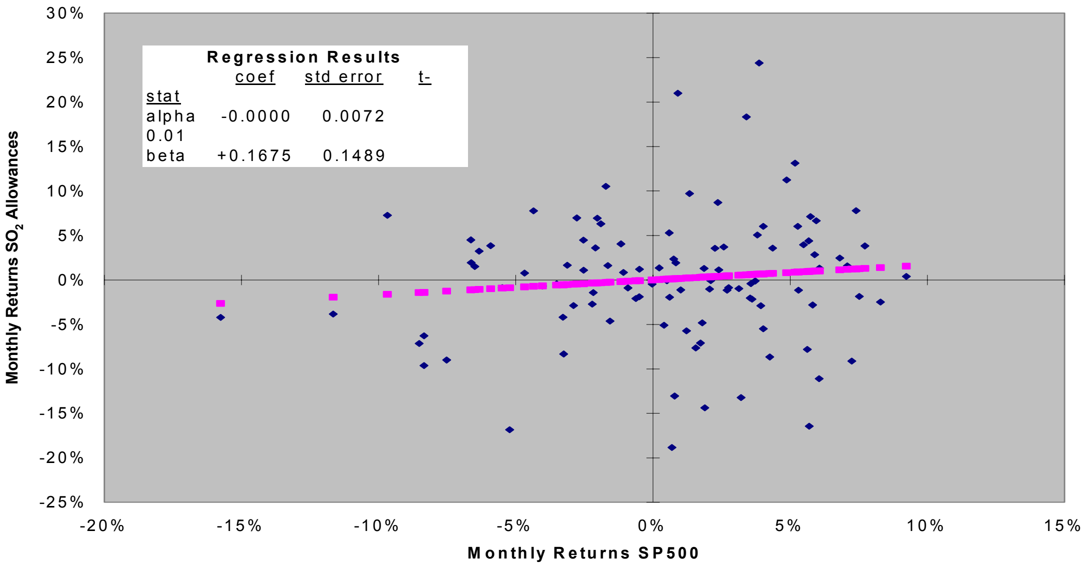
the product of that unit's 1998 emission rate and its 2000 heat input. Aggregate counterfactual emissions for any year is calculated by summing all the individual units.

behavior has been optimal, although it does eliminate the possibility of irrational hoarding, a common concern in the early days of Title IV. Any judgment on temporal efficiency requires that an appropriate discount rate be chosen, which is a non-trivial task.

The usual assumption has been that the owners of electric utilities would use an internal discount rate reflecting their weighted cost of capital; yet, finance theory is clear that the cash flows associated with certain projects or assets should be discounted by a rate reflecting the degree of undiversifiable risk, that is, the extent to which the returns from a particular type of asset vary with the returns from a well diversified portfolio of equities, such as the S&P 500. By the Capital Asset Pricing Model, the appropriate discount rate is the sum of the risk-free rate, associated with Treasury bills or notes, and a risk premium that depends on the asset's "beta," which is the slope of the line regressing the returns from the particular type of asset on the returns from a well-diversified portfolio of equities over a succession of periods. The empirically observed additional return associated with a well-diversified portfolio of equities (in comparison with T-bills for instance) is known as the equity premium for the undiversifiable risk of such a portfolio. The appropriate discount rate for any specific asset, such as SO_2 allowances, is then the risk-free rate plus the product of the asset's beta and the market equity premium. For example, a beta of 1.0 implies that on average the percentage returns from the specific asset (defined as the change in price of the asset plus any dividend payment) are the same as the general equity market; and lower or higher betas imply a lower or higher discount rate for the cash flows associated with the specific asset.

The capital asset pricing model is useful because it provides a means for determining the appropriate discount rate for any asset that is priced in some market. SO_2 allowances are financial assets whose ultimate value depends on the abatement costs avoided by their use for covering emissions in some period. They are also bought and sold in what appears to be a reasonably efficient market so that the returns from holding SO_2 allowances can be easily calculated and compared to those from holding a well-diversified portfolio of equities. Such a comparison is made in Figure 4 for the period from October 1994 through March 2003.

Figure 4. Returns from holding SO2 Allowances and the S&P500



The straight, slightly upward sloping line is the regression line, and its slope indicates the beta, which is statistically insignificantly different from zero. This result indicates that no correlation exists between the monthly returns from SO_2 allowances and the S&P500.[9] When the return from holding a diversified portfolio for some period is positive, the return from holding an SO_2 allowance in the same period is as likely to be negative as it is to be positive. Equivalently, SO_2 allowances constitute a zero-beta asset and this result implies that the appropriate discount rate for SO_2 allowances is the risk-free rate.[10]

It would take this paper to far afield to delve into the construction of an appropriate discount rate for SO_2 allowances, such as how to determine the risk-free rate and over what period of time; however, the result of that analysis, as developed more fully in Ellerman and Montero (2002), is given in Figure 5.

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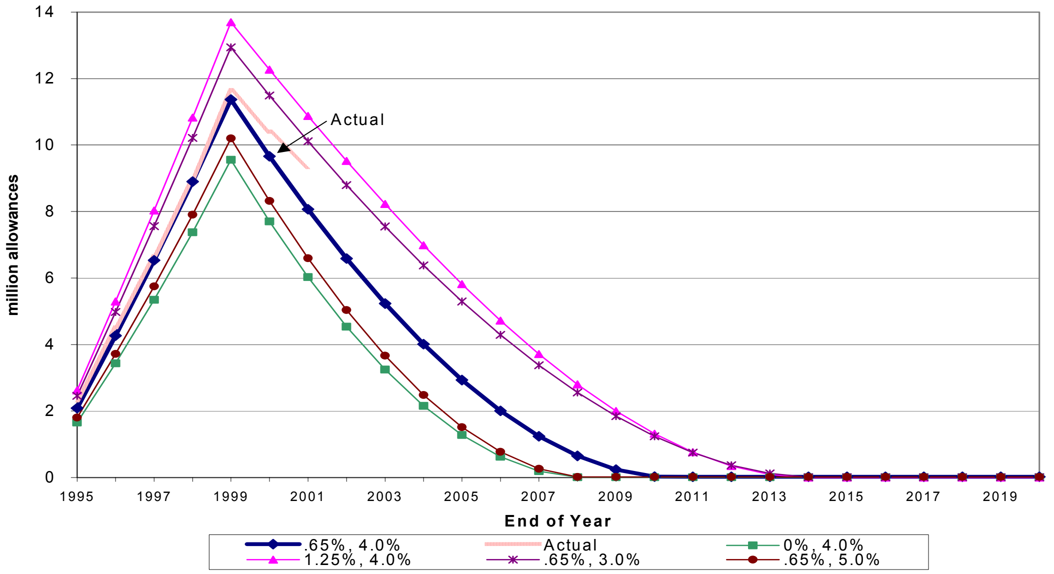
[9] Regressions on different market indices, for differing periods of time, and with corrections for serial correlation give similar results.

[10] It must be emphasized that the risk that is measured is systemic or undiversifiable risk, not asset specific risk. The latter can be reduced and avoided by constructing a portfolio with an appropriate weighting of assets whose returns are negatively correlated with the specific risk being diversified.

Figure 5. Simulation of optimal Title IV banking



The five peaked lines extending from 1995 through varying years in Phase II represent optimal aggregate bank holdings depending on plausible assumptions concerning discount rates and the expected growth of SO_2 emissions over the banking period. The fuzzy line that runs through 2001 represents actual aggregate bank holdings and it closely tracks the optimal path for a real discount rate of 4.0% and an expected growth of emissions of 0.65%. These are in fact reasonable assumptions for the real risk-free discount rate from the mid-1990s through 2001 and for pre-1995 expectations of expected SO_2 emissions growth without Title IV. However, the important point is not that the actual path tracks this particular line, but that it falls within the paths described by alternative plausible assumptions concerning real risk-free discount rates—3.0% and 5.0%—and for the growth of counterfactual emissions—0% and 1.25% per annum. The real risk-free discount rate varies over time, as do expectations of expected growth in counterfactual emissions, but these bounds fairly describe the variation in these parameters since Title IV began.

It would be too much to claim that banking has been optimal in any exact sense, but the lines in Figure 5 describe the range of reasonably efficient banking programs given reasonable assumptions about the most important parameters determining banking behavior. The envelope described by these banking programs would predict an end-of-Phase I bank of between 9.5 million tons and 13.5 million tons and the complete draw down of the bank sometime between 2008 and 2013. This envelope is consistent with what has been observed and what is expected, assuming no changes to Title IV during the remainder of the banking period. In summary, the response to the banking provisions of Title IV provides further evidence economic agents respond in a rational, cost-minimizing way when market-based incentives are made available.

NEW UNITS

A frequently maligned feature of Title IV is the endowment of allowances to incumbents (as of 1985-87) without any provision for allowances to new entrants. This feature is often decried as a barrier to entry for new generating units, an issue of particular concern when wholesale power markets are deregulated. This feature of Title IV could not be observed in Phase I, since existing plants only were included. However, any new fossil-fuel-fired generating unit of more than 25 MW^e that has come on line since enactment of the legislation in 1990 would be covered in Phase II, so that this effect can now be observed.[11]

One way to evaluate the effect on new units is to observe the frequency of generating units that were not allocated allowances. Zero-allowance units are not necessarily new units since re-activated, mothballed units not operating in 1985-87 would also not receive allowances, and there were some of these. Nevertheless, all new units would be zero-allowance units and the crux of the argument about barriers to entry concerns the absence of an allowance allocation. Of the nearly 3,000 units subject to reconciliation and emitting some SO_2 during 2000-2001, 981 are zero-allowance units, almost a third. This large number reflects mostly the increase in new gas-fired capacity that has been observed in 2000 and 2001.

Table 3 provides an accounting of these zero-allowance units by the time when they first appeared as generating units. In this presentation, a division is made between

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[11] A few units that were in the planning stage in 1990 received contingent allowance allocations in the Title IV legislation. In the following analysis, three of these units that were operating in 2000 and 2001 have been excluded.

Phase II units that make a significant contribution to heat input or emissions (1420 units), which have been cited above, and the remaining units (1200) with small contributions to aggregate heat input (1-2% of the total) and emissions (≈ 0.2%). Since many of the new units were used for peaking purposes only or were only starting up as combined cycles in 2001, any assessment of the role of zero-allocation units must include these "remaining" or "insignificant" Phase II units.

Table 3. Zero-allowance Phase II units, by time of first generation

	Significant Units	Remaining Units	Total Phase II
Online prior to 2000	109	264	373
New in 2000	34	189	123
New in 2001	31	354	385
Total	174	807	981

Nearly all of the zero-allowance units are new, gas-fired peaking or combined cycle units that emit little SO_2, but a small number are not. In 2001, 61 units had an average emission rate higher than 0.05 lbs/SO_2 per mmBtu, which implies they were burning a petroleum product or coal; and 20 emitted more than 100 tons of SO_2 during the year. These small numbers might be used to argue that the absence of an allowance endowment discouraged new coal or oil capacity, but it is more likely that the compelling economics of gas-fired peaking and combined cycle generation (at least before the recent and persistent higher price levels for natural gas) explain this phenomenon. At the very least, it is evident that the lack of an allowance endowment does not impede the entry of new low-emitting generation capacity.

Quite apart from the issue of barriers to entry, the new gas-fired units have had a significant effect on SO_2 emissions. The year 2001 was the first year since 1992 in which the heat input into fossil fuel fired generating units declined thereby breaking what had been an eight-year succession of rising demand for fossil-fuels for the generation of electricity. The 3.2% decline in heat input from 2000 to 2001was the more remarkable in that fossil fuel fired generation of electricity in these two years was approximately constant. The explanation lies in the significant increment of new gas-fired combined cycle generating capacity that came on line in 2001.

The differing trends in fossil-fuel fired generation and fossil-fuel heat input due to the new combined cycle units emerges clearly from the latest EIA data, as shown in Table 4.

Table 4: Generation and Heat Input at Fossil-fuel fired Generating Units, 1999-2001

	1999	% Chg	2000	% Chg	2001
Generation (000 Gwh)	2,578	+4.31%	2,689	+0.07%	2,691
Coal	1,884	+4.46%	1,968	-2.79%	1,913
Oil/Gas	694	+3.89%	721	+7.90%	778
Heat Input (Quads)	23.45	+2.22%	23.97	-3.46%	23.14
Coal	19.33	+3.93%	20.09	-2.59%	19.57
Oil/Gas	4.12	-5.83%	3.88	-7.99%	3.57
Implied Efficiency					
All Units		+2.04%		+3.66%	
Coal Units		+0.51%		-0.21%	
Oil/Gas Units		+10.32%		+17.27%	

Source: EIA, Monthly Energy Review, February 2003

The effect of the new combined cycle units can be seen in the statistics for implied efficiency, which is the change of generation divided by the change in heat input. For instance, in comparing 2001 with 2000, fossil-fuel fired generation increased by less than .1% and heat input declined by 3.5%, which implies an improvement in efficiency of 3.66%. As can be seen from the decomposition by fuel, all of this comes from the oil/gas fired units. The efficiency of the coal units has been relatively constant in the aggregate, but the oil/gas generating units have improved in aggregate efficiency by about 10% in 2000 and 17% in 2001. The result in 2001, when demand for electricity was flat, has been a backing out of the coal units (-2.8%) and an increase in oil/gas generation (+7.9%). The improvement in efficiency also implies less demand for natural gas for generating electricity, a trend that is clearly evident in the EIA statistics (-8.0% from 2000 to 2001).[12]

The effect of the new gas-fired combined cycle generating units can be readily observed when the annual changes in emissions at generating units are decomposed into changes in emission rates at individual units, caused by fuel switching, and changes in heat input at those units. Table 5 provides an accounting of the changes in SO_2 emissions from 1999 to 2000 and from 2000 to 2001 by summing the observed changes at all affected generating units.

Table 5. Changes in SO_2 emissions by fuel and cause

000 tons SO_2	All Units	Coal Units	Oil/Gas Units
1999-2000 Changes	**- 1,254**	**- 1,132**	**- 122**
Emission Rate Changes	- 1,392	- 1,382	- 10
Heat Input Changes	+ 138	+ 250	- 109
2000-2001 Changes	**- 567**	**- 649**	**+ 83**
Emission Rate Changes	- 64	- 135	+ 71
Heat Input Changes	- 503	- 514	+ 12

Source: Derived from EPA CEMS data

The source of SO_2 reductions changes dramatically from the comparison of 1999 with 2000 and 2000 with 2001. All of the reduction in emissions from 1999 to 2000 can be attributed to an average lowering of emission rates at affected units, mostly by switching to lower sulfur fuels. This change is the first-year effect that has been discussed earlier: the downward shift in emission rates that occurs when units are first required to pay a price for all emissions. In contrast, nearly all of the reduction from 2000 to 2001 is due to lower heat input at affected units, which reflects the influx of new combined cycle

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[12] The heat input data from the CEMS (Continuous Emissions Monitoring System) data collected by EPA confirms the general trend but not the magnitudes of improved generation efficiency for oil/gas units. For instance the CEMS data show oil/gas unit heat input to have increased by 2.7% from 2000 to 2001, instead of declining by 8.0%, as the EIA data indicate. A 2.7% increase in heat input would still imply some improvement in efficiency, given the increase in gas-fired generation, but not 17%. There are obvious problems of comparability concerning oil and gas units. While the EIA and EPA statistics agree closely with respect to heat input into coal-fired units, the disagreement for oil/gas fired units is large. EIA reports 3.57 quads of oil and gas heat input in 2001, while the EPA CEMS indicates 4.85 quads of oil and gas heat input, or 36% more.

capacity and the resultant backing out of coal-fired and single cycle oil and gas-fired generation. Had the new combined cycle units not been brought on line, the demand for electricity would have been met by existing generating capacity and SO_2 emissions would have been about 500,000 tons, or about 5%, higher than they were.

COST

No estimates of the actual cost of compliance with Title IV in Phase II have been made; however, two groups of analysts made ex post estimates of the cost of compliance in Phase I and both provided updated estimates of the expected cost in Phase II based on observed Phase I cost. These estimates of Phase II cost can be now be assessed based on the observed abatement in Phase II and allowance price behavior. The two ex-post evaluations of Phase I compliance cost were made by Carlson et al. (2000) and Ellerman et al. (2000) [hereafter, CBCP for the initials of the authors of Carlson et al. and MCA for *Markets for Clean Air*, the title of the book published by Ellerman et al.]

CBCP and MCA agree roughly on the cost of compliance in the early years of the Acid Rain Program. The latter estimates the cost of compliance at $726 million in 1995 and about $750 million in 1996, while the former places the cost at $832 million in 1995 and $910 million in 1996, all stated in 1995 dollars. These estimates are not as far apart as they would seem. Complete comparability is not possible because of differences in methodology; however, both treat scrubber expense in the same manner.[13] Although they largely agree on the fixed cost of scrubbers ($375 million in MCA and $382 million in CBCP), they differ significantly on the variable costs associated with scrubbers ($89 in MCA million and $274 million in CBCP).[14] CBCP uses scrubber data that reflect pre-1995 estimates of the variable cost of scrubbing, but the actual performance of the Phase I scrubbers has been much better than predicted. Correction of this item alone largely

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[13] MCA provides a bottom-up, plant-by-plant analysis based on reported capital costs and observed sulfur premia. CBCP conducts an econometric estimation of a translog cost function and share equations of unit-level data for 734 *non-scrubbed* units over the 1985-94 period and then takes the resulting parameter values to form marginal abatement cost functions for individual units, which are then used to estimate actual costs based on observed 1995-96 emission levels. Scrubbed units are handled separately on a cost accounting basis using identical cost of capital and depreciation assumptions as in Ellerman *et al.* (2000).

[14] The numbers cited from CBCP are from their break-out of the costs of 2010 compliance. This estimate will be approximately the same as the scrubber costs in 1995-96 since the fixed costs are annualized over 20 years, fuel costs are assumed not to change after 1995, the number of scrubbers is assumed to remain unchanged, and costs are stated in 1995 dollars.

removes the disparity in cost estimates between these two ex post evaluations. As an approximate figure, $750 million is probably a reasonable estimate of the annual cost of abatement in the first years of Phase I.

A simple estimate of Phase II cost can be obtained by extrapolation of this estimate using the increase in the amount abatement observed and the behavior of allowance prices, which can be taken as a reasonable indication of short and long-run costs of abatement. The estimate of $750 million for early Phase I costs corresponds to about 4.0 million tons of abatement, while currently observed abatement is about 6.5 million tons, or 63% more. Although three new retrofitted scrubbers were operating as of 2001, most of the 2.5 million tons of additional abatement since 1995 has occurred through switching to lower sulfur coal. Allowance prices provide a good proxy for the per ton cost of this additional abatement since there is every indication that utilities recognize that allowances are perfect substitutes for abatement at the margin and act accordingly.

After an initial downward adjustment, allowance prices have moved generally upward, as would be predicted for agents engaged in reasonably rational banking programs; and since early 1998, prices have ranged from highs of about $210 to lows of about $130. In addition, the significant observed reduction in scrubber cost has brought the total costs of scrubbing within the upper end of the range of allowance prices since 1998.[15] Hence, it is reasonable to assume that the increment total cost of the additional abatement observed since 1995-96 lies between $150 and $200 a ton. This implies an additional total cost of abatement between $375 million and $500 million (2.5 million tons of additional abatement times $150/ton and $200/ton, respectively) and a total estimated cost for early Phase II abatement of between $1.125 billion and $1.25 billion. Since another 1.5 million tons is to be abated as the Phase I allowance bank is drawn down, total annual costs for compliance with the completely phased-in Phase II limits would be about $1.5 billion assuming an incremental per ton cost of $200.

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[15] Ellerman and Joskow (forthcoming) provide a discussion of the evolution of estimates of scrubbing costs and estimates of the cost of scrubbing the remaining unscrubbed coal units. Taylor et al. (2001) also provide estimates of the decline in scrubber costs since the early 1970s.

By any reckoning, these estimated costs, made with the benefit of observed data and trends, are lower than the ex ante predictions when Title IV was enacted. Most of the often noted disparity between ex ante and ex post estimates of the cost of the Acid Rain Program reflects very different assumptions about the nature of proposed acid rain controls, the projected demand for electricity, and the relative availability and cost of low sulfur coal. For instance, the total annual costs associated with some of the early proposals to control acid rain precursor emissions were estimated at amounts ranging from $3.5 to $7.5 billion, 2 to 5 times what now appear likely to be the cost of a fully phased-in program. Although the details of these earlier proposals varied, they generally mandated scrubbers at a significant number of units and allowed very limited emissions trading. Once the proposal that ultimately became Title IV was proposed (in 1989) and enacted (in 1990), the ex ante cost estimates for the fully phased-in program with trading fell to a range from $2.3 billion to $6.0 billion, with most of this variation reflecting varying assumptions about the extent to which emissions trading would be used.

A good example is provided by the discussion in MCA (pp. 231-235) of the few ex ante estimates of Phase I costs and a comparison with the MCA estimate of actual cost. Most of the variation in the ex ante estimates, made only a few years before Phase I began, reflects differing assumptions about the extent to which utilities made full use of the flexibility afforded by emissions trading. When compared on an average cost basis to account for differences in assumptions about the quantity of abatement (due to differing assumptions about the growth in electricity demand and the extent of banking), MCA's ex post estimate of cost in 1995 was slightly above (3-15%) ex ante estimates assuming full use of emissions trading and 20-35% below estimates that assumed relatively little use of emissions trading.

CBCP provides a very helpful quantification of the causes of the change between the early estimates of fully phased-in Title IV costs and the current estimates. In analyzing the causes for the change between expected costs as of the mid-1980s and actual costs in early Phase I, CBCP find that the marginal cost of abatement for a representative generating unit has been approximately halved and that 80% of the reduction in cost is attributable to falling price of low-sulfur coal relative to the price of high sulfur coal and that the remaining 20% is attributable to technological change. Estimates of fully phased-in Phase II costs are then made using different assumptions about coal prices, technological change, and the use of trading, as illustrated in Table 6.

Table 6: Simulated Total Cost of Compliance with Title IV in 2010
(billion 1995 dollars)

Cost Assumptions	Command-and-Control	Efficient Trading
1989 Prices and Technology	$2.67	$1.90
1995 Prices and Technology	$2.23	$1.51
1995 Prices and 2010 Technology	$1.82	$1.04

Source: Carlson et al. (2000), Table 2, p. 1313

Since efficient trading is being observed, the relevant estimate for Phase II cost from this study lies between $1.04 billion and $1.51 billion, depending upon the amount of technological progress from 1995 to 2010. The estimate of $1.5 billion presented above lies at the upper end of this range, but it does not attempt to estimate further improvements in abatement technology. Even so, this table shows that, while costs depend on prices and technology, which are not subject to program design, the ability to trade, which is subject to program design, can lead to equally and even more significant reductions in the cost of compliance.

In summary, it seems clear that Phase II costs are considerably lower than what was expected and that this difference is attributable to 1) the flexibility allowed by Title IV, 2) improvements in abatement technology, especially in scrubbers, and 3) the lower prices for low sulfur coal due largely to changes independent of Title IV. As detailed in Ellerman and Montero (1998), the most important independent change was the reduction in rail rates that made low sulfur bituminous coals from the West economically attractive as a replacement for high sulfur, Midwestern bituminous coal and significantly reduced the abatement requirements imposed by the Title IV cap.

CONCLUSION

With two years of Phase II compliance data now available (and a third year's data about to be released), more confident answers concerning the effectiveness of cap-and-trade systems can be made. Although not discussed in this paper, nothing suggests that allowance markets are working less efficiently in Phase II than in Phase I; and there is plenty of anecdotal evidence to suggest that the owners of Title IV affected units are avoiding whatever less than optimal abatement choices may have been made in Phase I. The more important evidence arising from Phase II compliance concerns the distribution of total abatement, the efficiency of banking, the extent to which lack of an allowance endowment impedes the entry of new generating units, and not least the total cost of compliance. This evidence provides the basis for the following tentative conclusions.

1. By far, the bulk of the abatement by Title IV affected units is being made by the Phase I units that, by definition, are the larger units with relatively high pre-Title IV emission levels, located mostly in the Midwest. About three-quarters of the reduction in SO_2 emissions due to Title IV is occurring in this region of the country and this share is larger that that region's share of electricity generation or pre-Title IV emissions. This pattern of abatement implies that the cheapest abatement lies where emissions are greatest and that market-based incentives can be expected to direct abatement to these locations.
2. The amount of banking undertaken in Phase I and the rate of draw down in Phase II has been reasonably efficient. The observed response to the sharp discontinuity in marginal cost created by the two phases of Title IV suggests that, when banking is allowed, agents take a longer view and distribute abatement efficiently over time. This behavior also implies a non-mandated acceleration in the timing of the required cumulative abatement that is environmentally beneficial.
3. There is little evidence in Phase II that failing to endow new generating capacity with allowances impedes entry. While a frequently voiced complaint, and perhaps unfair in some non-economic sense, the practical realities are that neither short-run nor long-run marginal calculations concerning production or entry are affected by the allowance endowments in Title IV. Moreover, SO_2 allowance cost

is a relatively minor consideration when compared with permitting and siting costs and new source performance requirements.

4. While detailed studies of Phase II compliance cost have not been performed, reasonable extrapolations from carefully done earlier analyses of Phase I cost continue to indicate that the fully phased in cost of Title IV is and will be significantly lower than expected, somewhere between \$1.0 billion, at the very lowest, and perhaps \$1.5 billion at the high end. Much of the explanation for the disparity with the much higher ex ante forecasts lies in differing assumptions about the rate of improvement in abatement technology and other changes in the coal sector that are largely independent of Title IV; however, a significant share of the disparity can be attributed to the flexibility provided by Title IV and electric utilities' willingness to take advantage of the cost-saving opportunities provided by emissions trading.

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May 2, 2003 11:30AM
Question and Discussion Session

Q. Hale Thurston, US EPA, Office of Research and Development:
I am not as familiar with CSI as I would like to be, so I apologize to the experts in the room. A couple of quick questions for Mr. McLean or Dr. Burtraw: Does the CSI default to or propose a specific allocation method? And then, too, is an increase in deci-views an explicit goal of the program?

A. Brian McLean, US EPA, Office of Atmospheric Programs
In response to the first question on the allocation mechanism—yes. In the Clear Skies Act there is a specific allocation mechanism for each of the three emissions (pollutants). I have to call them emissions since someone might bring up the fourth one—the three that we have are all pollutants. The mechanism that is in there is a declining grandfathered system and an increasing auction. It recognizes some of the merits and advantages of an auction system but also recognizes the difficulty of moving abruptly to that kind of system, which is very new. Just wanted to mention to those who deal with this issue, prior to this kind of a program in the U.S., where we don't rely heavily on taxes or fees, all the permits are free and everything we give away is free. When we introduce a concept of paying for this, it's a new concept and a change to the way people operate. It works very well in a market system--naturally you start talking about paying for it, but all our command-and-control structures--people don't pay for that permit--they are given that permit to emit a certain amount. We charge some fees, but they are not comparable to what it would cost to buy that permit. So that's how the mechanism works, and we phase it in—actually it takes over 50 years to phase it in, so it's a very gradual phase in. The present value of those allowances is pretty high in terms of the gift that is still given.

In regard to the second question, the deci-view issue, that's what you are also raising, is tied to visibility. That is a measure of a noticeable change in visibility, and it's a way to describe an impact of the program. There are no visibility goals, just as there are no specific air quality goals and no specific deposition goals. The Clear Skies Initiative does not set air quality standards, visibility standards, or deposition standards—what it does is it controls emissions, and in that way it will contribute to the achievement of all those standards. So the goal of the program or objective is an emission-driven program.

Experimental Economics as a Tool for Developing Market-Oriented Environmental Management Programs

Nobel Laureate, Dr. Vernon L. Smith, George Mason University

I thought I would talk this morning about electricity and the environment because the electric power industry creates huge, terrible problems for the environment--problems that I think are unnecessary and can be fixed, but it's going to be very, very hard. I was going to talk a little about airport congestion because that's similar. Also, emission trading--the California experience. These are all things that we've had input in from the laboratory. Of course in the case of emission trading the laboratory was very essential in doing the testing of a two-sided combinatorial auction to match up the complex packages of SOx and NOx, and two regions, across time monthly, between buyers and sellers. And then I was going to talk a little bit about water.

I think I will, at the end, still have a chance to say something about electricity because I think that's really a kind of a paradigm problem of huge environmental impact, and nothing's really being done about it. [correcting himself:] Something's being done at the emission level, but there's much more involved than that.

I want to begin by talking a little about common property resources and two kinds of solutions--or types of analysis, frameworks of thinking--that are applied to common-property-resource and public-good-type problems. The first fall under the heading of what I call constructive rational analysis (and, sometimes, solutions) based upon incentium mechanism. Good examples of those would be Scott Gordon's path-breaking paper in 1954 in the JPHE [Journal of Public Health Education] that anticipated Garrett Hardin's science work by 14 years. That paper, though, is really about property rights and the problems created in the fishery [sic]. Of course, Garrett Hardin also dealt with some of those issues.

Another example of constructive rational analysis is of course, Samuelson's original public goods paper. Out of that paper, since there was no decentralized solution to that problem, the presumption has always been that the private sector could never solve public good problems and common property resource problems--the government had to solve them. Anyone who believes that has got to believe that Al Capone was a Catholic Cardinal in Chicago in the 1920's. It's unbelievable, those early naïve views that the government would solve those problems. We now look back on that and it's not clear whether the government is a source of solutions or a source of problems having to do with externality and public goods.

The title of this conference tells us, I think, that that whole way of thinking is completely changed now. The question now is not necessarily Who?, but How? The devil is in the details, and where people are worrying about incentives and the mechanisms that give the right incentives, there's still a huge, huge country mile between that kind of thinking though and some kind of actual real-world application.

The other type of rationality I call "ecological"--ecological rationality--and there are a lot of good examples of that. It turns out that people worked on common property and public good resource problems long, long before there were any economists around to analyze the problem. Some of you are no doubt familiar with these. My colleague Bob Netting, who is in anthropology at the University of Arizona, did this great work on the Swiss alpine cheese makers. (Their solutions . . .and there isn't just one full-blown solution that burst out of air around 1200 AD, but you can identify solutions there to the commons problems that go back about 800 years.) It's more complex than just the simple statement I'm going to make, but an important part to the solution to their common property problem was the rule that the number of cows that you were allowed to graze in the commons meadows in the summer depended on the number that you carried through the winter. And theirs is a cold climate--the cows have to be indoors and there has to be heat. This is an expensive operation, so there is a limited capacity to carryover cows through the winter. Here the solution to the common property access problem was tied into a private property right. As I said, that's an over-simplification--there were a number of other aspects to the solution besides that. (The list, for example, that people like Lynn Ostrum have given you in summarizing Bob Netting's work, that's the first one. There are another three or four.)

Also, some of you may be familiar with Atchison's Maine lobstermen. About a hundred or so years ago they basically created property rights in the sea for setting lobster traps, and they enforced them. None of them were lawyers and none of them were legislators, and, in fact, they were no doubt breaking the law. If you worked as a Boston banker and decided to retire and move up to Maine and, just as a hobby, catch lobsters by putting a trap out there, you would right away find your trap floating, rather than being on the bottom, because it had been broken. And if you tried again, you could get yourself in serious trouble – these things were enforced.

Also, I think most of us know of Ronnie Cosa's work related to the theory of public goods, and the universal example that people use is the lighthouse. He asked a startling question: Let's see what people actually did with lighthouses. Well, it turns out they were private--most of them in the early years were private. How did they collect? Well, it turns out that ships have to stop in port somewhere, so the private lighthouse owner went to the port authority and collected there.

See, these are examples of emergent ecological solutions to problems where people, with at most, high school educations but with a lot of experience with the nitty gritty of the problem and an awareness of how costly it is, try out things and think of things and they come up with solutions. Of course I'm not trying to argue that every problem can be solved in this way--I'm just giving you that example.

Now, goats were first domesticated, I think, 10,500 years ago and I don't know when the first branding of domesticated cattle took place, but in the Egyptian tombs and hieroglyphics there are all kinds of references to branding. Also, in this country there was a national cattle industry before most of the west of the U.S. even had states--there were just territories. So, in a territory like Arizona there was open range--there was no law; there was no local sheriff; there might have been a federal marshal, but he had a huge territory to cover. He didn't have much time and couldn't possibly handle your cattle rustling problems. So, people formed cattle clubs, and the cattle clubs financed hired gunmen, and the hired gunmen were to go around and check and make sure that the guy's cattle that he was talking to market didn't have somebody else's brand on it. So, they had a solution to that problem. It disappeared once you had a local sheriff. Think about it. We think of the government solving public good problems by solving the free righter [?] problem. No, it's often the reverse, as this example shows. Here was a solution that existed, and then the cattlemen, who had their own association and their clubs for solving the problem, said, "Wow, we're paying taxes--let's let the sheriff do this." So they wanted a free ride on the public budget and wanted the government to do something they had a solution to before.

I want to suggest that most of these emergent ecological solutions to problems could not have been invented by an economist because we [economists] have not traditionally thought about these problems in a way that would enable us to do that. I think now the great empirical work that has been done--and of course Lynn Ostrum's book on governing the commons is a magnificent source--now that so many of us are familiar with these ingenious mechanisms out there that people come up with, we are now sensitized more to those kinds of solutions, and I hope people have them in mind when they think about coming up with incentive mechanisms.

I sometimes use the example of a shopping mall. The shopping mall is a rather remarkable institution, and I don't think an economist could have invented the shopping mall because it's got too many shared-goods problems--public goods, common areas and then private--it's just a huge can of worms from that point of view. I don't think anyone has ever tried to do any kind of formal analysis of the shopping mall, but shopping malls have been around for a long time and they seem to work pretty well. People have worked out contracting arrangements for sharing public access stuff, for sharing utility bills on the commons part of it, the parking spaces, and yet also have a portion of the system that is under a private roof, and separating those things out.

I just want to bring to your attention that there are lots of these kinds of examples out there, and I think this points out a really important function of laboratory experiments. I think of laboratory experiments… Suppose you come up with a nice model, an incentive mechanism for solving a problem you see out there. If you are really daring and not very sensitive, you might actually go out there and try to put it into practice right away without testing it at all. You're asking for trouble when you do that, I think. If you're going to start in the field, you at least need to start on a small scale. To my way of thinking, it's better to test out the basic kind of incentive properties of that system in the laboratory. What you'll find is that by the time you've done the work that it takes to design the first experiment, your thinking will already have changed. The reason why it will already have changed is because we're not very good at forcing ourselves to express and define an institution in all of its details, if we're just sitting at our desk with a pencil and paper. But, if you ask yourself, 'How would I test this thing?' then you have to write instructions for subjects--you have to know what to do. When you design an experiment, you’re creating an institution in all of its detail. I think most experimentalists will tell you that maybe at least 40-50% of what they learn from any experimental program is in that before they even start running subjects. What you're doing is forcing a discipline on your thinking. In proving a theorem, you see, it’s natural to consider both the assumptions and the results as variables, and you’re trying to get a mapping from assumptions into results – that’s how we make our living as theorists. And in theorems, the results are very much determined by finding something that’s actually tractable. But for an experimentalist that’s really just a bare beginning. When you start running experiments, you’ll often find . . . Well, the first thing you find is that it's not what you expected or not completely what you expected, and you have to ask yourself why. That gets you back to thinking about the problem a little more from the point of view of the decision maker. It can force you to think about a lot of things that you have to come to terms with. You then go back and make some modifications and then go back to the lab again. Most studies involve this cycle, sometimes many times, especially if it’s a very complex experiment. This is a form of ecological rationality. You see, you're finding out what real people can do, what real people tell you about what their problems are in trying to make decisions. Of course, it’s some process like that that created the institution that we observe today with the Swiss Alpine cheese makers or with the Maine lobstermen.

I would be the last to argue that you are done when that mechanism goes out the door. All you’ve done is shake out some of the more obvious problems. You may have fairly fine-tuned it for that particular world, but when it goes into the field it’s going to have a life of its own. Problems will come up that you didn’t address in the laboratory, and sometimes it’s useful, when those problems arise, to go back to the laboratory and see if you can understand what that problem is. With a combination of the empirical work you're now doing and a back-to-the-laboratory kind of exercise, where you have more control, you're seeking to get a better understanding and a better evolutionary or ecological outcome for that particular world that you are trying to create a new institution for. This will continue to go on because the world will change, and so then the institution no longer fits the world that it may have fit originally or even in the laboratory. So, I see this as a continuous process of monitoring and modification. When it gets into the world, things become more difficult because now you have stakeholders. You have people who don’t want to change because it’s not in their interest to allow a change. Coming to terms with that is probably one of our most difficult problems, because you're dealing now with a political process, which is inevitably much harder, I think. The economics is often fairly easy, and even the experimental part of it, compared to the politics of it.

Let me just say a little bit about electric power because that’s something we’ve done a lot of experimental work in. The experiments tell us a lot about what the problem is out there. Here’s the problem: During the typical day in any region in the world that’s being served by electrical energy, the customer load will vary from off-peak to peak by a factor of about 2 to 1--sometimes less, sometimes more. The peak use of power is much, much higher, say double, what the off-peak use of power is. The capacity of the system--the capacity of generators, the capacity of transmission lines, the capacity of substations, all the wires in the system, the transformers, everything--is determined by that peak, not the off-peak. That huge capital investment, that mind-boggling amount of capital investment, is idle a good bit of the time. (The reason why that's the way it works is because there aren't any good prices, right down to the appliance level of the end-use consumer.) Now, if you dry your clothes at 3 PM in the afternoon, you're paying for all of that capacity that you wouldn't need if people didn't dry their clothes at 3PM in the afternoon, and I'm not even mentioning just the energy. I can show you data in which the marginal cost of peak energy is 6 and 7 times the marginal cost of off-peak…and that's just the energy--there's no capital in that. Now if you think about that, I think you'll realize how incredibly poorly managed and organized is one of the largest industries in the world. There's a huge environmental impact of that--all these unsightly transmission lines--and they are trying now… FERC [Federal Energy Regulatory Commission] wants to get better incentives for investment so people will build more of them when we don't even know whether we need more of them, because we don't have any way of prioritizing the consumption of power to the end-use consumer and asking whether it's cheaper simply to have the flow of electrons interrupted to particular low-priority uses of power. This would make the consumer happier because he wouldn't pay as much overall, but still wouldn't be interrupted in times of peak usage. The way it works now is, in the American-style regulation (and it's no better in foreign-style government ownership), what has been "put in the saddle" is this myth that all demand at all times will be served, and furthermore, it will be served at a constant fair price--everyone pays the same amount--and of course it's the world's most unfair system because it's a system that levies a tax on all the off-peak users in order to subsidize all the peak users. The peak users, the guys drying their clothes at 3PM in the afternoon, are not paying their full costs. It's the off-peak guys that are subsidizing that. That's what happens when you're just looking at an average price that will give you enough average revenue to cover your average costs--it's all that "average" thinking that has created this monstrosity.

Hopefully this conference is going to get away from that, and is already getting well away from that. I puzzle how to deal with this problem. The first thing we did--that FERC did--when we moved toward deregulations of the wholesale markets was they separated the wires from energy. That's what they did with the high-voltage wires. The high-voltage wires were separated from generation because they saw those tie-in sales as a problem, but the low-voltage wires are just the same. So, your friendly local distributor has for 95 years been tying in the sale of energy to you with the rental of the wires, but there's no requirement that they have to be tied together. Where do you buy your gasoline when you rent a car? All you do is rent the vehicle--the guy doesn't care whether you drive it at all--he's just got a per-day charge, and you get your energy somewhere else. The wires business does not have to be combined with the energy business. To create free entry in just the energy part of it (and that is 55% or more of your bill) and to get some ecological experimentations going to find out what blend of consumer preference and interruption technology is going to yield a return on your investment. [sic] In order to allow the experiment--the long-standing experiment in free entry and exit (that's what all that's about--trial and error--the right to lose money and the right to keep it when you make some)--in order to get that to work, if you want to come in and get a customer from your local distributor and sell him energy, you can't do it without getting access to the wires. Because you're going to give him a rate--the cheapest technology for giving him a rate that's going to depend upon use is just to go into his house and put a switch on a space heater, or a hot water heater if it's electric, or something like that. And you don't have to come into the house to turn it on or off--you would just have to send a signal to the switch, so there would be a contract to do that. Now, it really doesn't cost much to do that, but you have to get in the house. There's somebody else who's in the wires business who already owns those wires, and he's not well motivated to let you get in the house. Even if you pass a law and say that he can't block entry, he can still say, 'Well I can't let you in on Monday because we're doing some work and you'll have to wait two weeks.' If this sort of thing happens very much these guys [power providers] are out of business because there goes their margin.

In New Zealand there's actually a complaint procedure for alternative energy suppliers. If they're getting harassed by the local wires guy, they can file a complaint. Well, of course that's costly, and it will require an investigation, and they're trying to keep that from happening. All you have to do is remember… how many of you remember when no one was allowed in your house to work on the telephone wires unless that person came in Ma Bell's truck or AT&T's truck? How many remember that? And you remember that you couldn't buy a telephone to put in your house unless it was made by Ma Bell. Even some distinguished economists worried about network externalities--so that was a nice intellectual cover for all that baloney.

We're talking about a red, yellow, and green wire and any licensed technician can come in and do it. I know a lot of people that just did it themselves--they knew enough about that sort of thing--they always did their own. But the thing is, until we got a settlement that kept Ma Bell out of your house, we didn't have any means of allowing some competition for the provision of telephones and wires service.

I will leave those thoughts with you. This is a big environmental monstrosity, this electric power industry. We're being asked to provide more generation--that's one solution people are talking about. Also there is a lot of worry that we don't have enough transmission capacity, and yet there is no mechanism now whereby somebody can locate interruptability on the demand side below the substation and also generation below the substation. You see, in that industry there's a no-man's-land between the substation and the end-use consumer. And when you find that you can't satisfy all demand (in other words, the myth that you can has never been true--you can't because there are storms and that sort of thing that make it impossible), how do we shed load? We shed load by taking out substations, and when you take out a substation you take out all the customers below that. If you're riding on an elevator…you're out. If you're doing high-end computation…you're out, and all the other low-value uses are out. We found that out in California, except it wasn't just an unusual event--it came in and stayed. That can happen here. It can happen anywhere in the world. It even happened in Texas. All of a sudden the wholesale market skyrocketed in Texas and started to spike, and I know of at least one bankruptcy of a company in the energy business who was vulnerable to that--had contracts to sell it for a whole lot less money than they had to pay. You lose money real fast when you're paying $10 a kilowatt for something and reselling it for 12 cents. That's what happened in California, and it just sucks money out of your pocket so fast you can’t even believe it--$15 billion was sucked out of the local distributors' pockets, and they just sat there and let it fly in the breeze. No preparation was made for that. Here’s a case in which a friendly environment and greater security, including protection from terrorist attacks, is a free lunch if you just get the prices right. See, which would you rather have if terrorists take out half of the generation capacity going into Chicago: Would you rather see half the substations shut down or just the lowest-half priority uses of power in Chicago? That’s sort of the alternative

Thank you.

Market Mechanisms and Incentives: Applications to Environmental Policy

PROCEEDINGS
SESSION FIVE

EXPERIMENTAL METHODS

A WORKSHOP SPONSORED BY THE US ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS AND NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH

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Session V Proceedings

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A Laboratory Comparison of Uniform and Discriminative Price Auctions for Reducing Non-point Source Pollution[*]

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May 2003

Abstract

Land use changes to reduce non-point source pollution, such as nutrient runoff to waterways from agricultural production, incur opportunity costs that are privately known to landholders. Auctions may permit the regulator to identify those management changes that have greater environmental benefit and lower opportunity cost. This paper reports a testbed laboratory experiment in which landowner/sellers compete in sealed-offer auctions to obtain part of a fixed budget allocated by the regulator to subsidize pollution abatement. One treatment employs uniform price auction rules in which the price is set at the lowest price per unit of environmental benefits submitted by a seller who had all of her offers rejected, so sellers have an incentive to offer their projects at cost. Another treatment employs discriminative price rules that are not incentive compatible, because successful sellers receive their offer price. Our results indicate that subjects recognize the cost-revelation incentives of the uniform price auction as a majority of offers are within 3 percent of cost. By contrast, a majority of offers in the discriminative price auction are at least 10 percent greater than cost. But the regulator spends more per unit of environmental benefit in the uniform price auction, and the discriminative price auction has superior overall market performance.

JEL Classification: C91, Q15, Q28
Key Words: Uniform Price Auctions, Discriminative Price Auctions, Land Use Change, Laboratory Experiments, Environmental Policy.

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1. Introduction

Auctions have become common to allocate scarce resources. Recent applications of economic theory and experimental economics to auction design have substantially improved the performance of auctions and have also helped to expand their applications to a broad range of problems. One area where auctions have attracted attention is in allocating resources to protect the environment. Many environmental problems stem from agricultural land management practices. These include rising salt and nutrient levels in rivers and bays, wetlands degradation, destruction of remnant vegetation and dryland salinity. Non-point sources such as farms generate a substantial fraction of certain types of pollution, and it is difficult or prohibitively expensive to identify the amount and the source of many non-point emissions. Landowners have more information than the regulators about their production plans and their costs of reducing pollution. An incentive mechanism like an auction is well suited to address this information asymmetry and encourage different landowners to reveal their private opportunity cost of land management changes. This would help the regulator to identify the land use options with greater environmental benefit but lower opportunity cost.

The theoretical advantages of auctions to mitigate environmental problems are well understood (e.g., Latacz-Lohmann and Hamsvoort, 1997). However, using auctions to solve environmental problems in practice requires more empirical research. In this paper we use experimental methods to examine two kinds of auction designs for "environmental procurement:" uniform price auctions and discriminative price auctions. Landowners offer projects that generate environmental improvement in these auctions. More specifically, sellers offer projects with different costs and different levels of environmental benefits to the regulator, who ranks the offers on the basis of their offer price and the potential environmental improvement. The regulator has a fixed monetary budget and uses it to buy a maximum of one project from each seller, which corresponds to a specific land use change. In the uniform price auction, all participants submit sealed offers and successful sellers receive a uniform price (per unit of environmental benefit) equal to the lowest rejected offer. In the discriminative price auction, each successful seller receives the actual price offered, rather than a single price common to all sellers. In the discriminative price design the sellers face uncertainty about acceptance, but not about price, since the price obtained from the regulator equals the offer if the offer is accepted. When contemplating raising her offer, a seller trades off the decreased probability of acceptance against a higher trading surplus conditional on acceptance. She has an incentive to misrepresent her costs and submit offers higher than her true reservation values, because otherwise she would earn no trading surplus.

By contrast, in the uniform price auction all the successful sellers receive a market-clearing price that exceeds their offer and is set by a seller who does not trade. In these auctions each seller has the incentive to reveal her true costs, since submitting an offer greater than the cost of a unit lowers the probability of selling that unit but does not raise the price at which the item might be sold. We find that offers are substantially closer to costs in the uniform price auction compared to the discriminative price auction. Nevertheless, for the experimental parameters we employ, the overall performance of the discriminative price auction is superior.

Formal analysis of these types of sealed bid auctions dates back to Vickrey (1961), who compared the incentives resulting from different auction procedures. He obtained an important revenue equivalence theorem, which states that under the assumptions of bidder risk neutrality, independent private valuations, symmetry among buyers, single unit demand, payments a function of bids only and zero transaction costs incurred in bid creation and implementation, different auction formats yield the same expected revenue to the auctioneer. Much of the theoretical literature following Vickrey examines the robustness of this result to the introduction of alternative assumptions about buyers and sellers.[1] Empirical research comparing uniform and discriminative price auctions has used both field data and data from laboratory experiments. Kagel (1995) provides a survey of the early auction research. Smith (1982) reports the results of a number of experiments for multi-unit auctions in which the bidders submit single unit bids. The results neither support nor refute the revenue equivalence theorem. Cox et al. (1985) find that subjects failed to follow their dominant strategy of bidding equal to values in multiple unit, uniform price, sealed bid auctions. Cox et al. (1982) and Kagel et al. (1987) provide laboratory evidence that subjects respond strategically to the different incentives that alternative auction formats generate. Tenorio (1993) uses data from the Zambian foreign exchange auction to analyze the effects of a change in auction format from uniform price to discriminative price and finds that after controlling for other factors, the uniform price format yields higher average revenue than the discriminative price format. Umlauf (1993) reports similar results for auctions undertaken by the Mexican treasury.

Theoretical research on auctions cannot be directly applied to the auctions examined in this paper, however, because environmental goods and services violate many of the assumptions for the revenue equivalence theorem. For example, the auctions discussed in this paper assume that sellers offer multiple projects for sale, but because of the interaction of the environmental

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[1] Holt (1980) shows that for risk averse buyers, the discriminative auction results in higher expected revenue. Maskin and Riley (2000) relax the assumption of symmetry and assume that the buyers' reservation values are not identically distributed. In this case the revenue equivalence theorem does not hold and the ranking of different auctions would depend on how the distributions vary across buyers. Some researchers have argued that the uniform price auction has a lower winner's curse in common value environments and results in greater revenue to the seller than would a discriminative auction (see Milgrom, 1989; Bikhchandani and Huang, 1993). However this work was based on a single-unit auction theory and Back and Zender (1993) show that this result is critically dependent on the assumption that the good was indivisible.

benefits across projects the regulator would choose at most one project from each seller.[2] In this setting, sellers may not make optimal offers independently on each project. Instead they could infer that certain projects have a higher potential probability of winning and therefore they might focus their efforts on obtaining profits on these projects. Since they know that the regulator will purchase at most one project from each seller, they could make less aggressive offers on their other projects so as to avoid competing with themselves across projects. Moreover, the fixed budget constraint for the regulator implies that the number of projects accepted is endogenous. Hence our environment is not consistent with any particular existing theoretical model, and it is unlikely that any new tractable theory could capture these complications that are present in most relevant field applications.

Nevertheless, we can implement these realistic complications in our laboratory testbed and compare the behavior and performance of these two auction institutions. Our results show that laboratory subjects understand the cost revelation incentives of the uniform price auctions, with most submitted offers near the actual costs. By contrast, in the discriminative price auction almost all offers are greater than cost. For the parameters we employ, however, the discriminative price auctions result in more efficient environmental protection than the uniform price auctions. All three performance indicators we employ show that the discriminative price design leads to significantly greater overall performance, even though the discriminative auction rules are not incentive compatible.

The rest of the paper is organized as follows. Section 2 describes the experimental design and Section 3 presents the results. Section 4 provides a brief discussion of the findings.

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[2] For example, the installation of grassed swale drains with sediment traps to reduce nutrient loads would reduce the environmental benefit of decreased fertilizer applications. The benefits of these two alternative mitigation strategies are therefore interrelated, but the benefits would be evaluated separately in the auction for simplicity. To avoid the complication of project interactions we limit each seller to supply at most one project.

2. Experimental Design

2.1 Environment and Procedures

Experimental subjects are undergraduate students from Purdue University and the University of Melbourne. All participated in only one session reported here and had no previous experience in sealed offer auctions. We report 20 sessions, 10 conducted at Melbourne (5 in each auction format) and 10 conducted at Purdue (5 in each auction format). All sessions have 36 trading periods. In each session eight seller subjects offer items in a computerized sealed offer auction. Each auction period sellers can offer to sell three items that correspond to different land use changes and have different environmental benefits. Sellers submit offers using an electronic form on a web browser. After all offers are submitted, the server sorts the offers and ranks them on the basis of the offer price and the quality of the items (quality is the environmental benefit) and calculates the allocation for the period. The auctioneer buys the lowest-price projects per unit of quality, subject to the constraint that at most one item is bought from each seller and total auction expenditures are no greater than the auction budget (25,000 experimental dollars per period). The two auction institutions differ only in how they determine trading prices; see Table 2 below for a specific example. Once the allocation is made the results are conveyed to the subjects electronically.

As is usual in experimental economics, we use neutral terminology in the instructions to refer to the different items that sellers could offer. The appendix contains the experiment instructions. Subjects are asked to record the profits made in each of the 36 periods in their record sheets and they are paid privately in cash after the experiment. The conversion rate used for the Purdue sessions was 1000 experimental dollars = 1 U.S. dollar and the conversion rate used in Melbourne was 600 experimental dollars = 1 Australian dollar. Sessions typically lasted 60 to 90 minutes, including the instruction time. Average subject earnings were about US$24 each in the Purdue sessions and were about A$34 each in the Melbourne sessions.

As already noted, the revenue equivalence theorem does not apply in this environment, so it is possible that the relative efficiency of the two auction institutions under study might be sensitive to the specific parameters chosen for the laboratory testbed. This potential parameter sensitivity is not uncommon in laboratory research, but it is more relevant here because of the lack of clear theoretical predictions for the discriminative price auction and because we wish to strengthen the external validity of our results for potential field applications. We therefore chose parameters that correspond to costs and environmental benefits estimated specifically for nutrient runoff. In particular, we employ cost and quality parameters representing the estimated opportunities for environmental improvement through land use change in the Port Phillip watershed, in southern Victoria, Australia (also see Cason, Gangadharan and Duke, 2003). All subjects have their costs and quality drawn from broadacre (field cropping) and grazing land uses, which are the activities that represent the largest land use in the watershed (57 percent of the land) and contributes to 53 percent of annual nitrogen pollution.

Subjects make offers based on different costs and qualities to represent the heterogeneity across different activities on the same land and between the same activities on different plots of land. We introduce heterogeneity by drawing costs and environmental quality for each land use change independently for each seller, each period, from the uniform distributions based on the ranges shown in Table 1.[3] We use the same sequence of drawn values in all 20 sessions to minimize across session variation and to improve the power of our comparison across auction

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[3] The benefit ranges shown in Table 1 represent the best available estimates given the soil type and topography of the Port Phillip watershed. The cost ranges were developed through consultation with private landholders. For additional details, see Cason, Gangadharan and Duke (2003).

institution treatments. Sellers know the costs of their land use change projects, but they do not know the associated quality (environmental benefit). We do not reveal the environmental benefits to sellers because a primary conclusion of Cason, Gangadharan and Duke (2003) was that this information led sellers to misrepresent their costs more for high-benefit projects, and this reduced total abatement and other performance characteristics of the auction. In order to enhance the external validity of the experiment, we also did not provide sellers with any information about other sellers' costs and quality or the distributions that are used to generate the costs and qualities. They are told simply that the costs and quality levels would be different across sellers and could change from period to period. They also do not know the regulator's budget, which is fixed at $25,000 experimental dollars in all periods, but they are informed that the experimenter purchases the lowest priced items per unit of quality, spending the fixed budget in each period. At the end of each auction period sellers only learned which item (if any) they sold and the price they received.

2.2 Treatments and Predictions

Our goal in this experiment is to compare the performance characteristics of uniform price and discriminative price auctions. In the uniform price treatment if sellers sell an item they receive a price that is greater than or equal to the price that they offer to sell at. The uniform price in the market is determined by the lowest price per unit of quality submitted by a seller who had all of his or her offers rejected. In the discriminative price treatment sellers receive their exact offer price when they sell an item. Both auctions employ the *greedy algorithm* that finds the best local solution by accepting the items that have the lowest price per unit of quality, subject to the other constraints that (1) no more than one item is purchased from each seller and that (2) total expenditures do not exceed the overall auction budget.[4]

Table 2 presents an example from period 31 in two sessions to illustrate the rules. In both auction formats the algorithm first calculates ratio of the offer price to the environmental benefit for each project, and then prioritizes projects according to this ratio from lowest to highest. The top panel of Table 2 shows this ranking and allocation for a discriminative price session. The first and second projects in this ranking are sold, but the third is not because the algorithm already bought a project from seller 5. The auction only purchases five projects because the cumulative cost is $24,505 and no additional projects can be purchased with the $495 remaining in the auction budget. The bottom panel of Table 2 shows results in a uniform price session. Again, only five projects are sold. All are sold at the offer/benefit ratio of a seller (7) who submitted the lowest ratio (49.33) but had all of her offers rejected. For example, instead of his red-unit offer of 2999, seller 1 received 49.33 times his environmental benefit (124.46) = $6,140 for this project. Total auction expenditures are $23,073 this period.

The standard revenue equivalence results do not apply in these auctions since sellers have multiple items to offer, they do not observe the quantity of environmental benefits for their items, the number of items purchased is endogenous since it is based on an overall auction budget, not to mention other practical reasons equivalence results often do not apply such as risk aversion and bounded rationality. Our focus is therefore *not* on comparing the outcomes of these auctions to theoretical predictions, but rather it is on comparing the relative empirical performance of the two auction institutions for this environmental management application. Because of the multiple items per seller and the differing, unknown environmental benefits for each project, this environment is too complex to provide clear theoretical predictions.

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[4] We could have implemented a more complex algorithm that is more likely to find the globally optimal solution, but at the cost of not being able to explain the auction purchase rule to sellers. We chose this simple algorithm since our goal is to study auction rules that could be implemented in the field with a reasonable level of transparency.

Nevertheless, it is useful to have some theoretical benchmarks based on simplifying assumptions to motivate the institutional comparison.

The most reasonable benchmark for the uniform price auction is full revelation: offer=cost. In this type of "first-rejected-offer" uniform price auction sellers usually have a dominant strategy to offer their projects at cost. This is because submitting an offer below cost would only increase the probability of acceptance if the price received falls below cost, and submitting an offer above cost is very unlikely to raise the price.[5] For the actual realized costs and environmental benefits draws employed in the experiment, these uniform price auction rules extract 72.4 percent of the maximum possible abatement under full cost revelation.

Sellers costs are distributed independently in this laboratory environment, so independent private value auction theory for multiple-unit discriminative price auctions provides a benchmark approximation in the discriminative price auction treatment. Since sellers receive the price they offer, they clearly have an incentive to offer prices above costs. How much above costs they should offer depends on the number of sellers in the auction and the number of units accepted by the auctioneer. Our experiments employed N=8 sellers, and the sellers could infer over time from the rate that they successfully sold that typically the auctioneer purchased Q=5 units each period.[6] If, as a first approximation, sellers behave *as if* they know Q and that it is stable, and they prepare offers on each of their three units independently, we can estimate how much they will offer above cost based on standard results from Vickrey auctions (see, e.g., Cox, Smith and

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[5] An offer above cost could occasionally raise price in this environment because sellers' different projects have different environmental benefits and the auction has a monetary budget constraint. It is therefore possible to construct examples in which a seller could raise the offer price on one of her items above cost and have a different (higher environmental benefit) item accepted, which would in turn exclude different rivals' items and raise the uniform cutoff price. Sellers do not observe their projects' environmental benefits, nor do they observe the offers or costs of their rivals; therefore, the incomplete information setting of our experiment—chosen to reflect reasonable incomplete information in any field implementation—makes the identification of this misrepresentation incentive rather implausible.

[6] Exactly Q=5 units were sold in 64 percent of the periods, and the Q sold was 4, 5 or 6 in 99 percent of the periods.

Walker, (1984), for the relevant formula). As shown below in Figure 1, the equilibrium offer function under these simplifying assumptions is nonlinear and substantially exceeds cost for low cost draws. For our parameters the low-range cost draws have equilibrium offers that are two or three times higher than cost based on this approximation. For the actual realized cost and environmental benefits draws employed in the experiment, these discriminative price auction rules extract only 54.8 percent of the maximum possible abatement if this offer function approximation is accurate. This is substantially below the benchmark prediction for the uniform price auction (72.4 percent), so we expect that uniform price auction rules will result in more efficient pollution abatement than discriminative price rules.

3. Results

Figures 1 and 2 present an overview of the offer data.[7] Figure 1 indicates that nearly all offers (99%) exceed cost as expected in the discriminative price auction. Most offers (73%) lie in a band between cost and cost+$1000, and 45% are within $500 of cost. Figure 2 shows that offers are dramatically different in the uniform price auction. The scatterplot of offers is more centered on the offer=cost reference line (indeed, the offer dots practically obscure this line). While there is some variation in offers relative to costs and nearly two-thirds (64%) of the offers are above cost, 80% of the offers are within $500 of cost. In the first subsection we summarize the impact of the auction rules and these offers on overall market performance, before we return to analyze the offer behavior in more detail in Subsection 3.2.

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[7] This figure, and all the analysis that follows in this section, excludes a small number of offers that were obvious typographical errors. These occurred when sellers accidentally left a digit off of their offer, such as making an offer of 1,030 with a cost of 9,250 in the discriminative price treatment. This seller clearly intended a different offer (such as 10,300) since the offer of 1,030 virtually guarantees her a loss of 8,220, and this occurred in period 35 when this seller had plenty of experience. We excluded a total of 25 such typographical errors, out of 17,256 offers submitted (0.14%). We also lost all 24 offers from one period in one uniform price session due to a data recording error.

3.1 Overall Market Performance

Following Cason et al. (2003), we compare the auction formats using three market performance measures. These measures differ from the standard allocative efficiency measures typically applied in laboratory auction research. For the auction to be allocatively efficient, it must select the least costly projects. But in this policy application, to improve efficiency the auction also needs to select projects with high environmental benefits (quality). The first market performance measure, called P-MAR (for the *Percentage of Maximum Abatement Realized*), is the amount of pollution abatement realized by the auction mechanism, as a percentage of the highest amount of abatement that could be achieved with the government's auction budget. This maximum is based on the realized cost and benefit draws each period. This maximum abatement target could be achieved, for example, if the government knew both the cost and quality of each project and could implement its selected projects at their cost.[8]

Figure 3 shows that average P-MAR is greater in the discriminative price auction than in the uniform price auction in all 36 periods. The left side of Table 3 presents P-MAR averaged across periods, separately for each session. The lowest efficiency across the 10 discriminative price sessions (80.8%) is greater than the highest efficiency across the 10 uniform price sessions (74.2%), so a nonparametric Wilcoxon test based on one (statistically independent) observation per session strongly rejects the hypothesis of equal efficiencies (*p*-value=0.0014).

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[8] Sometimes this maximum abatement would occur in the discriminative price auction if all sellers offer their projects in the auction at cost. Cost-revealing seller behavior does not always result in maximum abatement, however. The auction ranks the offers on the basis of their offer/quality ratio, and selects those with the lowest ratios. This greedy algorithm does not always result in the maximum abatement achievable for a fixed budget, due to the discrete set of projects acceptable in any auction period. Some higher abatement projects could be excluded from the auction allocation due to a cost that exceeds the fixed budget, while higher offer/quality ranking projects are accepted because of their lower overall cost. Consequently, some rearrangement of the selected projects can sometimes modestly increase the total abatement realized. To determine the selected projects that maximize pollution abatement, we calculated the total abatement for the 4^8=65,536 possible project combinations each period, and determined the greatest abatement among all the affordable project combinations. If all sellers offered their projects at cost, then the discriminative price auction selects the combination of projects that maximize abatement in 12 of the 36 periods. In 28 of the 36 periods, full cost revelation achieves at least 95 percent of the maximum possible abatement.

The regression shown in the first column of Table 4 presents additional parametric evidence that controls for other factors such as experience (time period) and subject pool. These panel regressions are based on a random effects error structure, with the session representing the random effect, in order to account for the correlation of market outcomes within a session. We include a dummy variable for the experiment site to account for any cultural or demographic differences across subjects. We also include ln(period) to allow the model to capture differences in performance across periods. The negative and highly significant estimate on the uniform price treatment dummy variable indicates that P-MAR efficiency is about 15 percentage points lower in the uniform price auction than in the discriminative price auction. Although Figure 3 does not indicate any pronounced trend over time, the positive and significant ln(period) term indicates that performance improves modestly across periods.

The second market performance measure provides an alternative summary of the auctions' ability to obtain the most abatement for the auction budget. We use P-OCER (for the *Percentage of Optimal Cost-Effectiveness Realized*) to refer to the actual quantity of abatement per dollar spent in the auction, as a percentage of the quantity of abatement per dollar spent in the "maximal abatement" solution to this problem described above. It differs from P-MAR because different amounts are spent in this auction when it selects a discrete set of projects. Presumably the unspent resources have some alternative value, so a reasonable objective is to maximize the abatement per dollar.

Figure 4 and the middle of Table 3 show that P-OCER, like P-MAR, is uniformly higher in the discriminative price auction than in the uniform price auction (Wilcoxon *p*-value=0.0014). The regression in the second column of Table 4 indicates that P-OCER efficiency is on average about 11 percentage points higher in the discriminative price auction. The positive and significant ln(period) term indicates that like P-MAR, P-OCER increases across time.

The third performance measure is seller profits. Seller profits represent money “left on the table” that the government “overspends,” relative to the actual cost of implementing the land use changes. Therefore, lower seller profits are better from the government’s perspective.

Figure 5 shows that sellers always earn higher profits on average in the uniform price auction, and in some periods their earnings are dramatically higher—even double the profits of the discriminative price auction. The right side of Table 3 shows that similar to the efficiency calculations, the highest average seller profits in the discriminative price auction (4840) is less than the lowest seller profits in the uniform price auction (5467), so the Wilcoxon test also strongly rejects the hypothesis of equal seller profits across treatments (*p*-value=0.0014). The seller profits regression model in the third column of Table 4 also mirrors those of the abatement efficiency models. Seller profits are significantly higher in the uniform price auction, by over 3,000 experimental dollars per period on average. The negative ln(period) variable indicates that these profits fall over time, however. Overall, the results in Figures 3 through 5 and Tables 3 and 4 indicate that market performance is lower in the uniform price auction.

3.2 Offer Behavior

In this section we examine the individual offers made by sellers by estimating empirical offer functions that relate offers to cost draws. First, however, recall that our design employed the same set of cost draws across all 20 sessions; i.e., we use the same set of 8 sellers × 3 items × 36 periods = 864 cost draws in each session. Thus, we can pair the same cost draws for each of the 10 pairs of sessions and compare the corresponding offers across treatments. This simple and direct comparison between the offers indicates that offers are on average 572 experimental dollars higher in the discriminative price session (standard error of the mean = 43).

Table 5 presents random effects regressions of seller offer functions separately for the two treatments. Columns 1 and 2 report the results for the discriminative price treatment and column 3 presents the uniform price treatment. The dependent variable is the seller's offer price, and the explanatory variables include costs faced by sellers for the different projects, a dummy variable for the site of the experiment, and time (the natural logarithm of the period number). We report both linear and nonlinear specifications for the discriminative price treatment, since the theoretical approximation in Figure 1 suggests a nonlinear specification for this institution.[9] Note, however, that the nonlinear term ($cost^2$) is not significantly different from zero.

The results show that there is a strong positive relationship between the project cost and the offers in both the uniform and discriminative price treatments. In fact, the coefficient on the cost variable is not significantly different from one for either auction format, indicating a similar one-to-one relationship between costs and offers in both treatments. These estimated offer functions instead differ in their intercepts. The intercept in the uniform price auction is not significantly different from zero, so combined with the cost coefficient not different from one these estimates support the conclusion that sellers on average made offers equal to cost. That is, sellers' behavior on average is consistent with the revelation incentives for this auction institution discussed at the end of Section 2.

By contrast, the intercept in the discriminative price auction is significantly greater than zero. The estimate indicates that offers were on average at least 1,000 experimental dollars above cost. Figure 1 displays a quadratic offer function fit through all the offers in this treatment, and it

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[9] In particular, the theoretical approximation shown in Figure 1 is fit accurately with the quadratic specification $\text{Offer} = 7573 - 0.429\text{Cost} + 0.000067\text{Cost}^2$.

shows that on average the relationship between offers and costs is approximately linear. More importantly, this figure illustrates that sellers of low-cost projects in this incomplete information environment did not overstate their costs when submitting offers nearly as much as predicted by our benchmark approximation. These low-cost projects are particularly important for the overall efficiency and abatement realized in the auction, since they are most likely to be accepted by the auctioneer. Sellers offered these projects at prices closer to costs than we predicted, which is why the discriminative price auction performed better than the uniform price auction.

4. Discussion

Auctions allow an environmental regulator and landholders to use information about environmental benefits and land use management costs to achieve improvements in the environment. In the auctions testbedded here the agency uses public resources to subsidize land use changes that aim to reduce pollution. It is important therefore to ensure that the agency's environmental budget is well spent and this is where the details for the actual design of the auction become critical.

The laboratory auctions reported in this paper compare uniform price allocation rules with discriminative price rules. The offer function estimates indicate that offers were not significantly different from costs in the uniform price treatment, so sellers on average made offers in this auction format that were consistent with the cost-revelation incentives of this institution. Nevertheless, this auction format does not achieve full efficiency, since the uniform price was set by the first rejected seller's offer, and all successful sellers received this price per unit of quality. Since successful sellers receive prices that exceed their offers and offers were approximately equal to costs, prices exceed costs and some inefficiency occurred.

The offer function estimates indicate that offers exceed costs by at least 1,000 experimental dollars on average in the discriminative price treatment, and that each increase in costs by one dollar is matched with an increase in the offer by one dollar. Prices are set equal to offers, so submitting offers above costs is the only way that sellers can earn positive profits in this auction institution. This auction is also not fully efficient, but the results indicate that the inefficiency and the amount sellers are "overpaid" relative to their project costs is lower in the discriminative price auction than the uniform price auction. This occurred because sellers did not "mark up" offers above cost as much as suggested by an approximation based on multi-unit discriminative auction theory.

It is important to emphasize that these conclusions are based on a particular parameterization of project costs, land uses and potential environmental benefits. We chose these parameters carefully to approximate the conditions for a specific environmental problem being considered for land use change auctions, but these conclusions may not hold in other situations. For example, intuition from auction theory suggests that the degree to which sellers submit offers above cost in the discriminative price auction should depend on the number of sellers (N) relative to the number of items purchased (Q). We do not believe that it is worthwhile to search for conditions that would reverse the efficiency ordering of uniform and discriminative price auctions. We believe such conditions exist, such as less competitive situations with higher Q relative to N. Instead, it is more useful to determine whether the ordering clearly established in this initial experiment continues to hold in other settings that approximate non-point source pollution in other regions and land uses. We plan to conduct such experiments in the near future to evaluate the behavioral robustness of these findings.

We should also emphasize that these laboratory testbed experiments represent only the first preliminary step in the long process from auction design to field implementation. Following the robustness checks with other parameters, it will be useful to conduct experiments with actual landholders, using the environmental terminology—and the relevant value judgments that environmental protection and property rights evoke in this population. The preferred auction design that emerges from these experiments can then be evaluated in small-scale field experiments with landholders, implementing actual land use changes. The preliminary results reported here suggest that uniform price auction rules may not perform better than discriminative price rules, even though they have better cost-revelation incentives.

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Appendix: Instructions for Uniform Price Auction Treatment (Discriminative Price Auction instructions are similar)

General

This is an experiment in the economics of decision making. The instructions are simple and if you follow them carefully and make good decisions you will earn money that will be paid to you privately in cash. All earnings on your computer screens are in Experimental Dollars. These Experimental Dollars will be converted to real Dollars at the end of the experiment, at a rate of ______ Experimental Dollars = 1 real Dollar. The important thing to remember is that the more experimental dollars you earn, the more real dollars that you take home at the end of the experiment.

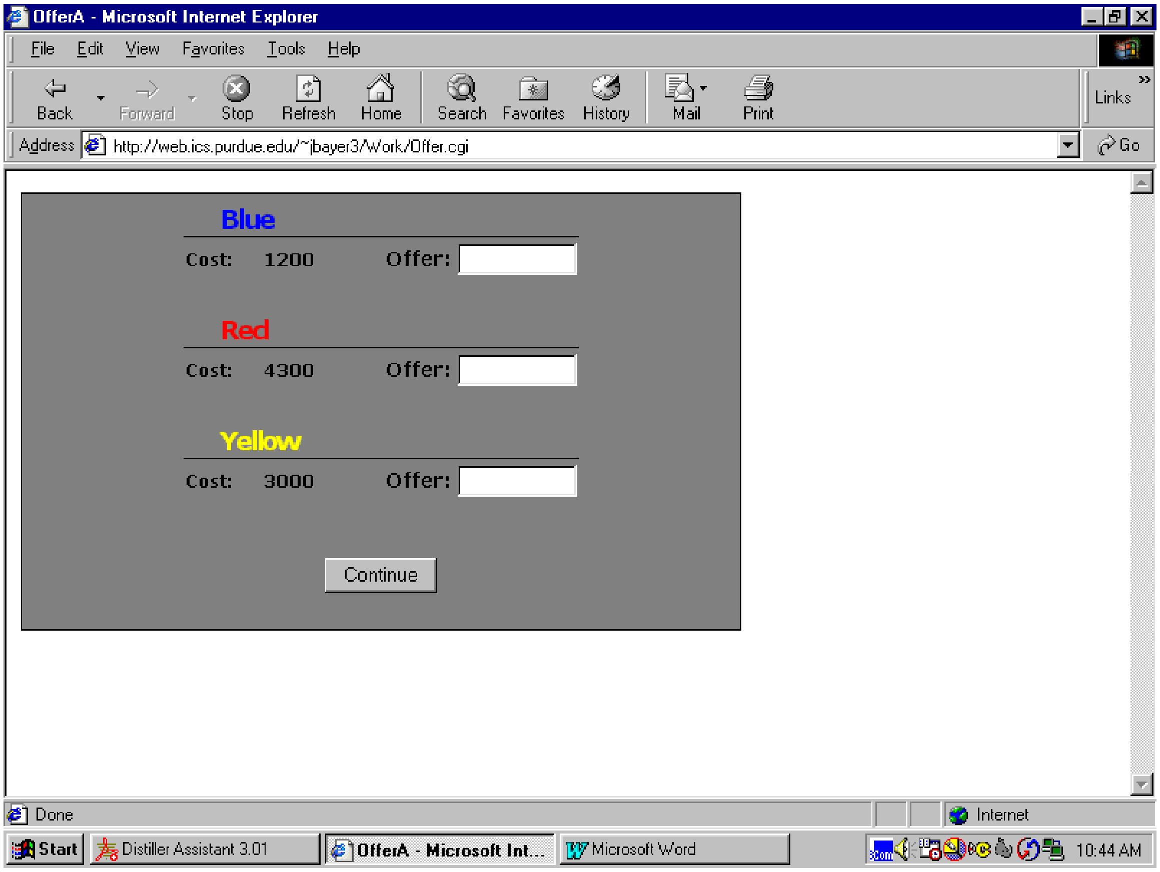
We are going to conduct a set of auctions in which you will be a seller in a sequence of periods. During each auction period you will sell up to one item. You have up to three types of items to sell, called Blue, Red and Yellow items. These items have different levels of "quality" that are valued differently by the experimenter, who is the buyer. Your quality levels may change from period to period, and they may be different from the quality levels of other participants. You can sell only one item per period, and if you sell that item then you must pay that item's cost. If you do not sell any item in a period then your earnings are zero for that period. Notice that you do not pay an item's cost unless you sell that item. Your costs may also change from period to period, and they may be different from the costs of other participants.

Your costs for each of the three types of items are displayed on your computer screen each period, as shown in the example figure on the next page. The profits from sales (which are yours to keep) are computed by taking the difference between the sale price of an item and the cost of that item. (How price is determined will be explained shortly.) That is, [your earnings = (sale price of item) – (cost of item)].

Suppose, for example, that the cost for your Blue item is 110. If you sell your Blue item at a price of 160, your earnings are:

Earnings = 160 – 110 = 50

Notice that if you sell an item for a price that is less than its cost, then you lose money on that sale.



http://web.ics.purdue.edu/~jbayer3/Work/Offer.cgi

Blue

Cost: 1200 Offer:

Red

Cost: 4300 Offer:

Yellow

Cost: 3000 Offer:

Continue

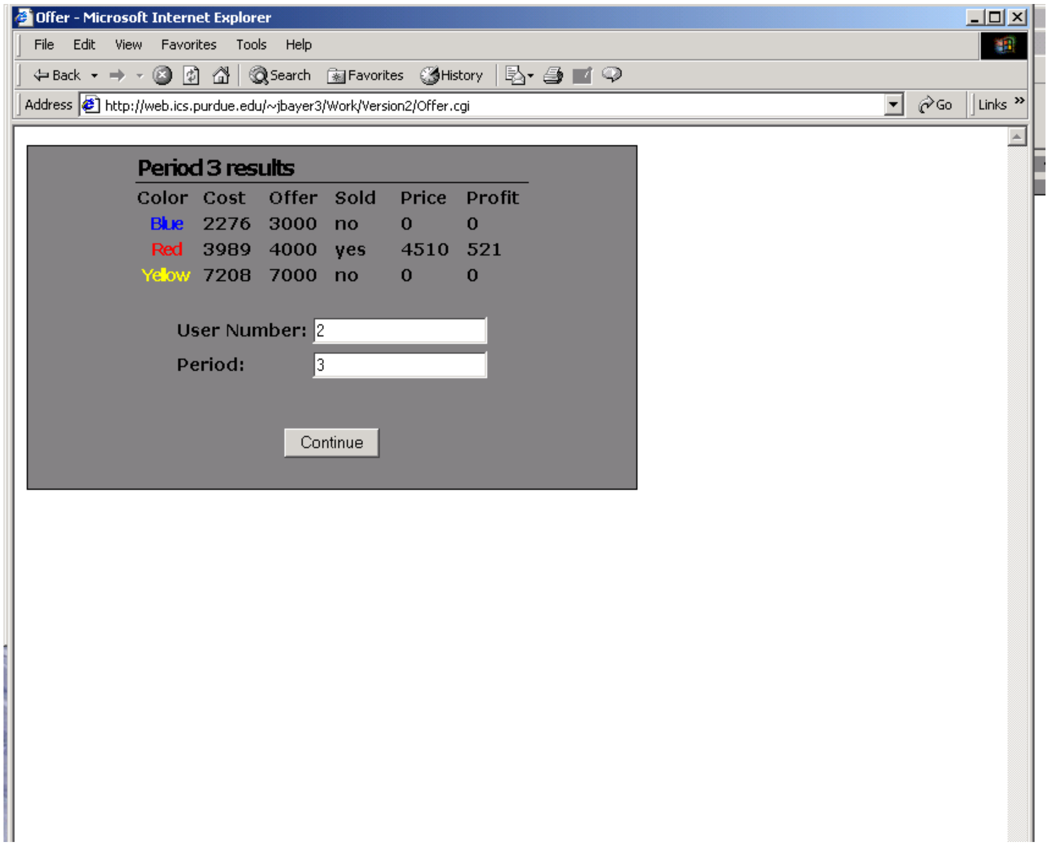
How Your Price is Determined

The price you receive if you sell an item and which (if any) item you sell is determined using a "sealed offer" auction. In each period you submit an "offer sheet" through your web browser, which lists the minimum amount that you wish to receive for each item. [Do not use a dollar sign when entering your offers on your web browser.] If you sell an item, you will receive a price that is greater than or equal to the price you indicated on your offer sheet for that item.

After everyone submits their offer sheets, the experimenter's computer then ranks the offers on the basis of the offer price and the quality of the items. The experimenter purchases the lowest priced items per unit of quality, spending all of the fixed and constant (and unknown to you) "budget" that is available in the auction. (In the case of a "tie," where two or more items are offered at the same per-quality-unit price but the experimenter cannot purchase them all, the computer randomly determines which item or items are purchased.) Sometimes you may sell an item that you offer at a higher price than some other item when that item has a higher quality. Sometimes you may not sell any item. Remember, the experimenter will buy no more than one item from each seller.

The price you receive if you sell an item is NOT determined by any of the offers you submit. Instead, everyone who sells an item in a period receives the same price per unit of quality, and this price is set by the lowest price per unit of quality submitted by a seller who had all of his or her offers REJECTED. Thus, your profit is not decreased by submitting offers lower than the lowest rejected offer that determines the price. The lower your offers the more likely you will have an offer below the lowest rejected offer and therefore make a successful sale.

In other words, by submitting lower offers you increase the likelihood that you make a sale, but lower offers do not directly reduce the price you receive since the price you receive is determined by a different (rejected) seller's offer. As long as you make offers that are no lower than your items' costs, you have no chance of losing money because if you sell an item you receive a price that is at least as high as your offer price. But if you make offers that are lower than your costs you run the risk of selling at a price less than your cost. This is because the lowest rejected offer could then also be less than your cost and result in a price for you that is less than your cost.



Period 3 results

Color	Cost	Offer	Sold	Price	Profit
Blue	2276	3000	no	0	0
Red	3989	4000	yes	4510	521
Yellow	7208	7000	no	0	0

User Number: 2

Period: 3

After each auction period, the experimenter will tell you when to click the "Continue" button to display the auction results. An example results screen is shown above. It indicates which (if any) item you sell by a "yes" in the Sold column. The results screen also displays the price you receive and the profit on the sale. Circle the color of the one item (if any) that is accepted in the column (1) of your Personal Record Sheet. Then enter the cost of this item, your offer price, the price you receive for the item, and your profit in the other columns of the record sheet. Use a calculator to keep track of your total (cumulative) Experimental Dollar earnings in the rightmost column (6) of your Record Sheet. The results page will automatically increment the period number by 1 for the next period, so after you write down your results on your Record Sheet you should simply press Continue to move to the next period.

Summary

- Seller earnings on a sold item = sale price of item – cost of item
- Sellers have three types of items, which can have different costs and quality levels valued differently by the experimenter (who is the buyer). Your costs are shown on your computer screen each period.
- Costs and quality levels may change from period to period and vary across sellers.
- Sellers submit offer prices for three types of items, but the experimenter will buy no more than one item from each seller.
- The experimenter purchases the lowest price items per unit of quality, and spends a constant budget in every auction.
- If you sell an item the price you receive is determined by the lowest price per unit of quality offered by a seller who has all of his or her offers rejected in the auction.

Are there any questions now before we begin the experiment?

Personal Record Sheet for User Number ____________

Period Number	Circle Color Sold (if any) (column 1)	Cost of Sold Item (column 2)	Offer Price for Sold Item (column 3)	Price Received for Sold Item (column 4)	Profit this Period (col. 4 – col. 2) (column 5)	Cumulative Profit (all Periods) (column 6)
1	Blue Red Yellow None					
2	Blue Red Yellow None					
3	Blue Red Yellow None					
4	Blue Red Yellow None					
5	Blue Red Yellow None					
6	Blue Red Yellow None					
7	Blue Red Yellow None					
8	Blue Red Yellow None					
9	Blue Red Yellow None					
10	Blue Red Yellow None					
11	Blue Red Yellow None					
12	Blue Red Yellow None					

Table 1: Cost and Environmental Benefit (Quality) Parameters

Note: Each of the eight sellers drew costs and benefits for three land use or management changes, one from each of the three categories indicated below, corresponding to 150 ha in land area.

Land Use or Management Change	Cost Range	Nitrogen Reduction Range
Filter/Buffer Strips	\$15-65 per ha/year	0.35-0.875 kg/ha/year
Stabilize Soil Erosion	\$15-65 per ha/year	0.28-1.05 kg/ha/year
Best Management Practices	\$17.5-65 per ha/year	0.35-0.70 kg/ha/year

Sources: Argent, R.M. and Mitchell, V.G. (1998) FILTER: *A Nutrient Management Program for the Port Phillip Catchment*. Centre for Environmental Applied Hydrology, The University of Melbourne.
Documentation of "Best Management Practices" for Nutrient Reduction and Management in Dryland and Irrigated Agriculture, a report by Rendal McGuckian Consultants for Agriculture Victoria, Department of Natural Resources and Environment (1996).

Table 2: Example Costs, Environmental Benefits and Offers for Two Sessions (period 31)

Period	Seller ID	Project "Color"	Environmental Benefit	Project Cost	Offer	Offer/Benefit Ratio	Ratio Ranking	Price-setting Ratio	Project Sold?
Discriminative Price Auction									
31	1	blue	73.19	6120	7219	98.63	19		
31	1	red	124.46	2889	3988	32.04	1		Yes
31	1	yellow	79.85	5377	6476	81.10	17		
31	2	blue	55.99	4818	4988	89.09	18		
31	2	red	153.41	9047	9247	60.28	9		
31	2	yellow	95.24	7265	7410	77.80	16		
31	3	blue	80.64	8698	9200	114.09	20		
31	3	red	68.07	3089	3900	57.29	8		
31	3	yellow	97.7	5960	6600	67.55	12		
31	4	blue	91.66	4901	6901	75.29	15		
31	4	red	111.26	5688	7600	68.31	13		
31	4	yellow	79.51	8772	11777	148.12	24		
31	5	blue	98.3	2848	3600	36.62	2		Yes
31	5	red	85.86	2969	3500	40.76	3		
31	5	yellow	84.45	4687	5200	61.57	10		
31	6	blue	74.3	3287	4200	56.53	7		Yes
31	6	red	153.19	9037	10000	65.28	11		
31	6	yellow	86.11	9380	10200	118.45	22		
31	7	blue	91.9	6117	6617	72.00	14		
31	7	red	126.03	6217	6717	53.30	6		Yes
31	7	yellow	77.04	9689	10000	129.80	23		
31	8	blue	124.42	4859	6000	48.22	4		Yes
31	8	red	53.34	4899	6200	116.24	21		
31	8	yellow	102.6	3691	5000	48.73	5		
Uniform Price Auction									
31	1	blue	73.19	6120	6255	85.46	19	49.33	
31	1	red	124.46	2889	2999	24.10	4	49.33	Yes
31	1	yellow	79.85	5377	5888	73.74	18	49.33	
31	2	blue	55.99	4818	4100	73.23	17	49.33	
31	2	red	153.41	9047	8500	55.41	12	49.33	
31	2	yellow	95.24	7265	6500	68.25	16	49.33	
31	3	blue	80.64	8698	8698	107.86	21	49.33	
31	3	red	68.07	3089	3090	45.39	8	49.33	Yes
31	3	yellow	97.7	5960	6500	66.53	14	49.33	
31	4	blue	91.66	4901	4901	53.47	11	49.33	
31	4	red	111.26	5688	5688	51.12	10	49.33	
31	4	yellow	79.51	8772	8772	110.33	23	49.33	
31	5	blue	98.3	2848	1500	15.26	2	49.33	Yes
31	5	red	85.86	2969	1600	18.63	3	49.33	
31	5	yellow	84.45	4687	2500	29.60	5	49.33	
31	6	blue	74.3	3287	3300	44.41	7	49.33	Yes
31	6	red	153.19	9037	9050	59.08	13	49.33	
31	6	yellow	86.11	9380	9400	109.16	22	49.33	
31	7	blue	91.9	6117	6117	66.56	15	49.33	
31	7	red	126.03	6217	6217	49.33	9	49.33	
31	7	yellow	77.04	9689	9689	125.77	24	49.33	
31	8	blue	124.42	4859	4200	33.76	6	49.33	
31	8	red	53.34	4899	5000	93.74	20	49.33	
31	8	yellow	102.6	3691	1	0.01	1	49.33	Yes

Table 3: Overall Performance by Session

	Average P-MAR		Average P-OCER		Average Seller Profits	
	Discriminative Price	Uniform Price	Discriminative Price	Uniform Price	Discriminative Price	Uniform Price
Ten Individual Sessions in Each Treatment	82.8%	69.4%	86.5%	81.6%	4722	6723
	85.2%	72.6%	90.3%	82.1%	3923	6682
	84.3%	72.4%	88.6%	83.1%	4383	6528
	80.8%	74.2%	86.9%	84.9%	4840	5467
	88.6%	69.6%	94.6%	77.4%	2501	7828
	90.7%	70.4%	97.0%	79.9%	2108	7242
	88.8%	71.1%	95.5%	80.8%	2387	6593
	88.8%	71.7%	94.6%	80.5%	2555	6962
	88.4%	73.4%	94.4%	82.8%	2527	6098
	88.4%	67.2%	94.4%	80.2%	2932	5952
Treatment Mean	86.7%	71.2%	92.3%	81.3%	3288	6608

Table 4: Regression Models for Market Performance Measures

Variable	**Percentage of Maximum Abatement Realized (P-MAR)**	**Percentage of Optimal Cost Effectiveness Realized (P-OCER)**	**Seller profits**
Intercept	0.83*** (0.01)	0.89*** (0.01)	4785.56*** (407.9)
Dummy =1 if Uniform price treatment	-0.15 *** (0.01)	-0.11*** (0.01)	3307.06 *** (386.91)
Dummy = 1 if site = Melbourne	0.01 (0.01)	0.02*** (0.01)	-645.16 (386.92)
Ln(period)	0.01*** (0.002)	0.01*** (0.003)	-436.96*** (86.95)
Observations	694	694	694
R-squared	0.57	0.38	0.41

Notes: Standard errors are in parentheses.
***: denotes a coefficient that is significantly different from zero at 1-percent.
All models are estimated with a random effects error structure, with the session as the random effect.

Table 5: Seller Offer Function Estimates

Variable	**Discriminative Price Treatment**		**Uniform Price Treatment**
	(1)	(2)	(3)
Intercept	1415.94*** (113.92)	1631.19*** (189.84)	307.02 (235.14)
Costs	0.98*** (0.009)	0.90*** (0.058)	1.03*** (0.02)
Costs^2		0.0000067 (0.0000047)	
Dummy = 1 if site = Melbourne	-311.99*** (111.9)	-311.94*** (114.4)	329.97 (248.34)
Ln(period)	-141.76*** (22.91)	-141.79*** (22.90)	-157.12*** (43.68)
R-squared	0.58	0.58	0.28
Number of Observations	8621	8621	8610

Notes: Standard errors are in parentheses.
***: denotes a coefficient that is significantly different from zero at 1-percent.
All models are estimated with a random effects error structure, with the subject as the random effect.

Figure 1:

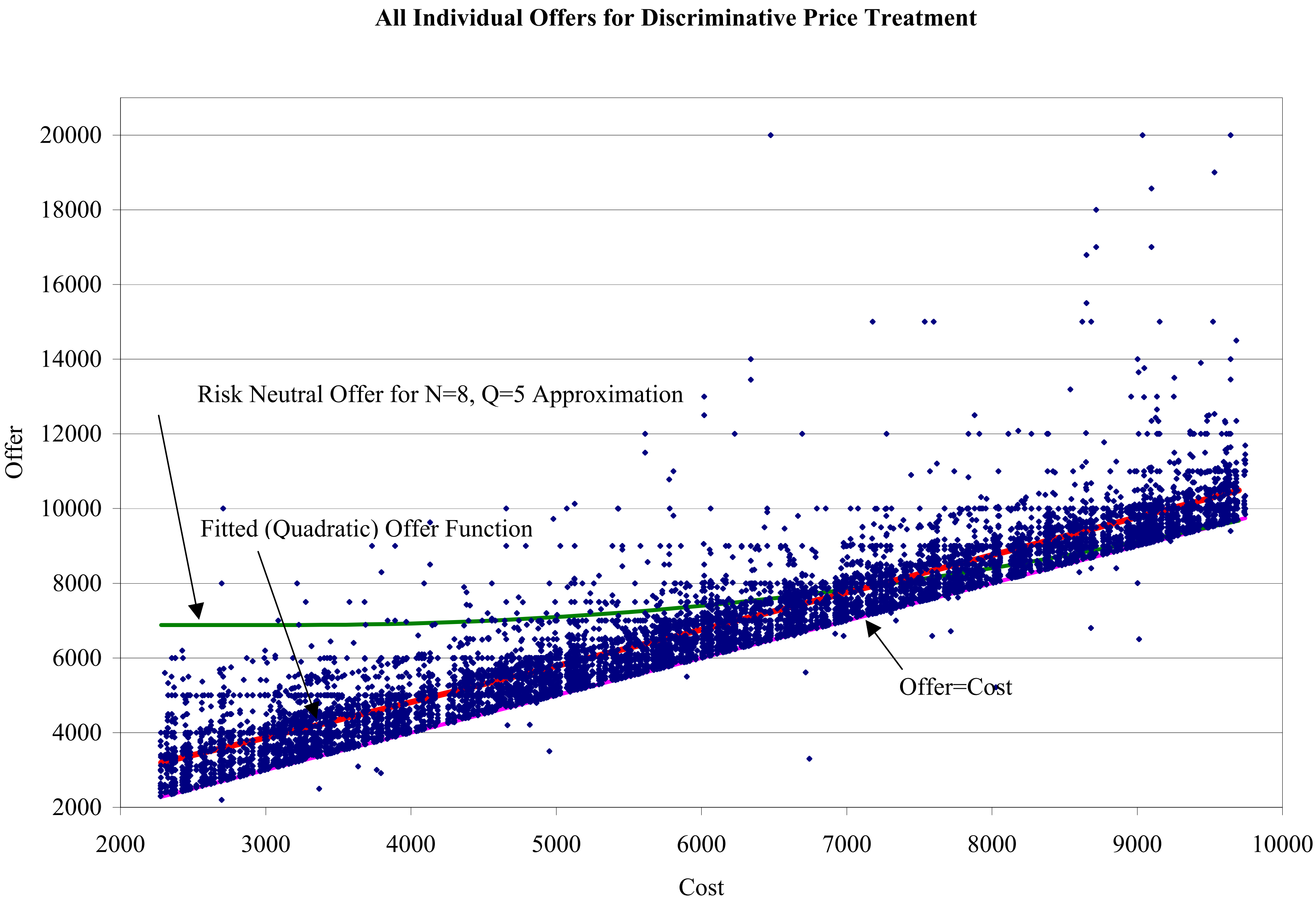

All Individual Offers for Discriminative Price Treatment
Offer
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
Cost
2000
3000
4000
5000
6000
7000
8000
9000
10000
Risk Neutral Offer for N=8, Q=5 Approximation
Fitted (Quadratic) Offer Function
Offer=Cost

Figure 2:

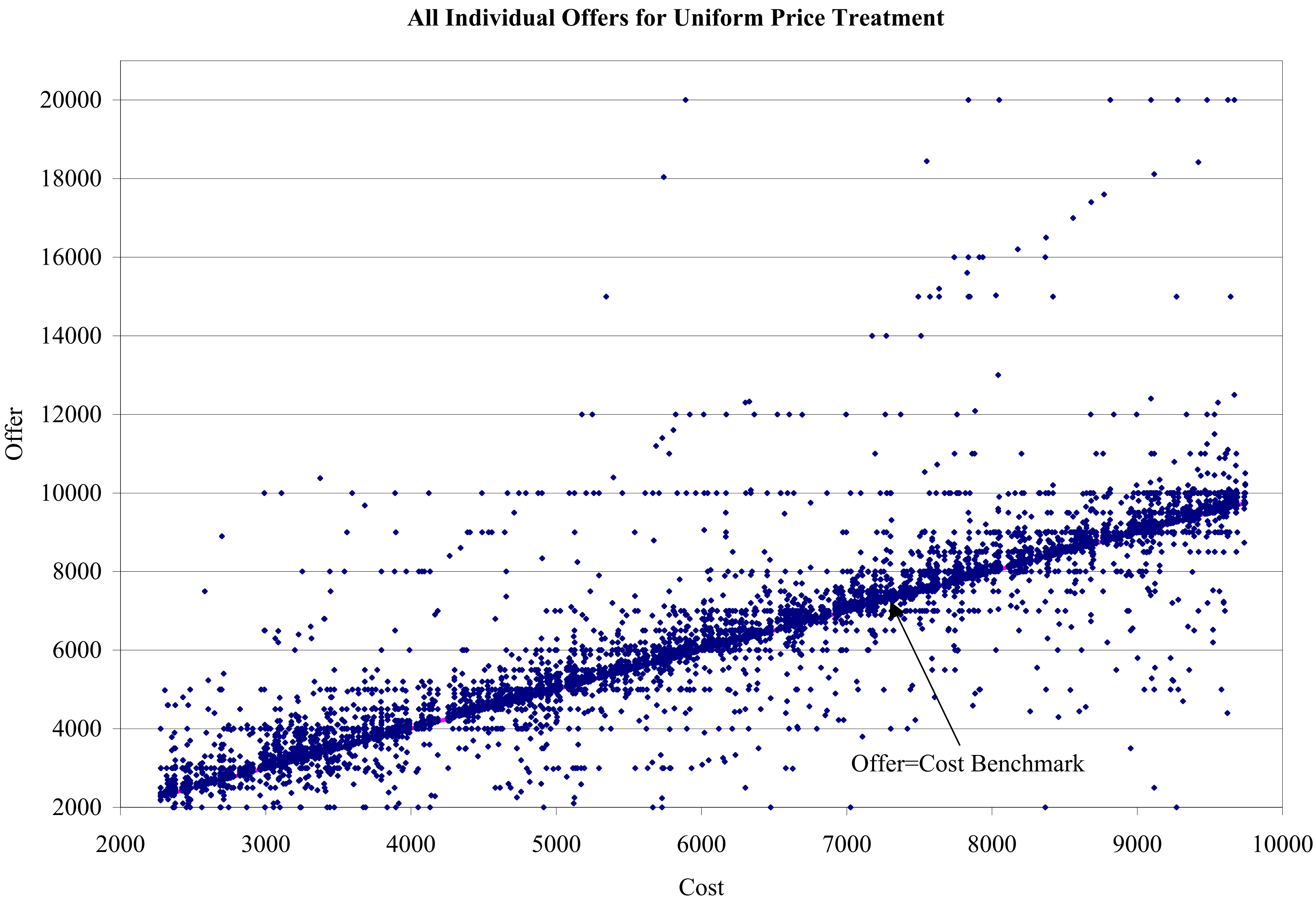

All Individual Offers for Uniform Price Treatment
Offer
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cost
Offer=Cost Benchmark

Figure 3:

Percentage of Maximum Abatement Realized, by Treatment for Each Period

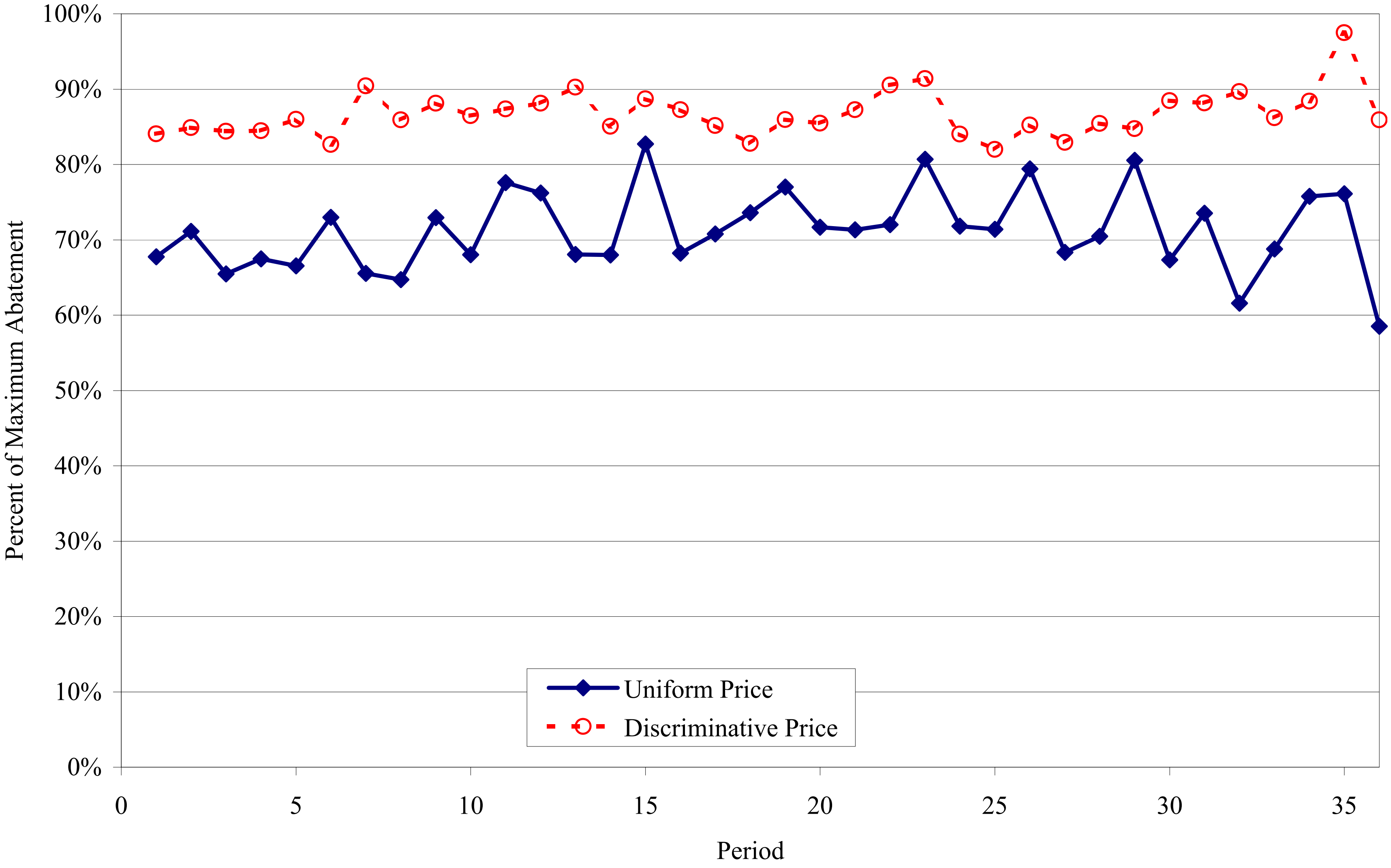


Figure 4:

Percentage of Optimal Cost-Effectiveness Realized, by Treatment for Each Period

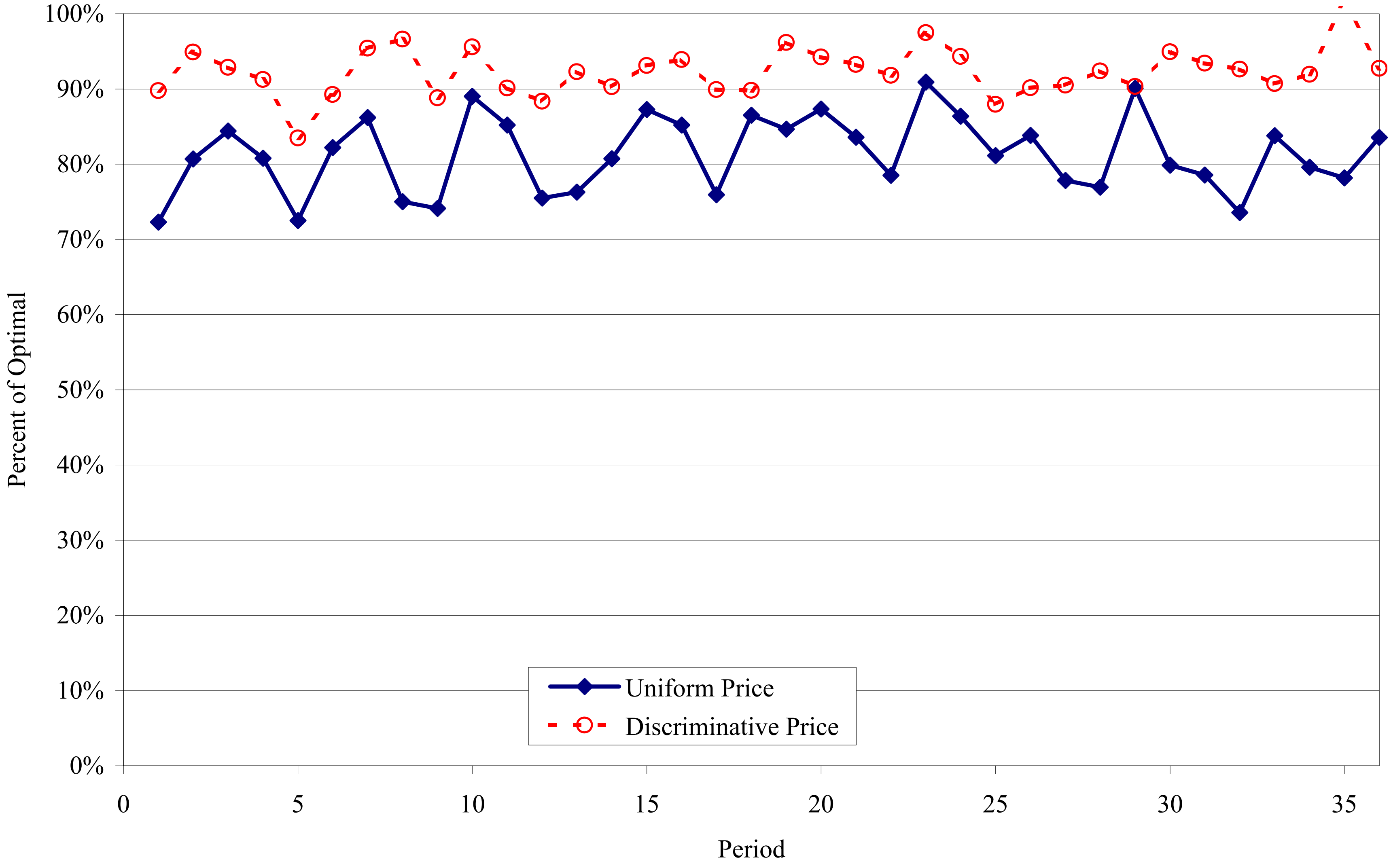
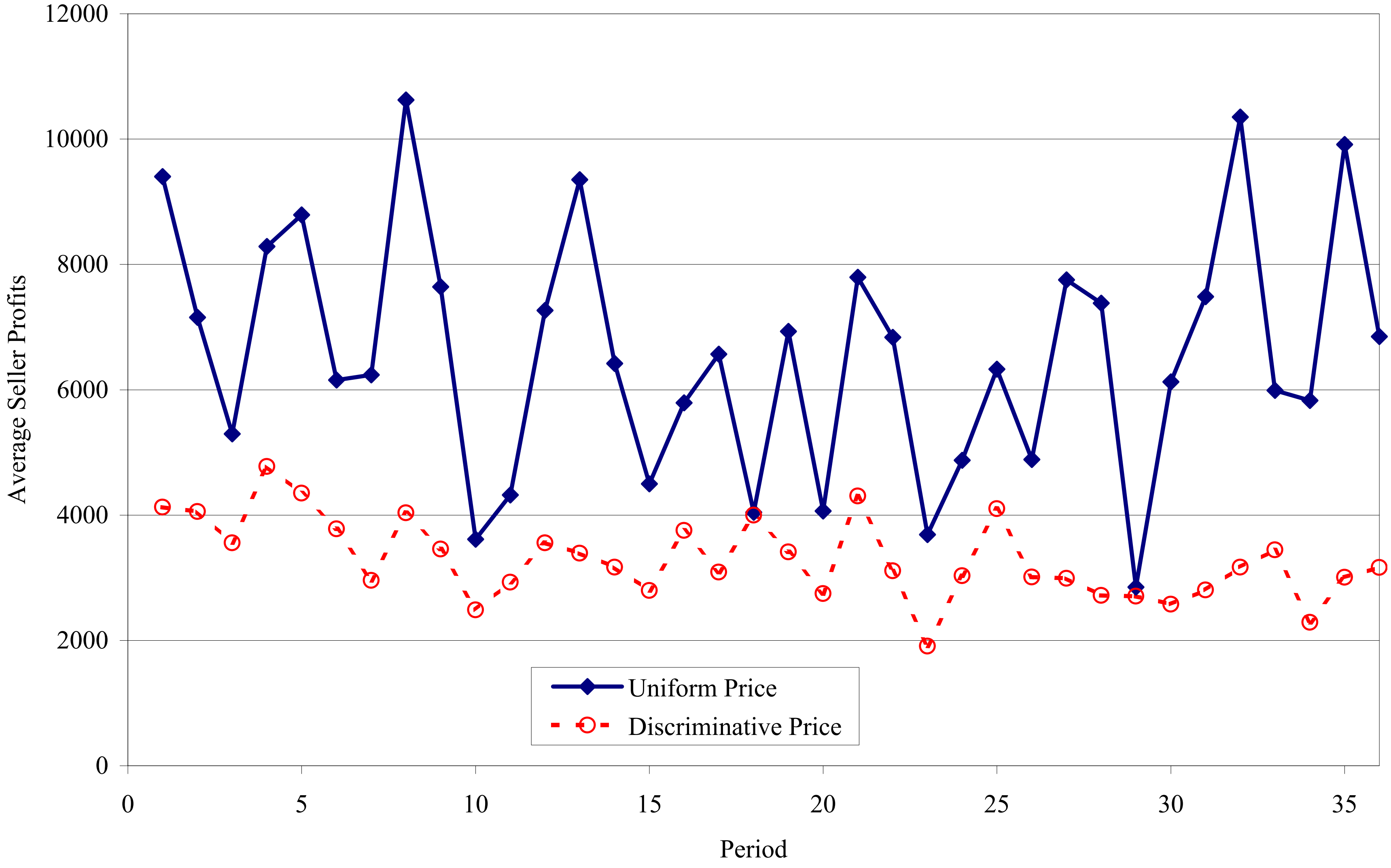


Figure 5:

Average Seller Profits, by Treatment for Each Period



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An Experimental Analysis of Compliance Behavior in Emissions Trading Programs: Some Preliminary Results

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Abstract

While there is a substantial body of economic theory about compliance and enforcement in emissions trading programs, and readily available information about how existing emissions trading programs are enforced, there are no empirical analyses of the determinants of compliance decisions in emissions trading programs. This paper contains preliminary results from laboratory experiments designed to examine compliance behavior in emissions trading programs.

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1. Introduction

Emissions trading programs are an innovative approach to controlling pollution that continues to gather support from policy makers and members of the regulated community. Conceptually, emissions trading programs are quite simple, yet have very powerful implications. By exploiting the power of a market to allocate pollution control responsibilities, well-designed trading programs promise to achieve environmental quality goals more cheaply than traditional command-and-control regulations.

Despite the perceived advantages of market-based environmental policies over traditional command-and control approaches, it is clear that the efficiency gains expected of emissions trading programs will not materialize if these programs are not enforced well. In fact, the problem of enforcing market-based pollution control programs is seen by some as one of the most important barriers to the widespread implementation of emissions trading programs [Russell and Powell (1996)]. There is now a fair-sized literature that addresses certain aspects of the problem of noncompliance in emissions trading systems, most of which is theoretical in nature. Some of this literature focuses on the consequences of noncompliance [Keeler (1991), Malik (1990, 1992, 2002), and vanEgteren and Weber (1996)], while some recent work in this area is devoted to the question about how to design enforcement strategies for emissions trading programs [Stranlund and Dhanda (1999), and Stranlund and Chavez (2000)].

While the theoretical work on compliance and enforcement in emissions trading programs progressed through the 1990's, full-scale emissions trading programs were implemented; most notably the Sulfur Dioxide Allowance Trading Program—the centerpiece of the EPA's Acid Rain Program—and the Regional Clean Air Incentives Market (RECLAIM) Program of the South Coast Air Basin of California. Thus, it is now possible to compare the theory of enforcing emissions trading programs to the actual practice of doing so. [See Stranlund, Chavez, and Field (2002) for such a comparison].

While there is a substantial body of economic theory about compliance and enforcement in emissions trading programs, and readily available information about how existing emissions trading programs are enforced, there are no empirical analyses of the determinants of compliance decisions in emissions trading programs. To begin to fill this empirical gap, we have embarked on an effort to design and conduct laboratory experiments to test existing theories about compliance behavior in emissions trading programs. In this paper we report on our experimental designs and provide preliminary results from these experiments.

Over the last 40 years, laboratory experiments have provided researchers with a better understanding of markets and human behavior. Experimental research has a well-established framework that is widely accepted for testing existing theories and for the design and analysis of public policies [Smith (1982), Bjornstad *et al*. (1999)]. Although, experimental techniques have been used to evaluate many other policy initiatives, including some aspects of emissions trading programs [Cason (1995), Cason and Plott (1996), Ishikida *et al*. (1998), Isaac and Holt(1999)], and individual compliance decisions for income taxation [Beck *et al*. (1991), Alm *et al*. (1992a), Alm (1998)], to our knowledge these techniques have not yet been used to analyze compliance and enforcement of environmental policies, including emissions trading programs.

At the simplest level, enforcement of any regulation is characterized by two components: monitoring to detect violations and the assessment of sanctions if a violation is found. Conceptually, a risk-neutral firm's decisions about whether to comply with a fixed emissions quota should be determined by the relationship between its marginal costs of reducing emissions and the marginal expected penalty it faces for a violation. (The marginal expected penalty is the probability of being found in violation times the marginal sanction for the violation). The reason is simple: when facing an emissions standard, the benefit to a firm of emitting more than the standard allows is the cost it would have to incur to reduce its emissions to satisfy the standard. Therefore, a firm's marginal control costs exactly indicate its marginal benefit of non-compliance to the standard.

Firms' compliance incentives when emissions quotas are tradable are quite different. Since compliance in this setting means holding enough permits to cover emissions, a competitive firm's marginal benefit of non-compliance is what it would have to spend for permits to make sure it is compliant; that is, the prevailing permit price. Furthermore, firms in an emissions trading program are linked together through the functioning of the permit market, whereas they are largely independent under command-and-control policies. Thus, because an individual firm's compliance decision is made by comparing the prevailing permit price to the marginal expected penalty, which summarizes the regulatory enforcement strategy the firm faces, enforcement decisions and how they impact compliance behavior are important determinants of prevailing permit prices. This suggests that any analysis of compliance behavior in emissions trading programs must examine both the direct effects on individual decisions from changes in say enforcement strategies, aggregate standards, and other exogenous factors, as well as the indirect effects that work through changes in prevailing permit prices.

The rest of this paper proceeds as follows: In the next section we specify the hypotheses about market prices and compliance decisions that will be tested with the experimental data. In the third section, we lay out our experimental design. We include ten different experimental treatments that vary according enforcement strategies and aggregate emissions standards. In the fourth section, we present some preliminary results from these experiments. At this date, these experiments are incomplete and the results have not been subjected to rigorous statistical tests. Therefore, the results we present should not be taken as conclusive. However, they do suggest that a fair number of theoretical hypotheses about compliance behavior are likely to be supported by the experimental data.

2. Hypotheses

The results we present address several hypotheses about how prevailing permit prices and compliance choices vary with changes of an aggregate emissions standard and changes in marginal expected penalties. The comparative static analysis that generated these hypotheses are in Appendix A.

Hypothesis 1: *The market price for permits should be decreasing as the aggregate standard increases.*

The first hypothesis is a simple test of a basic economic prediction: all else equal, as the supply of permits increases, the price of a permit should decrease.

Hypothesis 2: *Aggregate violations should be decreasing as the aggregate standard increases.*

Because price is a key determinant of compliance decisions in emissions trading programs, changes in the aggregate standard will also change aggregate levels of noncompliance. A higher aggregate standard will reduce aggregate violations, because the lower permit price will reduce firms’ incentives toward noncompliance.

Hypothesis 3: *Aggregate violations should be decreasing as the marginal expected penalty is increased.*

Of course, for a fixed aggregate standard, aggregate violations will respond to changes in the enforcement strategy as well. A higher marginal expected penalty (either a higher probability that a violation will be discovered, or increased marginal penalties for violations) implies a reduced incentive toward noncompliance.

Hypothesis 4: *The market price for permits should be increasing as the marginal expected penalty increases.*

Enforcement strategies will also affect firms' demands for emissions permits. Imagine an emissions trading program in which there is a fair amount of noncompliance. To reduce the amount of noncompliance, suppose that the marginal expected penalty is increased. This will motivate the noncompliant firms to demand more permits to reduce the magnitude of their violations, which will put upward pressure on the equilibrium permit price.

Hypothesis 5: *For two enforcement strategies that generate the same marginal expected penalty schedules, but with different monitoring probabilities and marginal penalty schedules, permit prices and rates of non-compliance should be identical.*

A basic result from the economic theory of law enforcement is that the probability of punishment and the severity of punishment are perfect substitutes for deterring noncompliance by risk-neutral agents [Becker (1968)]. However, risk-averse agents will be deterred more effectively by the severity of punishment, while the reverse is true for those who are risk seekers. Experimental results reported in Block and Gerety (1995) and Anderson and Stafford (2003) suggest that, at least in experimental settings, sanctions have a qualitatively larger effect on compliance behavior than auditing probability. Nearly all of the theory of compliance in emissions trading programs assumes risk-neutral firms.[1] We will address the issue of the relative impacts of monitoring and punishment with this hypothesis.

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[1] Malik (1990) appears to be the sole exception.

Hypothesis 6: *Individual violations in a permit market should be identical if firms are monitored with the same probability and they face the same penalties, even though they have different marginal abatement costs.*[2]

Stranlund and Dhanda (1999) argue that the differences in the size of individual violations of risk-neutral firms that trade emissions permit competitively should be independent of differences in their abatement costs. Thus, if two firms are audited with the same probability and the same enforcement effort is applied to each, they both should have the same level of violation even though one may employ a less-advanced emissions-control technology or use a dirtier production process. This suggests that, since nothing distinguishes the compliance incentives of competitive firms in emissions trading programs, there is no reason for an enforcer to contemplate a targeted enforcement strategy. That is, provided that penalties are applied uniformly, the firms should be monitored with the same probability.[3] We will address the empirical validity of this conclusion with this hypothesis.

3. Experimental Design and Procedures

3.1 Experiment design

The experiments are designed to test hypotheses about the different factors that might influence a firm's compliance decisions when emissions permits are tradable. During each period of the experiment, subjects simultaneously choose to produce units of a fictitious good and trade in a market for permits to produce the good. Participants can produce as many units of the good as they wish (subject to production capacity constraints) regardless of the number of permits that they own. However, at the end of the period, each individual is audited with a known probability. If an individual is audited and found to be non-compliant (i.e., total production exceeds permit holdings), then a penalty is applied. The treatment variables in this paper are the aggregate standard (or supply of permits), the probability of audit, and the marginal penalty function.

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[2] This result should extend to differences in initial allocations of permits as well. We plan to test this hypothesis, but have not yet run the experiments we have designed to do so.

[3] This result does not hold with emission standards. Garvie and Keeler (1994) show that firms with higher marginal abatement costs should be monitored more closely, because their incentives for noncompliance are greater than firms with lower marginal abatement costs.

Subjects received a benefit from their choice of production, q, according to the "Earnings from Production" schedules shown below in Table 1. If q is thought of as emissions, these marginal benefit functions are marginal abatement costs functions. Note that Type-A subjects have higher marginal benefit functions than Type-B subjects. Each experiment consisted of four Type-A subjects and four Type-B subjects. Subjects could choose any level of production up to a capacity constraint, which was eight units for Type-A subjects and 17 units for Type-B subjects.

To be compliant, subjects were required to possess permits, l, to cover their production choices. Limiting the number of permits put into circulation imposed a cap on aggregate production. We chose two aggregate standards: one high ($Q_H = 56$) and the other low ($Q_L = 28$). In the high aggregate standard experiments, each of the eight subjects in an experiment received an initial allocation of seven permits. In the low aggregate standard experiments, each of the four Type-A firms was allocated three permits, and the four Type-B firms were each given four permits.

To check for compliance, subjects' records were examined with a known probability π. If a subject was examined and was found to be non-compliant; that is, $q > l$, they were penalized according to a penalty schedule generated from a quadratic penalty function, $f = F(q-l) + (\phi/2)(q-l)^2$, where F and ϕ are positive constants. Note that the penalty function is strictly convex, so that each additional unit of violation brings a higher penalty.

Table 1. Earnings from production for each subject type
(E$ for each unit permit shortfall)

	Earnings from Production *(E$ for each unit produced)*	
Unit Produced	**Type-A**	**Type-B**
1st	17	16
2nd	16	14
3rd	15	12
4th	14	10
5th	13	8
6th	12	6
7th	11	4
8th	10	2
9th	9	
10th	8	
11th	7	
12th	6	
13th	5	
14th	4	
15th	3	
16th	2	
17th	1	

Notes
- Earnings from Production are expressed as marginal, not total, dollars.
- The Earnings from Production schedule is a discrete approximation to the quadratic benefit function $b(q) = \alpha q - (\beta / 2)q^2$, where α and β are positive constants, chosen in part to guarantee that $b(q) > 0$ for all feasible levels of production, q. The benefit function parameters are: $\left[(\alpha_A = 17, \beta_A = 1), (\alpha_B = 16, \beta_B = 2)\right]$. The subscripts A and B denote subject type.

By changing the parameters of the marginal expected penalty function, $\pi f' = \pi[F + \phi(q - l)]$, we developed four enforcement strategies which we labeled *High*, *Med*(π_H), *Med*(π_L), and *Low*. (The tag *Med* should be read "medium"). The *High* marginal expected penalty (*MEP*) function was designed to induce perfect compliance to the aggregate standards, Q_L and Q_H, using a high monitoring probability ($\pi_H = 0.70$) and a relatively high marginal Permit Shortfall Penalty function. The treatments *Med*(π_H) and *Med*(π_L) generate the same marginal expected penalties, but *Med*(π_H) uses the high monitoring probability and a relatively low marginal penalty function, whereas *Med*(π_L) uses a low monitoring probability ($\pi_L = 0.35$) and a higher marginal penalty function. Subjects were expected to choose to be noncompliant when facing both of these medium marginal expected penalty functions. The marginal expected penalty function *Low* was constructed to be the weakest enforcement strategy, with the low monitoring probability, π_L, and a low marginal penalty function. Enforcement parameter values were chosen, in part, so that the marginal expected penalty functions are parallel to each other—each has a slope of approximately one. The parameters for each experiment are shown in Table 2.

Table 2. Enforcement strategy parameters

	Aggregate Standard	
Enforcement Strategy	**$Q_L = 28$**	**$Q_H = 56$**
High MEP	(π_H, ϕ_1, F_1)	(π_H, ϕ_1, F_1)
Med(π_H) *MEP*	(π_H, ϕ_1, F_2)	(π_H, ϕ_1, F_2)
Med(π_L) *MEP*	(π_L, ϕ_2, F_3)	(π_L, ϕ_2, F_3)
Low MEP	(π_L, ϕ_2, F_4)	(π_L, ϕ_2, F_4)

The enforcement parameter values are $(\pi_L,\ \pi_H) = (0.35,\ 0.70)$, $(\phi_1,\ \phi_2) = (1.43,\ 2.90)$ and $(F_1,\ F_2,\ F_3,\ F_4) = (17.5,\ 6,\ 12,\ 2)$. The values for ϕ and F generate the Permit Shortfall Penalty schedules shown in Table 3.

Table 3. Permit Shortfall Penalties
(E$ for each unit permit shortfall)

Permit Shortfall	High	*Med*(π_H)	*Med*(π_H)	*Low*
1st unit	18.9	7.4	14.9	4.9
2nd	20.4	8.9	17.8	7.8
3rd	21.8	10.3	20.7	10.7
4th	23.2	11.7	23.6	13.6
5th	24.7	13.2	26.5	16.5
6th	26.1	14.6	29.4	19.4
7th	27.5	16.0	32.3	22.3
8th	28.9	17.4	35.2	25.2
9th	30.4	18.9	38.1	28.1
10th	31.8	20.3	41.0	31.0
11th	33.2	21.7	43.9	33.9
12th	34.7	23.2	46.8	36.8
13th	36.1	24.6	49.7	39.7
14th	37.5	26.0	52.6	42.6
15th	39.0	27.5	55.5	45.5
16th	40.4	28.9	58.4	48.4
17th	41.8	30.3	61.3	51.3

Notes

- Permit Shortfall Penalties are expressed as marginal, not total, dollars.
- The Permit Shortfall Penalty schedule was the same for each subject type with the exception that since Type-B firms could only produce a maximum of eight units, only the first eight steps in the penalty function were displayed.
- The Permit Shortfall Penalty schedule is a discrete approximation to the marginal penalty function $f' = F + \phi(q - l)$.

Table 4 summarizes the experimental design in a 5×2 matrix, where *MEP* denotes Marginal Expected Penalty. Each cell in the table was repeated twice.[4] The two columns represent the different aggregate standards (or total number of permits available), while the five rows reflect the different enforcement strategies.

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[4] We will be running a third repetition of each cell in the Fall. The data reported in this paper include two experiments per cell.

Table 4. Experimental design

	Aggregate Standard	
Enforcement Strategy	$Q_L = 28$	$Q_H = 56$
Forced Compliance	*A*	*B*
High MEP	*C*	*D*
$Med(\pi_H)$ *MEP*	*E*	*F*
$Med(\pi_L)$ *MEP*	*H*	*I*
Low MEP	*K*	*L*

In addition to the four *MEP* experiments that allowed non-compliance, we also ran a set of *Forced Compliance* experiments. By removing the ability to be non-compliant, and therefore any risks associated with a possible audit, these experiments provide a baseline against which the market outcomes of the other experiments can be compared. The *Forced Compliance* experiments are procedurally similar to other permit market experiments such as Cason *et al.* (1999) and Franciosi *et al.* (1999). During the period, subjects could only trade permits and did not make concurrent production decisions. Instead, production automatically occurred after the trading period ended, and production exactly equaled the minimum of the total number of permits owned or the maximum number of units that could be produced. (We permitted individuals to hold more permits than their maximum production capacity to allow for possible speculative trading). In both the *Forced Compliance* and *High MEP* treatments, firms are expected to be compliant, that is $q = l$. In the former treatment, this result is trivial since noncompliance is not possible. In the latter treatment, although the parameters are set such that a risk-neutral individual would choose to be perfectly compliant, noncompliant choices are possible. Because the competitive equilibrium outcomes in these two treatments are identical, this will allow us to draw some inferences about how permitting non-compliance affects individual decisions and market prices.

3.2 Experiment procedures

Table 5 summarizes the key aspects of the experiments.

Table 5. Experiment Summary

- Subjects
    - All subjects participated in a 2-hour training session prior to participating in real data sessions.
    - 54 University of Massachusetts students recruited from a pool of 116 trained subjects.
    - Paid \$7 for participating, plus experiment earnings (mean \$14, range \$10-\$17).
- Number and Type of Subjects
    - 8 subjects, 4 of each type
        - Type-A: High marginal abatement cost
        - Type-B: Low marginal abatement cost
- Periods and Length
    - 12 five-minute periods during which subjects could produce units and trade permits.
    - Data from first two periods were discarded.
- Production
    - Producing units generates "Earnings from Production" (i.e., redemption values).
    - Production allowed only during first four minutes of period.
    - Each unit produced sequentially; production takes 10 seconds/unit.
    - Maximum number of units a subject can produce: Type-A=17, Type-B=8.
- Permit Market
    - Permit market open for entire five-minute period.
    - Continuous double auction.
    - Permits cannot be banked for future use.
- Auditing
    - Each individual faced same probability π of being audited.
    - Random audits occur after production and market trading period is over.
    - Permit Shortfall Penalty function applied if audited and production exceeds permit holdings. The marginal penalties are increasing in the size of the shortfall.

Participants were recruited from the student population at the University of Massachusetts, Amherst. Subjects were paid \$7 for agreeing to participate and showing up on time, and were then given an opportunity to earn additional money in the experiment. These additional earnings ranged between \$10 and \$17, with a mean of \$14. Earnings were paid in cash at the end of each experiment. Each experiment lasted about 2 hours.

The experiments were run in a computer lab using software designed in Visual Basic specifically for this research. To familiarize subjects with the experiments, we initially ran a series of training experiments. In the first stage of the trainers, students read online experiment instructions, which included interactive questions to ensure that students understood the instructions before proceeding. After everyone had completed the instructions and all questions were answered, the training experiment began. These practice rounds contained all the same features as the "real data" experiments with the exception that we used a different set of training parameters. The data from the trainers were discarded.

For the real data sessions, we recruited participants from the pool of 116 trained subjects. Subjects were allowed to participate in multiple sessions. A total of 74 subjects participated in 20 eight-person market compliance experiments. Table 6 shows the distribution of the number of experiments in which an individual participated. The median and mode were two and one experiments, respectively. The maximum number of experiments was six, and the mean was 2.2.

Table 6. Distribution of the number of experiments in which an individual participated

Number of Experiments Participated In	Number of Subjects	Percent
1	29	39%
2	20	27%
3	15	20%
4	5	7%
5	4	5%
6	1	1%
Total number of subjects	74	100%

Prior to the start of the real data experiments, subjects were given a summary of the experiment instructions (see Appendix B). The experimenter read these instructions aloud and answered any questions. The review of the instructions took about 10 minutes.

Each experiment consisted of 12 identical five-minute rounds. At the start of each period, the eight subjects were each given an initial allocation of permits and E$10 in cash.[5] Data from the first two rounds of each experiment were discarded.

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[5] During the experiment, subjects earned experimental dollars (E$) that were converted to US dollars at a pre-announced exchange rate.

Each unit of the good was produced sequentially by clicking on a button that initiated the production process. Production of a single unit took 10 seconds. After production of the unit was completed the "Earnings from Production" were immediately added to the individual's cash balance. Subjects were able to "plan" future production by indicating the total number of units to produce. Once production of a unit was completed, if there were any "planned" units, the 10-second production process for the next would automatically begin. Subjects could increase or decrease their "planned" production, but units that were "in progress" or "completed" were committed and could not be changed. That is, subjects could alter planning decisions about units not yet produced, but they could not undo production of a good after the 10-second production process had begun.

A unique feature of our experiments is that the production decisions and permit market trading were unbundled into two separate, but simultaneous, activities. We did this to allow for the possibility that the production level and permit holdings could differ. Often in permit market experiments, perfect compliance is assumed (i.e., production exactly equals the number of permits owned at the end of the trading period) and subjects earn income based on their final permit holdings plus any net income from permit market trading [e.g., Cason *et al*. (1999), Franciosi *et al*. (1999)]. In our experiments, permits are useful because they are an instrument for choosing compliance rates, and they could also generate capital gains from speculative trading. Therefore, during the period and concurrent with the production decision, subjects also had the ability to alter their permit holdings by trading in a continuous double auction (CDA). In the CDA, individuals could submit bids to buy or asks to sell a single permit (provided that they had a permit available to sell). The highest bid and lowest ask price were displayed on the screen. A trade occurred whenever a buyer accepted the current ask or a seller accepted the current bid. After each trade, the current bid and ask were cleared and the market opened for a new set of bids and asks. The trading price history was displayed on the screen.

Each period lasted a total of five minutes. The permit market was open for the entire period, but production had to be completed in four minutes. The four-minute production time was more than sufficient for a subject to produce up to his or her capacity constraint. We provided the additional minute of permit trading after production was completed to give subjects a final opportunity to adjust their permit holdings. The computer screen displayed the time remaining for both production and the permit market.

As soon as a period ended, random audits were conducted and penalties were assessed. All information relating to audits penalties were private and not shared with the others in the experiment.

Since it was possible for individuals to lose money either through permit trading or permit shortfall penalties, we implemented a bankruptcy rule. If an individual's cash balance ever fell below negative E$800, he or she was declared bankrupt and was no longer allowed to participate. No subjects ever sustained a significant negative cash balance, let alone approached the bankruptcy threshold. We also instituted a price ceiling of E$20 above which offers to trade permits were not allowed. This ceiling was set above the highest possible "Earnings from Production" so had anyone paid this price for a permit she or he would have lost money. This constraint was non-binding as the maximum permit price in any experiment was E$14.

4. Results

In this section, we present some preliminary results from the experiments. At this date, the experiments are incomplete and the results have not been subjected to rigorous statistical tests. Therefore, the results we present should not be taken as conclusive. However, they do suggest that a fair number of theoretical hypotheses about compliance behavior are likely to be supported by the experimental data. Since we are primarily interested in equilibrium behavior, data from the first two periods were discarded to minimize the effects of learning, leaving us with 10 periods per experiment. We begin by presenting some simple descriptive statistics comparing competitive equilibrium and observed outcomes. We then make some observations about the hypotheses discussed above.

The competitive equilibrium outcomes presented in Table 7 assume that subjects are risk-neutral and trade in a perfectly competitive market. Note that the competitive equilibrium outcomes in the *Forced Compliance* and *High MEP* treatments are identical, likewise the *Med*(π_L) *MEP* and *Med*(π_H) *MEP* have the same competitive equilibrium. Table 8 contains the average observed outcomes for each subject type and treatment. The final permit balance, production quantity, and level of violations for each subject type are the mean of 80 observations per cell (two experiments, four subjects per type, 10 periods). In Table 8, the first line of each cell is the mean outcome from the two experiments. The second line is the percent difference between the mean outcome and the corresponding competitive equilibrium outcome in Table 7; a positive value indicates that the mean observed value exceeds the competitive equilibrium value.[6]

Table 7. Competitive Equilibrium Outcomes

Low Aggregate Standard (Q_L = 28)

		Type-A			**Type-B**		
Enforcement Strategy	**Permit Price**	**Permits** l_A	**Production** q_A	**Violations** $v_A=q_A-l_A$	**Permits** l_B	**Production** q_B	**Violations** $v_B=q_B-l_B$
A. *Forced Compliance*	(12, 13)	5	5	not applicable	2	2	not applicable
C. *High MEP*	(12, 13)	5	5	0	2	2	0
E. *Med*(π_H) *MEP*	(8, 9)	6	9	3	1	4	3
H. *Med*(π_L) *MEP*	(8, 9)	6	9	3	1	4	3
K. *Low MEP*	6	(6, 7)	11	(5, 4)	(1, 0)	5	(4, 5)

High Aggregate Standard (Q_H = 56)

		Type-A			**Type-B**		
Enforcement Strategy	**Permit Price**	**Permits** l_A	**Production** q_A	**Violations** $v_A=q_A-l_A$	**Permits** l_B	**Production** q_B	**Violations** $v_B=q_B-l_B$
B. *Forced Compliance*	8	(9, 10)	(9, 10)	not applicable	(5, 4)	(4, 5)	not applicable
D. *High MEP*	8	(9, 10)	(9, 10)	0	(5, 4)	(4, 5)	0
F. *Med*(π_H) *MEP*	(6, 7)	10	11	1	4	5	1
I. *Med*(π_L) *MEP*	(6, 7)	10	11	1	4	5	1
L. *Low MEP*	4	(10, 11)	13	(3, 2)	(4, 3)	6	(2, 3)

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[6] For those cases in which the competitive equilibrium is a range, we used the value in the range that was closest to the mean value, i.e., how far is the mean value from just falling into the range.

Table 8. Average Observed Outcomes[a]

Low Aggregate Standard ($Q_L = 28$)

		Type-A			Type-B		
Enforcement Strategy	**Permit Price**	**Permits** l_A	**Production** q_A	**Violations** $v_A = q_A - l_A$	**Permits** l_B	**Production** q_B	**Violations** $v_B = q_B - l_B$
A. *Forced Compliance*	12.64	4.81	4.81	not applicable	2.19	2.19	not applicable
C. *High MEP*	12.41	4.31	4.78	0.46	2.69	2.89	0.20
E. *Med*(π_H) *MEP*	9.54	4.54	7.56	3.03	2.46	4.81	2.35
H. *Med*(π_L) *MEP*	12.07	3.95	5.35	1.40	3.05	4.20	1.15
K. *Low MEP*	8.19	4.75	8.08	3.33	2.25	5.44	3.19

High Aggregate Standard ($Q_H = 56$)

		Type-A			Type-B		
Enforcement Strategy	**Permit Price**	**Permits** l_A	**Production** q_A	**Violations** $v_A = q_A - l_A$	**Permits** l_B	**Production** q_B	**Violations** $v_B = q_B - l_B$
B. *Forced Compliance*	7.78	9.11	9.11	not applicable	4.89	4.89	not applicable
D. *High MEP*	7.67	9.00	9.16	0.16	5.00	5.09	0.09
F. *Med*(π_H) *MEP*	6.63	9.29	10.48	1.19	4.71	5.64	0.93
I. *Med*(π_L) *MEP*	6.79	9.49	10.69	1.20	4.51	5.20	0.69
L. *Low MEP*	3.59	8.36	11.83	3.46	5.64	7.44	1.80

[a] These averages are from two experiments for each treatment. Each experiment consists of 10 periods (we ran 12 periods and dropped the first two).

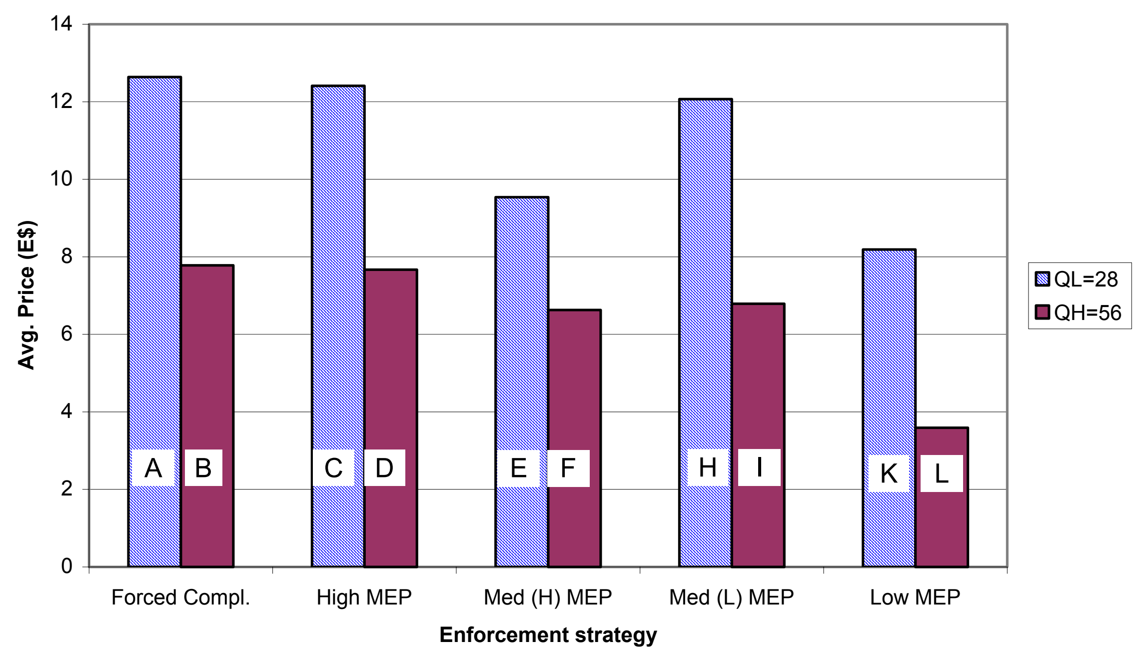
In six of the twelve experiments we ran (two experiments per treatment), the average permit price approximately equaled the competitive equilibrium price, and in five experiments the average price exceeded the equilibrium price. In only one of the 12 experiments was the average permit price below the equilibrium price.

Within each experiment the observed prices were relatively stable. As a measure of price dispersion, we calculated the mean absolute percentage price difference between the individual trade prices and the mean price for the experiment. This measure of dispersion ranged between 2% and 7%. With the same measure, Newell, Sanchirico, and Kerr (2002), found average price dispersion of 2 % for the SO_2 market over 2001-2002; 5% for nitrogen oxide trading in the northeastern U.S. over the same period, and 28% for the RECLAIM markets over 1995-2002. They also found that for the markets that make up New Zealand's individual transferable fishing quotas (ITQs), dispersion of ITQ lease prices averaged 35% in 1987 and 25% in 2000, while the average dispersion of ITQ sales prices was about 25% in 1987, falling to 5% in 2000. It is reassuring that that average price dispersion in our experiments is in line with, and sometimes much lower than, existing markets for tradable property rights, suggesting that our experimental markets are functioning reasonably well.

Hypothesis 1: *The market price for permits should be decreasing as the aggregate standard increases.*

For each enforcement strategy, Figure 1 contains a simple pairwise comparison of the mean price for low and high aggregate standard (Q_L and Q_H) treatments. The letters on the bars (E, F, etc.) refer to the treatment cell from Table 4. Although the data in Table 8 suggest that observed prices may sometimes differ from the competitive equilibrium prices, the average price is moving in the hypothesized direction with respect to changes in the aggregate standard for all enforcement strategies—average prices are clearly lower when the aggregate standard is high (Q_H).

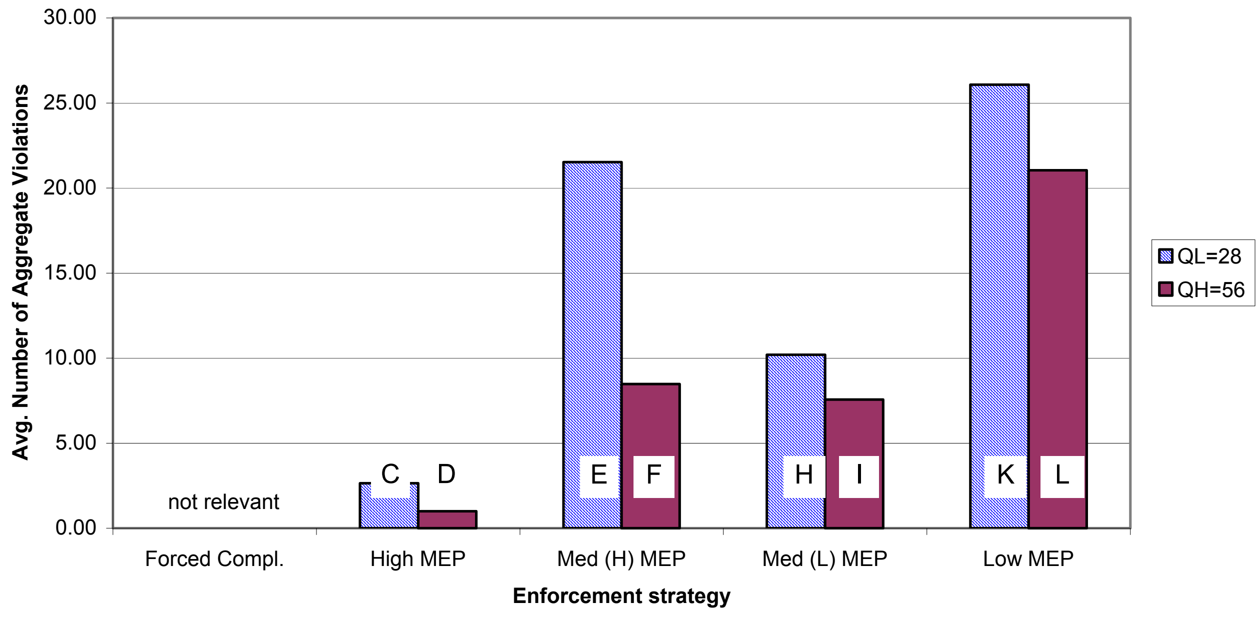
Figure 1. Comparison of average prices as the aggregate standard changes



Hypothesis 2: *Aggregate violations should be decreasing as the aggregate standard increases.*

Table 8 indicates that in the low aggregate standard experiments (Q_L), average rates of non-compliance are generally lower than the competitive equilibrium. In the high aggregate standard experiments (Q_H), however, the results are mixed. Figure 2 compares aggregate violations as the aggregate standard changes. As hypothesized, aggregate violations are lower with the higher aggregate standard when the subjects faced the $Med(\pi_H)$ and *Low* marginal expected penalties. However, the reverse is true with the $Med(\pi_L)$ marginal expected penalty. Recall from Tables 7 and 8 that, relative to the prediction for the H treatment ($8-9), the actual average price is quite a bit higher ($12.07). Furthermore, the predicted aggregate violation (24) for the H treatment is much higher than average aggregate violations (about 10). The high average price for this treatment is consistent with the low aggregate violation—low noncompliance implies stronger demand for permits and consequently higher permit prices.

Figure 2. Comparison of aggregate violations as the aggregate standard changes



Hypothesis 3: *Aggregate violations should be decreasing as the marginal expected penalty is increased.*

Figure 3 is a re-formatted version of Figure 2 to highlight how average aggregate violations vary with the marginal expected penalties. As hypothesized, aggregate violations are higher with the *Low* marginal expected penalty as compared to the *Med*(π_H) and *Med*(π_L) marginal expected penalties. Note again the low average aggregate violation for the H treatment.

Hypothesis 4: *The market price for permits should be increasing as the marginal expected penalty increases.*

Given an aggregate standard, weaker enforcement and higher noncompliance implies lower permit prices. Figure 4 highlights the how average permit prices change as the marginal expected penalty decreases. Consistent with Hypothesis 4, note that average permit prices for both the low and high aggregate standards (Q_L and Q_H) are lowest with the *Low* marginal expected penalty.

Figure 3. Comparison of aggregate violations as the MEP changes

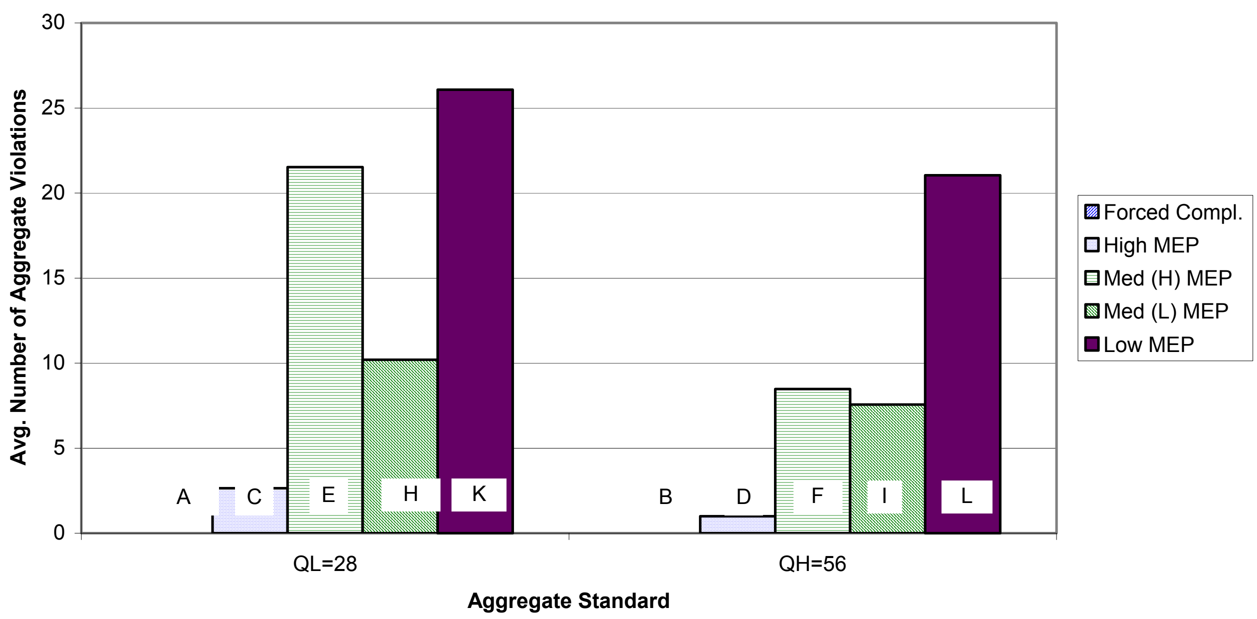
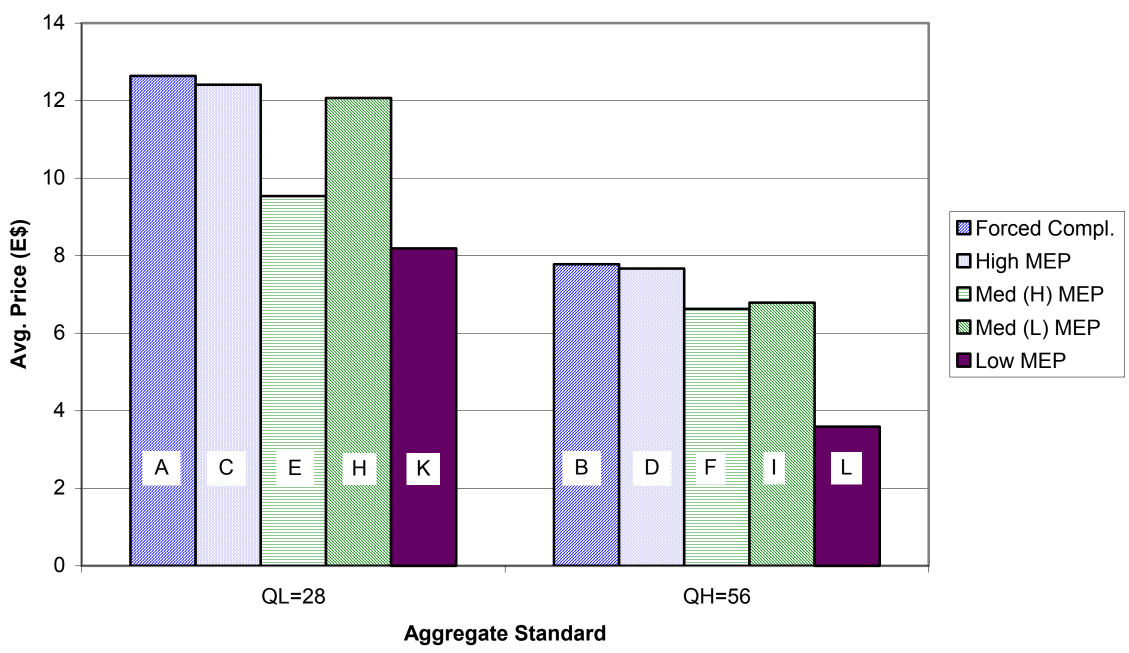


Figure 4. Comparison of average prices as the MEP changes



Hypothesis 5: *For two enforcement strategies that generate the same expected marginal penalty schedules, but with different monitoring probabilities and marginal penalty schedules, rates of non-compliance and permit prices should be identical.*

Refer to treatments E, H, F and I in Figures 3 and 4 to compare average aggregate violations and permit prices for the $Med(\pi_H)$ and $Med(\pi_L)$ marginal expected penalties. It appears that the data are not likely to support Hypothesis 5. Average aggregate violations are clearly not the same. Furthermore, violations are higher for the $Med(\pi_H)$ marginal expected penalty than the $Med(\pi_L)$ marginal expected penalty when the aggregate standard is low (Q_L), while they are lower when the aggregate standard is high (Q_H). At this stage of the research, we are unable to say anything about whether subjects' violation choices are more or less responsive to the probability of apprehension or the severity of punishment.

Looking now at average prices in Figure 4, we can see that there may be some support for the hypothesis in the high aggregate standard experiments (Q_H)—the average price in both the $Med(\pi_H)$ and $Med(\pi_L)$ marginal expected penalty treatments are about the same ($6.63 and $6.79, respectively). (These prices are within the competitive equilibrium price range of $6-7). In the low aggregate standard experiments (Q_L), however, the average price with the $Med(\pi_L)$ marginal expected penalty is $12.07 which is significantly higher than the average price of $9.54 with the $Med(\pi_H)$ marginal expected penalty. The competitive equilibrium price for both treatments is between $8 and $9. It is premature to speculate as to why the average permit price was so high in the two experiments with the low standard and $Med(\pi_L)$ marginal expected penalty. It is seems likely that average values mask a group-specific effect. For example, the mean prices in the two experiments with the low standard (Q_L) and the $Med(\pi_L)$ marginal expected penalty (cell H) were quite different: $12.97 and $9.72: with the low standard and the $Med(\pi_H)$ marginal expected penalty (cell E), the mean prices were $8.93 and $10.49. Not surprisingly, a simple t-test of the null hypothesis that the mean price of the two groups within the treatment is equal is strongly rejected at the 1% level of significance. As we subject the data to a thorough statistical analysis, we will probably need to control for group effects.

Hypothesis 6: *Individual violations in a permit market should be identical if firms are monitored with the same probability and they face the same penalties, even though they have different marginal abatement costs.*

Figures 5a and 5b compare average individual violations by subject type for the low (Q_L) and high (Q_H) aggregate standard, respectively. Recall from Table 6 that Type-A subjects have the higher marginal benefit functions (marginal benefit is synonymous with marginal abatement cost). These figures suggest that for all enforcement strategies and aggregate standards, the average level of violation is higher for Type-A subjects than for Type-B subjects, which is inconsistent with Hypothesis 6. However, note that for four of the six treatments reported (H, K, F, and L), these values are quite close to each other. Therefore, even if these differences turn out to be statistically significant, it is possible that they may not be "economically significant."

Concurrent with running the market experiments reported in this paper, we have also been running experiments that are identical except that permits are not tradable. We are doing so in order to compare compliance behavior with transferable permits to compliance with fixed emissions standards. Our preliminary results from these fixed standards experiments suggest that the differences in violation levels between Type-A and Type-B subjects are significantly larger than the differences in the market experiments.

Figure 5a. Violations for low aggregate standard (QL)

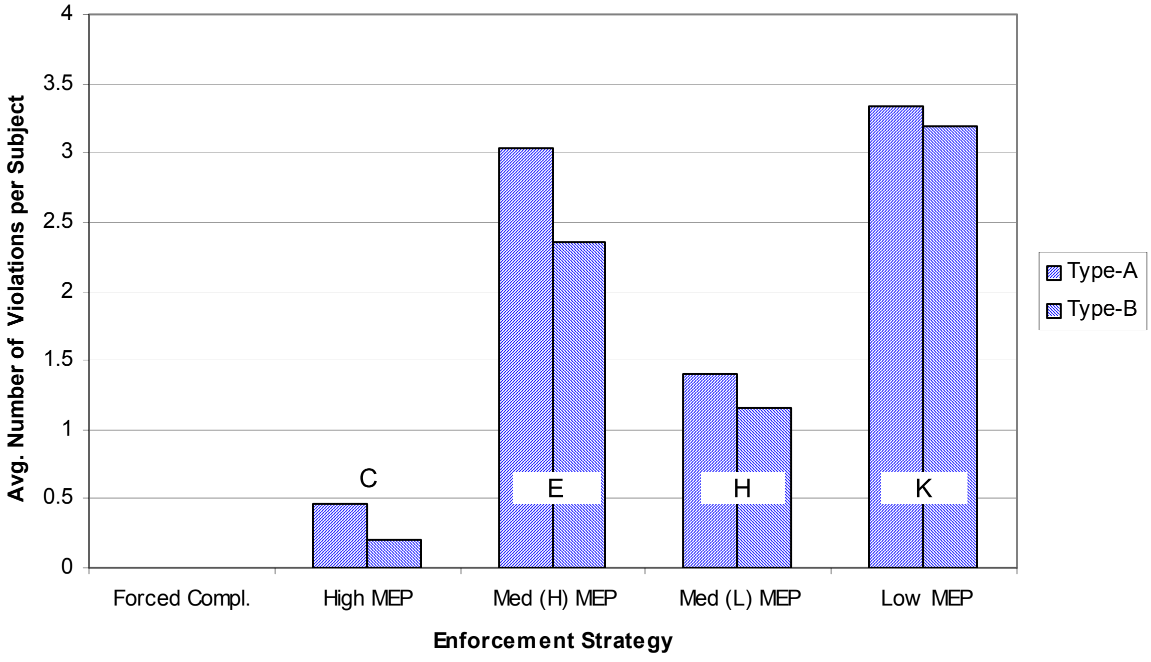
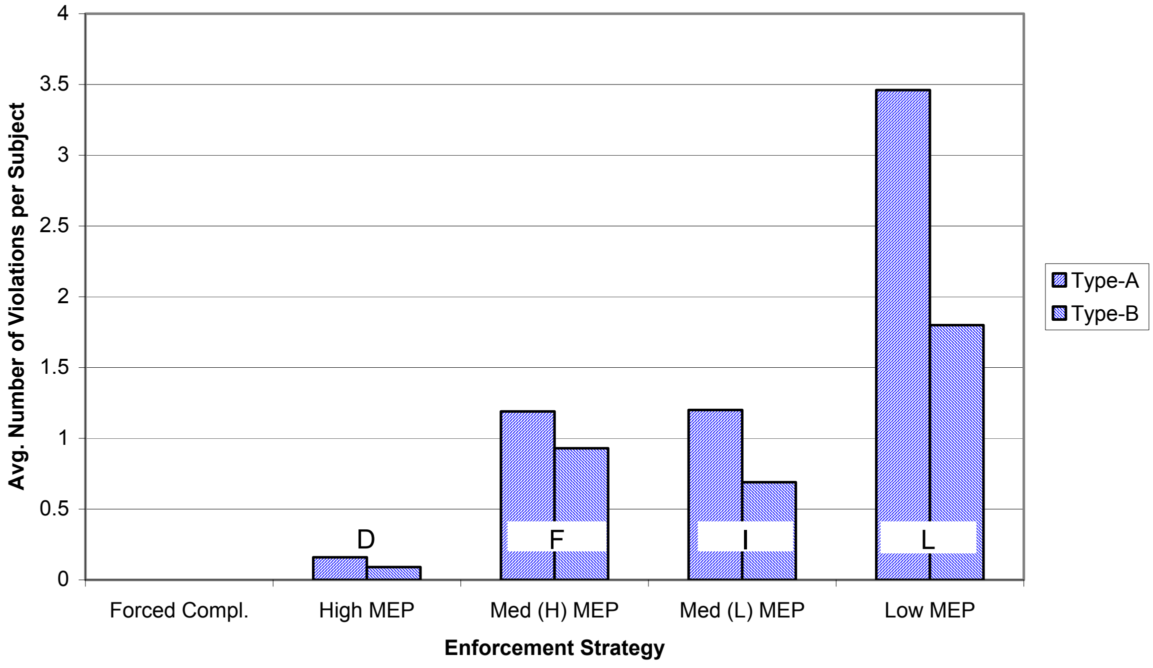


Figure 5b. Violations for high aggregate standard (QH)



5. Concluding remarks

While there is a substantial body of economic theory about compliance and enforcement in emissions trading programs, and readily available information about how existing emissions trading programs are enforced, there are no empirical analyses of the determinants of compliance decisions in emission trading programs. Furthermore, there are no empirical analyses of various elements of actual or proposed enforcement designs. Toward filling these gaps, the overall objective of this research is to use laboratory experiments to test a number of hypotheses about compliance behavior and enforcement strategies for emissions trading programs.

Clearly, it is premature to draw any significant conclusions from this preliminary presentation of the results. Although the observed average prices and violations may differ from the competitive equilibrium predictions, there does appear to be general support for most of the comparative static predictions. Permit prices and aggregate violations are generally responding to changes in aggregate standard and enforcement strategies in a manner that is consistent with our hypotheses. However, the simple averages we present mask variations across periods and groups and it is also possible that risk attitudes could play an important role in individual decisions.

We expect that further analysis of this data will provide policy-makers, regulators and researchers with a more comprehensive understanding of compliance behavior and the effectiveness of various enforcement tactics in emissions trading programs than is currently available. This will lead to a better understanding of how market mechanisms and incentives in managing environmental problems should be designed, implemented, and managed to meet environmental quality goals cost-effectively.

Appendix A: Comparative statics of compliance under competitive emissions trading

Basic assumptions

Throughout we consider a fixed set of heterogeneous, risk-neutral firms that are grouped by type into a set K. There are n^k identical firms of type k. We assume competitive behavior so that a single firm's choices have no affect on the equilibrium of the emissions permit market; however, we assume that there are enough firms of each type so that the aggregate choices of firms of a particular type will impact the market. At the time the firms make their choices, a fixed number of emissions permits have been allocated to the firms free-of-charge, and the enforcement authority has committed itself to a type-specific monitoring and enforcement program.

The emissions-control (abatement) costs of a k-type firm are summarized by $c(q^k, \alpha^k)$, which is strictly decreasing and convex in the firm's emissions q^k [$c_q(q^k, \alpha^k) < 0$ and $c_{qq}(q^k, \alpha^k) > 0$; throughout subscripts denote partial derivatives in the usual manner]. Firm heterogeneity is captured by the shift parameter α^k. We assume that total and marginal abatement costs are increasing in α^k; that is, $c_\alpha(q^k, \alpha^k) > 0$, and $-c_{q\alpha}(q^k, \alpha^k) > 0$.

Suppose that a total of Q emissions permits have been issued and that possession of a permit confers the legal right to release one unit of emissions. Let l_0^k be the number of emissions permits that are initially allocated to each k-type firm, and let l^k be the number of permits each of these firms holds after trade. Assume competitive behavior in the permit market so that trade establishes a constant price per permit p. If a k-type firm is noncompliant, its emissions exceed the number of permits it holds and the magnitude of its violation is $v^k = q^k - l^k > 0$. If a firm is compliant, $q^k - l^k \leq 0$ and $v^k = 0$.

We allow the probabilities with which firms are audited (monitoring) and penalties to vary among firm-types, but not among firms of the same type. Suppose that each k-type firm is audited with constant probability π^k. We have in mind here that the enforcement authority commits to auditing $\overline{n}^k < n^k$ firms of type k at random so that $\pi^k = \overline{n}^k / n^k$. If a firm is found to be in violation, a penalty $f(v^k, \phi^k)$ is imposed. Assume that the penalty for a zero violation is zero but the marginal penalty for a zero violation is greater than zero [$f(0, \phi^k) = 0$ and $f_v(0, \phi^k) > 0$]. Furthermore, for a positive violation the penalty is increasing at an increasing rate in the level of the violation [$f_v(v^k, \phi^k) > 0$ and $f_{vv}(v^k, \phi^k) > 0$]. The parameter ϕ^k is a shift parameter with $f_\phi(v^k, \phi^k) > 0$ and $f_{v\phi}(v^k, \phi^k) > 0$.

Assume that each firm chooses positive emissions and permits, and never over-complies. Then, a k-type firm's problem is to choose emissions and permits to

$$\begin{aligned} &\min \quad c(q^k, \alpha^k) + p(l^k - l_0^k) + \pi^k f(q^k - l^k, \phi^k). \qquad \textbf{[1]} \\ &s.t \quad q^k - l^k \geq 0. \end{aligned}$$

The Lagrange equation for this problem is $\theta^k = c(q^k, \alpha^k) + p(l^k - l_0^k) + \pi^k f(q^k - l^k, \phi^k) - \eta^k(q^k - l^k)$ and the Kuhn-Tucker conditions are:

$$\theta_q^k = c_q(q^k, \alpha^k) + \pi^k f_v(q^k - l^k, \phi^k) - \eta^k = 0; \qquad \textbf{[2a]}$$

$$\theta_l^k = p - \pi^k f_v(q^k - l^k, \phi^k) + \eta^k \leq 0, \ \theta_l^k \times (q^k - l^k) = 0; \qquad \textbf{[2b]}$$

$$\theta_\eta^k = q^k - l^k \geq 0, \ \eta^k \geq 0, \ \eta^k \times (q^k - l^k) = 0. \qquad \textbf{[2c]}$$

Given our assumptions about abatement costs and the penalty schedule, [2a-c] are necessary and sufficient to determine the firm's optimal choices of emissions and permits uniquely.

Individual Choices

Whether a *k*-type firm is compliant or noncompliant, it chooses its emissions so that the price of a permit is equal to its marginal abatement cost; that is,

$$q^k(\alpha^k, p) = \{\, q^k \mid c_q(q^k, \alpha^k) + p = 0\}. \qquad \textbf{[3]}$$

To see this, suppose at first that the firm is noncompliant so that $q^k - l^k > 0$. Then, [2b] and [2c] require $\theta_l^k = \eta^k = 0$. In turn, [2a] becomes $c_q(q^k, \alpha^k) + \pi^k f_v(q^k - l^k, \phi^k) = 0$, and [2b] becomes $p - \pi^k f_v(q^k - l^k, \phi^k) = 0$. Taken together, [2a] and [2b] then imply $c_q(q^k, \alpha^k) + p = 0$. Now suppose that the firm is compliant. In this case its objective function reduces to $c(q^k, \alpha^k) + p(q^k - l_0^k)$, the minimization of which requires $c_q(q^k, \alpha^k) + p = 0$.

Consistent with an observation by Malik (1990, pg. 101), when the probability with which a firm is audited is constant as in the case of random audits, a firm's choice of emissions is independent of the intensity with which it is monitored and the enforcement pressure applied to it. As Malik notes, and we repeat here, this does not imply that the equilibrium distribution of emissions among the firms is independent of the particular monitoring and enforcement policy -- the policy will affect a firm's equilibrium choice of emissions, but only through its impact on the equilibrium permit price.

Turn now to the firm's demand for emissions permits. When it is compliant the number of permits it demands is simply equal to its choice of emissions; that is, $l^k(\alpha^k, p) = q^k(\alpha^k, p)$. When the firm is noncompliant its demand for emissions permits is

$$l^k(\alpha^k, \pi^k, \phi^k, p) = \{\, l^k \mid p - \pi^k f_v(q^k(\alpha^k, p) - l^k, \phi^k) = 0\}. \qquad \textbf{[4]}$$

To obtain [4] note from [2b] and [2c] that $q^k - l^k > 0$ implies $\eta^k = 0$ and $\theta_l^k = p - \pi^k f_v(q^k - l^k, \phi^k) = 0$. Substitution of the firm's choice of emissions $q^k(\alpha^k, p)$ into $p - \pi^k f_v(q^k - l^k, \phi^k) = 0$ yields [4]. Note that although a noncompliant firm's choice of emissions is not affected by the monitoring and enforcement effort applied to it, its demand for emissions permits is.

Having specified a firm's choice of emissions and its demand for permits, we can now turn to its choice of violation. We start with its choice of whether to be compliant or not: A *k*-type firm is compliant if and only if

$$p - \pi^k f_v(0, \phi^k) \le 0. \qquad \textbf{[5]}$$

Although this result is not new, one aspect of it has been overlooked; namely, [5] does not depend on α^k. A firm's decision to be compliant or not depends only on the relationship between the permit price and the marginal expected penalty of a vanishingly slight violation, not on parametric characteristics of its emissions-control costs. In fact, Stranlund and Dhanda (1999) show that this independence extends to the choice of violation by a noncompliant firm. That is, a *k*-type firm's choice of violation, including whether it is compliant or not, is independent of the abatement cost shift parameter α^k. (We will verify this result in a moment).

Since a noncompliant firm's choice of violation does not depend on its marginal abatement costs, we can use this fact and [3] and [4], we write the firm's choice of violation

$$v^k(\pi^k, \phi^k, p) = q^k(\alpha^k, p) - l^k(\alpha^k, \pi^k, \phi^k, p). \qquad \textbf{[6]}$$

[3], [4], and [6] describe the choices of emissions, permits, and violation of a noncompliant k-type firm. The marginal impacts of α^k, π^k, ϕ^k, and p on theses choices are presented in Table 1 and derived below.

Let $\beta = (\alpha^k, \pi^k, \phi^k, p)$. Then, assuming a non-compliant firm, [2a] and [2b] can be written as the following identities:

$$c_q(q^k(\beta), \alpha^k) + \pi^k f_v(q^k(\beta) - l^k(\beta), \phi^k) \equiv 0; \qquad \textbf{[7]}$$

$$p - \pi^k f_v(q^k(\beta) - l^k(\beta), \phi^k) \equiv 0. \qquad \textbf{[8]}$$

Differentiate [7] and [8] with respect to α^k and place in matrix form:

$$\begin{bmatrix} c_{ee} + \pi^k f_{vv} & -\pi^k f_{vv} \\ -\pi^k f_{vv} & \pi^k f_{vv} \end{bmatrix} \begin{bmatrix} q_\alpha^k \\ l_\alpha^k \end{bmatrix} = \begin{bmatrix} -c_{e\alpha} \\ 0 \end{bmatrix}, \qquad \textbf{[9]}$$

where q_α^k and l_α^k denote derivatives of q^k and l^k with respect to α^k. Let H denote the Hessian matrix in [9]. Its determinant is

$$|H| = (c_{qq} + \pi^k f_{vv})\pi^k f_{vv} - (\pi^k f_{vv})^2 = c_{qq}\pi^k f_{vv} > 0. \qquad \textbf{[10]}$$

The solutions to [9] are

$$q_\alpha^k = \frac{1}{|H|}\begin{vmatrix} -c_{q\alpha} & -\pi^k f_{vv} \\ 0 & \pi^k f_{vv} \end{vmatrix} = \frac{-c_{q\alpha}\pi^k f_{vv}}{c_{qq}\pi^k f_{vv}} = \frac{-c_{q\alpha}}{c_{qq}} > 0,$$

and

$$l_\alpha^k = \frac{1}{|H|}\begin{vmatrix} c_{qq} + \pi^k f_{vv} & -c_{q\alpha} \\ -\pi^k f_{vv} & 0 \end{vmatrix} = \frac{-c_{q\alpha}\pi^k f_{vv}}{c_{qq}\pi^k f_{vv}} = \frac{-c_{q\alpha}}{c_{qq}} > 0.$$

As asserted earlier, $v_\alpha^k = q_\alpha^k - l_\alpha^k = 0$. This reveals that, holding monitoring, enforcement and the permit price constant, a change in some parameter that affects the abatement costs of a firm has no effect on its choice of violation. The intuition behind this result is as follows: The marginal expected benefit to a firm of a marginal reduction in its violation is the marginal expected penalty it avoids, which clearly does not depend on the firm's characteristics. To reduce its violation it may purchase the legal right to emit, the marginal cost of which is the equilibrium permit price, or it may reduce its emissions, the marginal cost of which is $-c_q(q^k, \alpha^k)$. But, the firm always chooses its emissions to equate its marginal abatement costs to the price of an emissions permit (see [3]). Hence, the marginal cost of reducing its violation is simply equal to the permit price, and therefore, independent of the firm's marginal abatement costs.

The result that $v_{\alpha}^{k} = 0$ also suggests that a difference in the violations of any two types of firms is independent of differences in their abatement costs. Thus, if two firms are audited with the same probability and they face the same penalties, they should have the same level of violation even though they may have very different marginal abatement costs.

Now differentiate [7] and [8] with respect to π^k to obtain:

$$H\begin{bmatrix} q_{\pi}^{k} \\ l_{\pi}^{k} \end{bmatrix} = \begin{bmatrix} -f_v \\ f_v \end{bmatrix}. \qquad \textbf{[11]}$$

The solutions to [11] are

$$q_{\pi}^{k} = \frac{1}{|H|}\begin{vmatrix} -f_v & -\pi^k f_{vv} \\ f_v & \pi^k f_{vv} \end{vmatrix} = \frac{-f_v\pi^k f_{vv} + f_v\pi^k f_{vv}}{c_{qq}\pi^k f_{vv}} = 0,$$

and

$$l_{\pi}^{k} = \frac{1}{|H|}\begin{vmatrix} c_{qq} + \pi^k f_{vv} & -f_v \\ -\pi^k f_{vv} & f_v \end{vmatrix} = \frac{f_v(c_{qq} + \pi^k f_{vv} - \pi^k f_{vv})}{c_{qq}\pi^k f_{vv}} = \frac{f_v}{\pi^k f_{vv}} > 0,$$

Furthermore, $v_{\pi}^{k} = q_{\pi}^{k}$ - $l_{\pi}^{k} = -f_v/\pi^k f_{vv} < 0$. We have already noted that a firm's choice of emissions is independent of the monitoring and enforcement effort applied to it (see [3]); therefore, its choice of violation is affected by monitoring and enforcement only through induced changes in the number of permits it chooses to hold. For example, if a *k*-type firm is monitored more intensely, then noncompliance is a relatively less attractive strategy. Hence, it is motivated to reduce its violation ($v_{\pi}^{k} < 0$) by purchasing more permits ($l_{\pi}^{k} > 0$), not by reducing its emissions ($q_{\pi}^{k} = 0$).

Now differentiate [7] and [8] with respect to ϕ^k to obtain:

$$H\begin{bmatrix} q_{\phi}^{k} \\ l_{\phi}^{k} \end{bmatrix} = \begin{bmatrix} -\pi^k f_{v\phi} \\ \pi^k f_{v\phi} \end{bmatrix}. \qquad \textbf{[12]}$$

The solutions to [12] are

$$q_{\pi}^{k} = \frac{1}{|H|}\begin{vmatrix} -\pi^k f_{v\phi} & -\pi^k f_{vv} \\ \pi^k f_{v\phi} & \pi^k f_{vv} \end{vmatrix} = \frac{(\pi^k)^2[-f_{v\phi}f_{vv} + f_{v\phi}f_{vv}]}{c_{qq}\pi^k f_{vv}} = 0,$$

and

$$l_{\phi}^{k} = \frac{1}{|H|}\begin{vmatrix} c_{qq} + \pi^k f_{vv} & -\pi^k f_{v\phi} \\ -\pi^k f_{vv} & \pi^k f_{v\phi} \end{vmatrix} = \frac{\pi^k f_{v\phi}(c_{qq} + \pi^k f_{vv} - \pi^k f_{vv})}{c_{qq}\pi^k f_{vv}} = \frac{f_{v\phi}}{f_{vv}} > 0.$$

Furthermore, $v_\phi^k = e_\phi^k - l_\phi^k = -f_{v\phi}\big/ f_{vv} < 0.$ The effects of increasing marginal penalties are qualitatively the same as increased monitoring.

Lastly, differentiate [7] and [8] with respect to p to obtain

$$H\begin{bmatrix} q_p^k \\ l_p^k \end{bmatrix} = \begin{bmatrix} 0 \\ -1 \end{bmatrix}. \qquad \textbf{[13]}$$

The solutions to [13] are

$$q_p^k = \frac{1}{|H|}\begin{vmatrix} 0 & -\pi^k f_{vv} \\ -1 & \pi^k f_{vv} \end{vmatrix} = \frac{-\pi^k f_{vv}}{c_{ee}\pi^k f_{vv}} = -\frac{1}{c_{ee}} < 0,$$

and

$$l_p^k = \frac{1}{|H|}\begin{vmatrix} c_{qq} + \pi^k f_{vv} & 0 \\ -\pi^k f_{vv} & -1 \end{vmatrix} = \frac{-(c_{qq} + \pi^k f_{vv})}{c_{qq}\pi^k f_{vv}} < 0.$$

From these obtain

$$v_p^k = q_p^k \text{ - } l_p^k == \frac{-\pi^k f_{vv} + c_{qq} + \pi^k f_{vv}}{c_{qq}\pi^k f_{vv}} = \frac{1}{\pi^k f_{vv}} > 0.$$

A higher permit price implies that purchasing the legal right to emit is a relatively less attractive option than reducing emissions, so a firm is motivated to hold fewer permits and reduce its emissions ($q_p^k < 0$ and $l_p^k < 0$). In addition, a higher permit price makes noncompliance a relatively more attractive option so that a firm is motivated to increase its violation ($v_p^k > 0$).

	***Emissions* (q^k)**	***Permits* (l^k)**	***Violation* (v^k)**
α^k	$q_\alpha^k = \frac{-c_{e\alpha}}{c_{ee}} > 0$	$q_\alpha^k = l_\alpha^k > 0$	$v_\alpha^k = 0$

$\boldsymbol{\pi^k}$	$q^k_\pi \;=\; 0$	$l^k_\pi \;=\; \dfrac{f_v}{\pi^k f_{vv}} > 0$	$v^k_\pi \;=\; -l^k_\pi < 0$
$\boldsymbol{\phi^k}$	$q^k_\phi \;=\; 0$	$l^k_\phi \;=\; \dfrac{f_{v\phi}}{f_{vv}} > 0$	$v^k_\phi \;=\; -l^k_\phi < 0$
$\boldsymbol{p}$	$q^k_p \;=-\dfrac{1}{c_{ee}} < 0$	$l^k_p \;=\; \dfrac{-(c_{qq}+\pi^k f_{vv})}{c_{qq}\pi^k f_{vv}} < 0$	$v^k_p \;=\dfrac{1}{\pi^k f_{vv}} > 0$

Table 1: Comparative statics of a firm's choices of emissions, permits and level of violation.

Equilibrium comparative statics

We turn now to characterizing the equilibrium of an emissions permit market with noncompliant firms. Define the vectors $\boldsymbol{\alpha} = (\alpha^k)_{k \in K}$, $\boldsymbol{\pi} = (\pi^k)_{k \in K}$, and $\boldsymbol{\phi} = (\phi^k)_{k \in K}$. Given that a total of Q permits are issued to the firms, and the enforcement authority has committed itself to a type-specific monitoring and enforcement program $[\boldsymbol{\pi}, \boldsymbol{\phi}]$, the equilibrium permit price is $\bar{p} = \bar{p}(\boldsymbol{\alpha}, \boldsymbol{\pi}, \boldsymbol{\phi}, Q)$. Using [4], the equilibrium permit price must equate aggregate demand for permits to aggregate supply; that is, $\bar{p}$ must satisfy

$$\sum n^k l^k(\alpha^k,\ \pi^k,\ \phi^k, \bar{p}) \equiv Q. \qquad \textbf{[14]}$$

(Summations throughout are taken over the entire set K). Combining [14] with [3], [4], and [6] gives us equilibrium emissions, permits, and violations:

$$\begin{aligned} \bar{q}^k(\boldsymbol{\alpha}, \boldsymbol{\pi}, \boldsymbol{\phi}, Q) &= q^k(\alpha^k,\ \bar{p}(\boldsymbol{\alpha}, \boldsymbol{\pi}, \boldsymbol{\phi}, Q)); \\ \bar{l}^k(\boldsymbol{\alpha}, \boldsymbol{\pi}, \boldsymbol{\phi}, Q) &= l^k(\alpha^k, \pi^k, \phi^k,\ \bar{p}(\boldsymbol{\alpha}, \boldsymbol{\pi}, \boldsymbol{\phi}, Q)); \\ \bar{v}^k(\boldsymbol{\alpha}, \boldsymbol{\pi}, \boldsymbol{\phi}, Q) &= v^k(\pi^k, \phi^k,\ \bar{p}(\boldsymbol{\alpha}, \boldsymbol{\pi}, \boldsymbol{\phi}, Q)). \qquad \textbf{[15]} \end{aligned}$$

Let us first examine the equilibrium effects of a change in the aggregate supply of permits. (The qualitative directions of the equilibrium comparative statics are summarized in Table 2). From [14] obtain

$$\partial\bar{p}/\partial Q = 1\Big/\sum n^k l^k_p < 0. \qquad \textbf{[16]}$$

The sign follows from $l^k_p < 0$ (refer to Table 1), and indicates that the equilibrium price is decreasing in the supply of permits. Using [15] and [16] obtain:

$$\begin{aligned} \partial\bar{q}^k/\partial Q &= q^k_p \bar{p}_Q > 0; \\ \partial\bar{l}^k/\partial Q &= l^k_p \bar{p}_Q > 0; \\ \partial\bar{v}^k/\partial Q &= v^k_p \bar{p}_Q < 0. \end{aligned}$$

More permits induce a lower permit price. Firms respond to the lower price by increasing their emissions and permit holdings, while decreasing their violations. Note that aggregate emissions are increasing in the supply of permits, while aggregate violations are decreasing the supply of permits.

Now turn to the equilibrium effects of a change in the monitoring of *h*-type firms, holding the monitoring of the other types constant. From [14] obtain

$$\partial \bar{p} \big/ \partial \pi^h = -n^h l_\pi^h \Big/ \sum n^k l_p^k > 0 . \qquad \textbf{[17]}$$

The sign of [17] follow from $l_\pi^h > 0$ and $l_p^k < 0$ (Table 1). Intuitively, increased monitoring of noncompliant firms of a particular type motivates them to purchase more permits ($l_\pi^h > 0$) to reduce the magnitude of their violations ($v_\pi^h < 0$). This increased demand for permits then puts upward pressure on the equilibrium permit price. From [15] obtain:

$$\partial q^k \big/ \partial \pi^h = \begin{cases} q_\pi^h + q_p^h \partial \bar{p} / \partial \pi^h = q_p^h \partial \bar{p} / \partial \pi^h < 0, \text{ for } k = h; \\ q_p^k \partial \bar{p} / \partial \pi^h < 0, \text{ for } k \neq h. \end{cases} \qquad \textbf{[18]}$$

[18] indicates that emissions of all firms fall as one type is monitored more closely, because this increased monitoring puts upward pressure on the equilibrium permit price.

To examine the effect of increased monitoring on equilibrium violations, it is convenient to begin with aggregate violations,

$$\sum n^k \bar{v}^k (\alpha,\pi,\phi,Q) = \sum n^k v^k (\pi^k, \phi^k, \bar{p}(\alpha,\pi,\phi,Q))..$$

Differentiate this with respect to π^h to obtain

$$\frac{\partial}{\partial \pi^h}\left[\sum \bar{v}^k\right] = n^h v_\pi^h + \partial \bar{p} \big/ \partial \pi^h \sum v_p^k .$$

Substitute for $\partial \bar{p} \big/ \partial \pi^h$ from [17] and use $v_\pi^h = -l_\pi^h$ from Table 1 to write this last as

$$\frac{\partial}{\partial \pi^h}\left[\sum \bar{v}^k\right] = n^h v_\pi^h \left[1 + \frac{\sum n^k v_p^k}{\sum n^k l_p^k} \right] \qquad \textbf{[19]}$$

To sign [19], first recall from Table 1 that $v_p^k = e_p^k - l_p^k > 0$. This along with $e_p^k < 0$ and $l_p^k < 0$ implies $| l_p^k | > v_p^k$. Consequently, the bracketed term of [19] is positive. Since $v_\pi^h < 0$, [19] is negative, indicating that aggregate equilibrium violations fall with more intense monitoring of *h*-type firms.

Now turn to individual violations. From [15]:

$$\partial\bar{v}^k/\partial\pi^h = \begin{cases} v_\pi^h + v_p^h \partial\bar{p}/\partial\pi^h < 0 \text{ for } k = h; \\ v_p^k \partial\bar{p}/\partial\pi^h > 0 \text{ for } k \neq h. \end{cases} \qquad \textbf{[20]}$$

The sign of $\partial\bar{v}^k/\partial\pi^h$ for types $k \neq h$ follows from $v_p^k > 0$ and $\partial\bar{p}/\partial\pi^h > 0$. Finally, since aggregate violations are decreasing in π^h and the equilibrium violations of all $k \neq h$-type firms are increasing in π^h, the equilibrium violations of *h*-type firms must be decreasing in π^h.

Although more intense monitoring of *h*-type firms leads them to reduce their equilibrium violations, this is not immediately obvious from [20]. A firm's equilibrium violation-response to more intense monitoring is made up of a two countervailing effects. Holding the permit price constant, more intense monitoring of *h*-type firms motivates each of them to reduce their violation [$v_\pi^h < 0$] by purchasing more permits [$l_\pi^h < 0$]. But as a result of their increased demand for emissions permits, the equilibrium permit price increases [$\partial\bar{p}/\partial\pi^h > 0$], which motivates each of them to increase their violation [$v_p^h < 0$]. However, the direct effect of more intense monitoring outweighs the indirect price effect so that more intense monitoring of one group of firms leads each of them to decrease their equilibrium violation. In contrast, all other firms only experience the price effect, so more intense monitoring of one group leads all of them to increase their violations. This finding should serve as a cautionary note for enforcement of emissions trading programs—efforts to induce greater compliance by one group of firms will be partially thwarted because these efforts lead all other firms to become less compliant.

Increasing the penalty for one type of firm has the same qualitative effects as increasing the monitoring of one type. Clearly, increasing the monitoring or penalties of all firms at once will lead all of them to reduce their violations.

Let us now consider the equilibrium impacts of a parametric change in the marginal abatement costs of one type of firm. Recall that a firm's choice of violation is independent of its marginal abatement costs. However, as the following proposition indicates, a change in the marginal abatement costs of one type of firm will affect the equilibrium violations of all firms through the permit price.

From [14] obtain

$$\partial\bar{p}/\partial\alpha^h = -n^h l_\alpha^h / \sum n^k l_p^k > 0,$$

the sign of which follows from $l_\alpha^h > 0$ and $l_p^h < 0$. Thus, an increase in the marginal abatement costs of one type of firm leads to an increase in the equilibrium permit price. From [15] obtain

$$\partial\bar{v}^k/\partial\alpha^h = v_p^k \partial\bar{p}/\partial\alpha^h > 0 \ \forall\ k \in K,$$

indicating that an increase in the marginal abatement costs of one type of firm will lead to higher violations by all firms, because of upward pressure on the equilibrium permit price. Since aggregate violations are increasing in the marginal abatement costs of a firm type, so too are aggregate emissions. That is,

$$\frac{\partial}{\partial\alpha^h}\left[\sum \bar{v}^k\right] > 0 \text{ and } \frac{\partial}{\partial\alpha^h}\left[\sum \bar{q}^k\right] > 0.$$

As for individual emissions, from [15] obtain

$$\partial\bar{q}^k\big/\partial\pi^h = \begin{cases} q_\alpha^k + q_p^k\,\partial\bar{p}\big/\partial\alpha^h > 0 \text{ for } k = h; \\ q_p^k\,\partial\bar{p}\big/\partial\alpha^h < 0 \text{ for } k \neq h. \end{cases}$$

The sign of $\partial\bar{q}^k\big/\partial\pi^h$ for types $k \neq h$ follows from $q_p^k < 0$ and $\partial\bar{p}\big/\partial\alpha^h > 0$. Finally, since aggregate emissions are increasing in α^h and the emissions of all $k \neq h$-type firms are decreasing in α^h, the equilibrium emissions of h-type firms must be increasing in their marginal abatement costs.

	Q	π^h	ϕ^h	α^h
Price $\bar{p}$	(−)	(+)	(+)	(+)
Violations				
Violations, type h	(−)	(−)	(−)	(+)
Violations, types $k \neq h$	(−)	(+)	(+)	(+)
Aggregate violations	(−)	(−)	(−)	(+)
Emissions				
Emissions, type h	(+)	(−)	(−)	(+)
Emissions, types $k \neq h$	(+)	(−)	(−)	(−)
Aggregate emissions	(+)	(−)	(−)	(+)

Table 2: Equilibrium comparative statics

Appendix B: Instructions Summary

Thank you for agreeing to participate in today's experiment. You have all seen a version of this experiment before. Before we begin, I would like to review the instructions for today's experiment.

It is very important to remember that although the experiment may be similar, some or all of the numbers may have changed. **Do NOT assume that any of the information or results from a previous experiment will be useful in helping you to make your decisions today**.

The purpose of the experiment is to give you an opportunity to earn as much money as possible. What you earn will depend on your decisions, as well as the decisions of others. As before you can produce as many units as you want regardless of the number of permits you own, but you could face a financial penalty if you do not own a permit for each unit you produce.

- During the period, you can earn money in two ways:
    1. Produce units of the fictitious good. For each unit you produce, you will earn a specified amount of money that will be added to your cash balance.
    2. Sell permits in the permit market. The selling price you receive for a permit will be added to your cash balance.
- Money will be subtracted from your cash balance if:
    1. You choose to buy additional permits. The purchase price you pay will be deducted from your cash balance.
    2. You are audited and if the total number of units you produce exceeds the number of permits you own.

Production Highlights

- Your Earnings from Production table tells you how many units you can produce and how much you will earn from each unit you produce. You might earn a different amount of money for each unit produced.
- Production of each unit takes a specified amount of time
- You can only produce one unit at a time.
- The Production Timer tells you how much time is left for you to produce more units.

- In order to start production of a unit, there must be sufficient time on the Production Timer to complete production of the unit.
- To start production or to place an order for additional units, click the plus (+) button. If production is idle, then production will begin immediately.
- You can cancel units that have been ordered if production has not yet begun. To do so, click the minus (–) button.
- Earnings from the units produced are automatically added to your cash balance when production is completed.
- The last row of the "Earnings from Production" table tells you the maximum number of units you are able to produce.
- Under the "Earnings from Production" table, you can see the production status of each unit (produced, in production, or planned).

Permit Market Highlights

- You will be given an opportunity to buy and/or sell permits in the Permit Market.
- There are 4 ways in which you can participate in the market:
  1. Make an offer to buy a permit.
     a. To do so, enter your price next to the My Buying Price and click Buy.
     b. All buying prices must be GREATER than the Current Buying Price.
  2. Make an offer to sell a permit.
     a. To do so, enter your price next to the My Selling Price and click Sell.
     b. All selling prices must be LOWER than the Current Selling Price.
  3. Purchase a permit at the Current Selling Price.
     a. To do so, enter the Current Selling Price next to My Buying Price
     b. or click the Buy? button next to the Current Selling Price.
  4. Sell a permit at the Current Buying Price.
     a. To do so, enter the Current Buying Price next to My Selling Price
     b. or click the Sell? button next to the Current Buying Price.

- After each trade is completed, your permit balance will be automatically updated. Your cash balance will automatically be updated to reflect price you paid to buy the permit, or the price you received for selling the permit. This is shown in the My Balances section of your screen.

Auditing Highlights

- The computer monitor always knows how many permits you own and your cash balance. The computer does not know how many units you actually produced unless you are audited.
- There is an XX% chance that you will be audited, and (1-XX)% chance you will not be audited.
- If you are audited, the computer monitor will check to see how many units you actually produced. If the number of units you produced exceeds the number of permits you own, you will receive a financial penalty. The Permit Shortfall Table lists the penalties you will face.

To summarize, your total earnings for the period will be calculated as follows:

Your initial cash balance
\+ Earnings from production of the good
\+ Selling price for permits you sell in the permit market
– Purchase price for permits you buy in the permit market
– Penalties for a permit shortfall (only if you are audited and if you over produced)

= Total earnings for the period

At the end of the experiment, we will add up your total earnings for each period and you will be paid in cash for these earnings. Please raise your hand if you have any questions.

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May 2, 2003 2:30PM
Question and Answer Session

Q: Alex Farrell, University of California at Berkeley:
This question is actually an observation for Murphy and Stranlund. In the air pollution markets that we have seen so far, people have mentioned there are really good monitoring capabilities and enforcement hasn't really been much of an issue. But, for climate, for the variety of sources of greenhouse gases, there's a wide array of potential for monitoring and difficulties in monitoring. So one of the things that might be interesting in that context, I don't know if you've been thinking about it or if you can, is to have participants who vary dramatically on the MEP and probably not through the penalty so much as the likelihood of the successful audit. I think that could vary a lot and that may be true in some other instances as well.

Jim Murphy and John Stranlund
A. The probability that you are going to get caught is likely to be fairly important. There is not an obvious way to model that. We are cognizant of that problem, although the law and economics literature is almost silent about it. It's certainly something that we ought to consider in the future.

A. I would also like to add that this first round of experiments that we designed had a very neutral frame to it. It was cast, and conceptually we motivated it in our heads, with respect to air pollution, but when we presented it to students we didn't tell them it was air pollution permit markets—there's no environmental context per se. In fact, all they're trading is permits giving them the right to produce. The rationale behind that was hopefully to come up with some broader results that aren't peculiar to just air pollution permit markets but possibly to water, and maybe down the road to something like climate, although I'm not sure I'm ready to make that leap with what we have, but at least, hopefully, we'll have some water implications with what we're doing.

Q: Dallas Burtraw, Resources for the Future:
Question for Tim. I'll start with the premise of what I thought you said and then ask my question—if my premise is wrong, please correct me. The green line in the discriminating price auction I interpreted as being sort of what theory suggested would be optimal individual behavior—is that what you're saying? And, if that's the case, would you expect (say if there was an agent who you could hire to give you guidance on how to behave in the market or if there was enough repeated experimentation in the market) to see conversions to some other behavior other than what you observed? And, finally, how then are the measures of market performance under some kind of theoretical construct?

A. Tim Cason:
That green line, that nonlinear alpha function, was actually an approximation based on simplifying assumptions to see if people behaved as if they didn't have multiple projects they could sell—to see if people behaved as if they knew the range of costs that others were drawing from. It was an attempt to see whether that approximation was correct or not. Since the offers were not in line with that at all—if they were on that green line,

then the discriminate price auctions performance would have been considerably worse, because the offer is much higher than the cost. That approximation doesn’t seem to hold—the functional form doesn’t even seem right.

Market Mechanisms and Incentives: Applications to Environmental Policy

PROCEEDINGS
SESSION SIX

LEGISLATIVE ISSUES WITH MARKET MECHANISMS

A WORKSHOP SPONSORED BY THE US ENVIRONMENTAL PROTECTION AGENCY'S NATIONAL CENTER FOR ENVIRONMENTAL ECONOMICS AND NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH

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Session VI Proceedings

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Comparison of Multi-Pollutant Trading Proposal
William Pizer, Resources for the Future

This talk is centered on Multi-pollutant legislation. When David and I talked about this a few months ago at RFF we focused exclusively on allocation. The conclusion was that the differences in the bills, namely the inclusion of carbon in the Jeffords Lieberman Bill and the exclusion of carbon in the Administration's Clear Skies initiative really seem to explain a lot of the differences between the two. With carbon present, there is a lot more money at stake, and the burden is not being borne primarily by the electric power sector, instead a lot is being borne by the consumers. In such cases, if you are going to deal with the equity concerns as well as the political concerns with the people who are adversely affected, you need to have to have some element of an auction in the system. In contrast, this is not true when dealing with conventional pollutants. With conventional pollutants, a lot of the costs were being borne by the regulated entities (the power plants), in which case it made more sense to have a larger grandfather program, although both programs did eventually tend to an auction.

So in thinking about what I was going to talk about today and make it a little more interesting, I thought I'd broaden it and talk a little more about the differences among pollutants. Some of my personal thinking about elements to bill, the two proposals, and things that might be done different in both and draw some conclusions.

Let me state that I am not going to summarize the bills in detail. On the RFF Website Dallas Burtaw and I wrote up a summary, primarily of Jeffords-Lieberman and the Clear Skies initiative, and we added a column for the Carper Bill. We had a column comparison as well as a write up. The overall conclusion of that analysis was that there is actually a lot of similarities among the bills. In particular you have very similar long term caps for NOx and SO_2 and you also have very flexible trading programs. In a lot of ways we felt this was a very significant step given where environmental regulation was 20 or 30 years ago. Right now we are discussing and debating the nuances of the specific caps, the specific pollutants, and various architectural features. We are no longer discussing whether or not there should be trading, as this is a given, and illustrates how far we have come in our thinking.

In addition, both bills encourage auction. As I mentioned a second ago, the Jeffords Lieberman bill which includes carbon dioxide has an auction right up front, in contrast to the Clear Skies initiative which moves very slowly towards an auction.

As stated earlier, the major difference between the bills is the no carbon dioxide requirement in the Clear Skies Initiative (CSI), in contrast to the Carpers Bill (CB) and the Jeffords-Lieberman Bill (JLB). Another difference between the bills is that there is a much lower Hg target in the JLB than in the CSI. Moreover, there are also quicker declines in NOx and SO_2 under JLB than under CSI (on the order of a decade). Part of this is due to using auctions early on in the JLB than in CLI.

The main points I want to make today fall into two categories. One category deals with architectural issues and the other category deals with the specifics of the pollutants. Between the two categories there exists some overlap.

From an architectural standpoint, the first issue is to use a safety valve. This builds off a lot of research I have done and is addressed below. There is a lot of uncertainty in the forecast that modelers do in order to estimate the cost and benefits of these policies, specifically the costs. Even if such estimates were very accurate, there is a lot of inherent uncertainty in electric generation and fluctuation due to weather and other unpredictable things. Since you want to have a regulatory system that is resilient to those sorts of events, I believe a safety valve is good way to go.

The second point in the general architectural categories is that there are some legitimate reasons, including some political ones, which may preclude an auction right off the bat. There are some significant losers when environmental regulations are enacted. They bear a lot of costs and you are going to have to compensate them if you are going to make a political reality of a proposal. However, in the long run a lot of those arguments break down, and in fact, you create problems not having an auction.

The third architectural point is that most people agree that we will have to deal with carbon dioxide across the entire economy. Only about 33% to 40% of emissions are coming from electricity. There is a large chunk coming from transportation. The costs of a long term carbon dioxide policy are likely to be quite large. Having sectors at different levels of effort is really quite inefficient and potentially very expensive. So if you know in the long run you want an economy wide program, what does it mean to have a fourth pollutant in your power plant bill? Is that fundamentally a good or bad idea?

And the last two points are really just focusing on a couple of things. One is that the Hg costs and benefits are very uncertain and we should think about what that means for our policy choices. The last point is that the rough calculations of marginal benefits from, at least SO_2, appear to exceed their costs. This leads to the question of whether we should be going for more reductions of SO_2 based on a cost benefit analysis, rather than the Clean Air Act.

In terms of a safety valve, this graph (shown) highlights the potential problems. Bear in mind this is not necessarily the best designed trading in the world, it is the NOx reclaim market. What are shown are graphs of the price of different vintages of allowances in different years. The blue line that's labeled 2000 is a 2000 vintage allowance that could only be used to meet your requirements in 2000 if you are in this particular market. The 1999 is the 1999 and all the lines grouped at the bottom are the preceding 5 years. What happened in California where this market exists, beginning in 1999 to 2000 there was dramatic shortage of allowances, primarily due the power shortages, more generation taking place of electricity, and the fact that there wasn't as much coming from the hydro sources in Northwest. All this lead to a shortage of allowances because there was no banking in this market people didn't have a rainy day fund to provide them with allowances and the prices shot up. Whereas prices had typically been in the order of a couple thousand dollars per ton, they shot up to almost fifty thousand dollars per ton. The idea of a safety valve is that when prices reach a certain point, and that point might be $15,000, $10,000, it might be $5,000, the government or regulatory agency sells additional allowances at that point to allow people participating in that program to meet their requirements without having to pay an exorbitant price. So it caps the amount people have to pay to meet the requirement.

This does not mean that you are guaranteed to meet your cap. For example, if you had a particular number of allowances that you had given out and then you give out extra allowances at the safety valve price you are going to go over your emissions allowance (your initial allocation). The point is that usually when we set these allowances schemes and set the target, we balance cost and benefits and if the cost end up being much higher than they were supposed to be we probably don't care if the emissions get a little higher than they were in the original plan. In my mind if we had a safety valve in this market we would not have had the break down that happened in 1999 and into 2000.

This is just a graph to illustrate a South Coast Air Quality Management (SCAQM) analysis of what happened in 1999 and 2000, and what should be done to fix it. All their calculations showed that you could have obtained reductions for about $3,000 a ton, that there was really no need, in the long run, for prices to go up to $50,000 in order to encourage reductions. Yet the design of the policy allowed that to happen.

So what does that mean? Even the SCAQM that was responsible for the reclaim program effectively recommended a price cap, a safety valve at about $15,000 a ton which is pretty high but it still adopts the philosophy of a safety valve.

The Clear Skies Initiative, which is one of the two things that was a focus of this conversation, has a safety valve built in at exactly $4,000 per ton for SO_2 and NOx and about $2,200 per ounce for Hg. The research that I did two years ago which was subsequently published last year, examined the fact that even though CO_2 had a really high safety valve, huge benefits were still present. For example, in the NOx reclaim program, maybe their cost benefit analysis suggested that their allowances should be about $3,000 per ton. In fact, even having a safety valve at $15,000 is very beneficial in terms of the expected out comes and what might happen in a bad situation.

In summarizing, the safety valve is a very integral part or should be an integral part of these policies. It need not be low in order to be effective. I think initially when people at RFF were talking about safety valves we were talking about levels that people thought of as just valves, they weren't safety valves, they were always just open. And they were effectively fixing the price at a particular level. That may be people's preferences, including my own, but the value of the safety valve is that it helps you avoid bad outcomes. So I think it's just a sensible thing to think about.

The second broad point, architectural point, concerns auctions. Earlier today, you heard about the efficiencies advantages of auctions, namely raising revenues and off setting distortionary taxes elsewhere in the economy.

The reality, as Sam [Napolitano] pointed out, is this runs counter to the interests of a lot of the regulated entities paying for those allowances when they think they should be getting them for free, as well as getting some compensation for the fact that they may be bearing the cost of control. My point is simply over the long run if you have competitive markets, in 20 or 30 years facilities that aren't efficient are going to be exiting the market anyway, and consumers are going to be bearing the costs of those emission allowances as they will likely be passed on. In the long run, it's hard to argue that the owners of the electricity generator units need to compensated or receive their allowances for free. The equity concerns that drive the near term interests really don't apply in the long term.

The existence of these allowances can create a hurdle when you try to reform the policy. People who hold these allowances have some expectation that their property right (interests in these allowances), is going to be propagated in the next regulatory scheme. They naturally don't want the value of those allowances to decline. So for example if you look at the CSI, the SO_2 allowances are allocated primarily based on the Title IV allocations, which in turn were based on data from 1985. You think about the fact that allowances in 2010 are going to be based on the circumstances that existed data wise in 1985 and the politics in 1990 when these were debated. It does not appear that this is the most practical way to allocate allowances. So that's a sense in which I think existence of such perpetual entitlements creates problems in the future.

So just to summarize, the arguments for grandfathering or giving away the allowances freely don't appear advantageous in the long run, although in the short run there may be a basis. Also, formulas that were developed for allocating allowances are out dated or irrelevant. Lastly, efficiency while it points to auctions, equity in the future probably points towards the consumers and not towards the owners of the power plants.

Now let's talk briefly about the different pollutants that are being covered by these bills, the differences between them and why we might think the regulation would look different and the design of the policy would look different for the allowance allocations as well as the other features.

First let's discuss CO_2. While Hg, SO_2 and NO_x are all controlled by some sort of end of pipe treatment, CO_2 is controlled by switching from coal to natural gas or coal and natural gas to carbon free technologies. The prospect of actually capturing CO_2 and doing something with it, injecting it into the ground for example, is going to be very costly for the next couple of decades. It's important to keep that in mind that we're not simply talking about making coal fire generation more expensive, we're talking about getting rid of some coal fire generation if we're going to have some significant reductions.

The second feature to keep in mind is the origin of the emissions. Hg and SO_2 are only associated with coal and oil, but oil is not used very much, and a point to keep in mind is that coal is usually not the marginal cost producer (they are not setting the price of electricity). When you have a regulation that only affects coal, none of that gets passed on to the consumers and all of it basically gets eaten up by the people in the coal plants. In the short run this is going to be a significant cost, and that's why for Hg and SO_2 there are certainly strong arguments just on the equity concerns for grandfathering allowances. For NOx it's different, because both gas and coal emit it (although nuclear doesn't) and other sources don't. You have to think about in the future there are going to be more gas plants, those new gas plants are going to emit NOx and how are they going to feel if all these old gas plants got their allowances for free, which is basically the concern that a lot of people raised.

Let's discuss regulating specific pollutants. For CO_2, the costs are relatively well understood. While there is a lot of uncertainty about cost in the short term, it is driven by unseen events, e.g., whether or not we have a cold winter and a warm summer, whether not there's a drought in the northwest where they use hydro power. However, we know exactly what needs to be done in order to reduce CO_2 emissions and how much it's going to cost.

The benefits from CO_2 reduction from mitigating global climate claims are highly uncertain, but what's interesting is that we actually have estimates. People have tried to work through the consequences of climate change and make estimates of what mitigating climate change and reducing CO_2 emissions would actually be valued at.

For Hg, I would argue that we actually have uncertainty on both sides. The costs, at least when I was in the administration, were hotly debated – there was the questions about how much Hg reductions you get for free when you reduce other pollutants. There are also concerns about the fact that we haven't done many studies of pollution control technologies for Hg, we just don't have the best handle on how much it's going to cost. The other issue is that we really have very little idea of the exact quantitative benefits of reducing Hg. We understand what's happening and why it's a problem, but the actual quantification in terms of dollars per ton or dollars per ounce have been elusive so far. Meanwhile for NOx and SO_2, we have a much better grasp of costs and benefits so we can say a little more.

My point on CO_2 emissions is mainly that electricity is only a piece of the puzzle. Here we see an estimate of what emissions will be like in 2010 and what you see is that while electricity emissions from gas and oil and coal are a large chunk of the problem, an enormous piece is transportation.

So relative to long term costs, you need to be very concerned about making sure you're looking for equivalent reductions or equally cheap reductions in all sectors. This is the basic argument, you're looking for significant reductions in the long term and those significant reductions are going to cost a lot. Thus, if you only focus on one sector, aside from high cost, you may actually distort choices. For example, if electricity is regulated and industrial sources don't have to pay any overhead on direct emissions of CO_2 from burning gas, this will create leakage and encourage people just to burn directly instead of using electricity in a way that's not efficient.

Let's discuss the costs to reduce CO_2. I'm showing you economy wide costs pilfered from a study by the energy modeling forum, and these are estimates of the marginal costs on the vertical axis and percent reductions in the US on the horizontal axis. The prices are in 1990 dollars, but what you see is that for the economy as a whole we may be slightly more expensive in the electricity sector. Prices on the order of $50 per ton are only getting you between 5 and 10, 15 percent reductions depending on which of these models you believe. So is this expensive? Well, when you start talking about large percentage reductions (for example 25% reductions) the area under the curve yields a total cost estimate of about $30 billion. This would make CO_2 the most expensive regulatory program in the country by a large margin. In comparison, both the CSI and the JLB are estimating costs on the order of $10 billion, so when you start talking about significant reductions in CO_2 you're really talking about a lot of money.

This slide discusses the estimate of benefits. The point to keep in mind is that even though CO2 and greenhouse gases and their consequences are very uncertain, the IPCC in their 1995 second assessment report surveyed the literature, and found you have a range of estimates and people have been able to bracket what the marginal cost should be. For example, a high estimate by William Kline is up to about $150 per ton but most of the estimates are much lower on the order of $20 or $30 dollars a ton. If you escalate these estimates up to 2000 dollars, the mean is roughly $30 per ton.

In summary, the conclusion is that eventually we're going to need an economy wide program to avoid wasting billions of dollars. The question I have is how do you grow an economy wide program out of an electricity only program? Moreover, what problems arise? I would argue the longer the discrepancy exists between the cost of CO_2 in the electricity sector and the cost elsewhere, the harder it's going to be to get them to come together at some point in the future. But that's just sort of a gut reaction. In this case, I have put forward my own belief that it may be better to wait to get the design right than going ahead with CO2 in the power sector. That's open to debate.

I want to briefly talk about Hg. The important thing to remember with Hg is that you have a lot of uncertainty with the cost. In particular, guessing the right price for how much it's going to cost to reduce Hg is an uncertain game. In addition, there is no quantification of benefits, due to the fact that we don't exactly know how emissions from the power plants get deposited. There is kind of a global circulation of mercury in the world and if we reduce the emissions of the US, it's not clear how much the deposition of the US is actually going to decline. We probably have a better model of accumulation in the biosphere. The mechanism for affecting humans and the largest benefit, if we were going to try to monetize them, come from consumption of fish. There may be a lot of inexpensive ways to deal with this like encouraging people to not eat fish that are cheaper than spending a lot of money on Hg reductions from power plants.

We should try to evaluate what we are getting under CSI ($1,000 an ounce), while under the JLB, it's more like $10,000-$20,000 an ounce. The question is not whether Hg is bad, it's whether we are using our resources wisely to reduce emissions by this much from power plants.

On the cost and benefits of SO_2 and NOx, the EPA analysis (which is the only analysis of the exact proposal), shows cost ranging from $400 per ton to $1,800-$1,200 depending on which pollutant you are talking about and which zone because NOx has two zones (an east and a west) under CSI. On the benefits side, EPA has two estimates in their technical summary. There's a base case which estimates $96 billion and there's a conservative summary $14.2 billion. The difference between the estimates is the discount rate they use and how they value mortality, in terms of life years. Even if you take the conservative estimate of $14.2 billion, and divide it by the ton reductions you are getting in 2020, you obtain $1,900 per ton on an average as the benefit.

Whether or not the benefit are linear or not is a separate question, but it's certainly suggestive to me there are a lot of benefits there. An additional point is that you can't really treat SO_2 and NOx as being equally contributing to the particulate problem. If you divide the $14.2 billion into the 5 million tons of SO_2 reductions, you actually get a higher marginal benefit on SO_2. The point therefore is if you look at the marginal analysis where the costs are on the order of a thousand dollars (maybe going up to $1,400 for NOx and never really going over a thousand dollars for SO_2), under CSI you want to ask the question of whether or not we're really at the right point on SO_2 or NOx. This is where we actually have the best data.

This slide summarizes the cost and benefits of the two bills, and illustrates the JLB analysis. You see a cost of $50 to $100 per ton carbon, and the studies I cited earlier seem to be at about $30 a ton carbon. The JLB costs on Hg are quite high at about $10,000 to $23,000 an ounce. In CSI in 2010, they are $600 an ounce going up to $800 or $1,000 an ounce by 2020, and we have no idea what the benefits are, and we may be very uncertain about those costs. On NOx and SO_2, we see benefits in the order of $2000 per ton (they may be higher for SO_2 than NOx). Meanwhile the costs are actually lower for SO_2 than for NOx. So it suggests on the margin that maybe we should be looking at tighter regulation on SO_2 and less strict regulation on NOx. I would note of course that this has nothing to do with what is mandated under the Clean Air Act. This is just our economics coming to bear on these pollutants. If you are going to make changes or debate different bills it's kind of handy to have this information on hand.

In conclusion, I think we need to focus first on architecture because I think that's where economics has the most "cleanly cut" things to say. A safety valve makes sense no matter what at some level and then we can debate what the level is. If you want to encourage people to use a market based program you don't want to set up a system where you may accidentally have the market fall apart, as has happened with the reclaim market. Especially if you are thinking about CO_2, and you are thinking about a long term strategy, you don't want to mess-up in the first step because that first stumble could set you back quite a ways.

I think in the long run, there really are no strong arguments against auctions. I think in the short term for some pollutants it makes sense to think about giving them away.

On CO_2, I think you have to think about the long term of having an economy wide approach and how exactly you are going to go from having a sector based approach if you a introduce a 4-P bill to an economy wide approach where there's going to be a large discrepancy in prices for 10 or 15 years.

On the targets themselves, just quickly summarizing, per evidence on Hg I think we should ask the question is it really worth a $1,000 or $10,000 an ounce - given other opportunities and maybe doing further research on it.

There seems to be good evidence on SO_2 and NOx that it might be worth, especially on SO_2, to probably do a little bit more than what the bills are currently suggesting.

More Multi-Pollutant Trading Proposal Comparisons
David Doniger, Policy Director - Natural Resources Defense Council

[speaker opens with a disclaimer stating that he'll skip over some of the background information on "the four pollutants" that he would normally cover with a more-general audience—dives right into it]

We think there really is an opportunity in a four-pollutant bill to achieve these four values – lower emissions, lower costs, greater certainty, and greater consistency. We don't think the three-pollutant approach has any merit—it doesn't address CO2. Less attention has been paid to the comparison between what's in the Clear Skies Bill (CSI) for SOx, NOx and Hg and what would be required by the Clean Air Act (CAA) or what was considered in the original Clear Skies proposal that was developed by EPA, which was much watered down before it came out of the administration. Either under this original proposal, which is available and has much of the same analysis behind it with the same tools that EPA uses for CSI, shows that it would have much greater benefits at marginally higher costs to make much quicker and deeper cuts in SOx, NOx and Hg. [sic]

The difference between this original EPA proposal on Clear Skies and the administration's proposal is an estimated 61 billion dollars per year in benefits when you get out to the year 2020. That dollar figure represents the projected savings in health and medical expenditures associated primarily with the proposed tighter controls on fine particles. The extra industry costs for implementing this EPA proposal were estimated to be about 3.5 billion dollars annually. So, that's 61 billion dollars in extra health costs placed on the public to save the power industry 3.5 billion dollars a year—not a good deal.

In comparing CSI with existing laws, we find that: (1) It delays the implementation of the air quality standards. (2) It would allow local pollution increases, because it weakens the new source review controls. (3) It weakens downwind states' abilities to control upwind state's pollution. (4) It weakens the protection of the special air quality values of the national parks and wildernesses.

Now, separately, the President has a climate plan, a voluntary climate plan. To his credit he acknowledged a year ago in February that some day, somehow, we have to slow, stop, and then reverse the growth of global-warming pollution. But voluntary goals have been tried and failed. What is a voluntary goal? It's industry self-regulation. The President's goal for industry self-regulation works out—it's stated in terms of an intensity target and a reduction in intensity of emissions—but it works out, when you do the math, to the same 14% percent actual increase in CO2 and other global-warming pollution over the next decade as we had in the last decade, so it presents no progress over the voluntary programs of the past. One of the cute things is that the power sector itself volunteered, in response to a call for new pledges from the administration, to a target that works out to even more emissions than the business's usual calculations of the Energy Information Administration (EIA).

Here you see these two things graphed - 14% economy-wide emissions growth in the last 10 years and 14% expected in the next 10 years if the President's plan is fully carried out by the industries. In the power sector the EIA projected 11% more CO2 in 2010 than in 2000 and the Edison Electric Institute is graciously promising to bring us 13-16% more. This little box in the lower left represents sort of an envelope of carbon concentration on the y- axis and temperature on the x-axis. We've never gone above 380 and that's about where we are right now, and we're about a degree higher than we were at the beginning of the Industrial Revolution in terms of average temperature. Here we are, sitting on the right hand corner of the graph and going northeast. It's not a pretty picture and it has a lot of risks. Most of those risks can't be well captured in cost benefit analysis, which attempts to gather known information, because we've never been there before. We know a lot about what these risks are, but it's very hard to quantify them and put benefits on them. In the words of the MasterCard ad…some things are priceless.

We focus on the power plants, but not exclusively. I should say that the targets—the priorities—of the climate center of the NRDC are on power plants, because they represent 40% of the U.S. CO2 emissions, and on motor vehicles—passenger vehicles—because they represent 20% of the emissions. That's a good chunk between them. But more than that, we think that if someone cracked the nut on these industries, had a breakthrough on these industries, the rest of the economy would follow. It is not our objective to have any long-term condition of separate sectoral approaches, but we do think the path forward is to focus on power plants and vehicles first. Most of our vehicle work these days is in California, where the state passed its law last summer to regulate CO2 and other global-warming pollution from vehicles. We will also be supporting an oil savings provision that will likely come up in the energy bill debate later on this spring.

Going back to power plants…we need to act now. There is a basic point about power plants that everyone in the debate agrees on, and it can be summed up in a train analogy. There are three trains that are already leaving the station. They are running on different tracks at different speeds, and some would think the tracks are maybe criss-crossing each other and there is some inconsistency. There certainly is a lot of uncertainty—which train do I catch?—and how do I coordinate them? And there's a fourth train sitting at the station that everybody knows is going to move at some point. So, does it make sense to pass a bill—even one that rationalizes three of the four problems—and not deal with the fourth? We think there is a logical economic argument as well as an environmental one for integration, which saves a ton of money by reducing regulatory uncertainty and surprise and reducing the potential for companies making a lot of choices that turn out to be stranded.

Another reason to move forward here, though I basically agree with Billy [Pizer] that the primary pathway to solve the global warming problem is to move away from putting fossil carbon into the atmosphere, that does not necessarily mean that you can't use fossil fuels—if you can find a way to tuck the fossil carbon back underground. Our organization has been somewhat forward-leaning among the environmental groups in considering and even talking up the potential for carbon capture and underground sequestration as a significant part of the solution, for at least the middle century so to speak, where the coal resources and the coal industries might continue to have life provided they can isolate the carbon from the atmosphere. And, finally, a signal would be sent to other sectors that would be helpful in getting the whole economy under control.

Now, a hugely important consideration is this one: the longer we wait the more painful the cuts. If you assume that there is some target out there, some atmospheric concentration that you do not want to exceed because it would be dangerous, you can make a respectable case that we are already at levels that are dangerous. Certainly 450 - 550 parts per million carbon a great many people would consider the impacts that would come with that to be dangerous and to be avoided. Higher levels bring even higher levels of danger. Whatever level you settle on, the longer you run the emissions up, the steeper the slope you have to come down on if you are going to stay within that target—and the gentler path is one which starts sooner.

We want to strengthen, not weaken, the CAA. We want to protect public health and we want to include CO2 both for environmental and economic reasons. A quick comparison between the CSI and the Jeffords-Collins-Lieberman Bill shows a big difference on Hg, a big difference on SOx, a fairly big difference on NOx, and a big difference on CO2.

A couple of structural issues, or hotspots: The original premise of the original Clear Skies bill proposed by the EPA in 2001 was that you could deliver the same overall tonnage reductions that were anticipated to come from implementing the CAA through a cap-and-trade program, and that doing so might eliminate the need for some of the command-and-control infrastructure that's currently in the bill. There was a belief that you would pick up some efficiencies, and there is a case for this. However, there are two problems: (1) Even in that setting, there needs to be some addressing of the potential that pollution can be loaded up in one place in ways that are detrimental to local public health. You can end up with increases in pollution in one particular place, even though overall levels are going down, because of the workings of emissions trading. So, when the Acid Rain Program was added to the CAA in 1990, it was not—and never has been—the only safeguard against dangerous SO2 concentrations or particulate levels. The New Source Review program and SIP process remain underneath the Acid Rain Program, and we think that it's essential to keep some serious curbs on local pollution increases within any cap-and-trade program. It's especially acute a problem under the Clear Skies proposal that was actually made because the emission limits for SO2, NOx and Hg under the President's proposal are much weaker and much delayed compared to the original EPA proposal, which in turn was intended to be an approximation of what the CAA right now was going to deliver. So, I think there's a very strong case that the President's proposal is a rollback of the CAA. One of the most troubling statements the administration spokesmen make is that in comparison to the CAA there is a 35-million-ton benefit coming from CSI. This is based on a set of assumptions that Jeff Holmstead, the Air Chief, has repeatedly characterized as the Rip Van Winkle scenario. In this scenario, you implement the Acid Rain Program and the NOx Sipcal—the 1997 Sipcal for power plants—but you don't do anything else—you put the CAA to sleep for 10 years and make that your baseline. That's not what the CAA requires; it's not a fair comparison. We think a fair comparison shows CSI to be running about 20 million tons *behind* implementation of the CAA in that time period—not 35 million tons ahead. The precise number is not important, but the *sign* is tremendously important.

The Clean Power Act doesn't allow any Hg trading for this hotspot reason: There are reasonable arguments that can be made that there's some hybrid approach that might be used for Hg that allows some amount of trading above a minimum reduction or a maximum emission rate for individual sources. These hotspot issues are generally not an issue for CO2.

Second structural issue is a question of whether to use off-system flexibility. I want to make clear that the Jeffords bill, the Clean Power Act, contemplates that there will be carbon caps for other sectors, and automatically there should be a window for seamless trading between any two carbon-cap sectors. If there are tons of allowances in another sector, they should be equally usable so that the trading would allow the tons to flow into the power sector or, if the situation is reversed, out of the power sector to the other one. The bill is constructed so that you don't need any new enactments with regard to the power sector to turn on inter-sectoral trading once there is another sector to trade with.

What we are very concerned about, however, is credit trading from uncapped sources. The 1605-B program run by the Department of Energy is a walking, stumbling example of what happens when you turn loose the uncapped credit trading. Every lesson we learned from the bubble concept about how that can be abused is being repeated in the 1605-B context. We put out a report that demonstrates that even as the power sector, which is the only sector that actually has to report its emissions, so you actually know what the power sector's emissions are, even as they report their emissions (and they have gone up by more than 400 million tons over the last decade), the power industry has reported more than 100 million tons of bogus reductions to the Department of Energy. There may be a couple of small opals or semi-precious stones tucked in there somewhere, but mostly it can be characterized with a barnyard metaphor—it's real junk. Most of the reductions are for the selfless act of running nuclear power plants up to their economic capacity and then comparing that to a base case in which they were not run well and in which they were shut down more and coal plants had to be used instead. Most of the emissions credits come from this counter-factual.

Bad credits inflate the cap. The Carper Bill, which is another entry into the sweepstakes here, allows for unlimited use of off-sector offsets from uncapped sources. It doesn't specify any real criteria for controlling the quality or the quantity, and you can end up with some bad results from our vantage point. You could even have a situation where the off-sector credits allow the power sector to emit even more than in the BAU case.

The McCain-Lieberman Bill, which we haven't talked about much here, does allow for some use of these off-system credits from uncapped sources but there is a quantity limit on how many there can be. There are also some useful controls in the McCain-Lieberman Bill to make sure that sequestration in the biosphere is done with some credibility to it.

A little bit on allowance allocations: This probably does sky off what Billy [Pizer] has said fairly well. Especially when one is talking about a program with carbon in it you have this anomaly where the total value of the allowances is much greater than the program resource costs. So when you ask how much is it really costing the power plants to reduce carbon to a given level it turns out to be only a small fraction of the total value of the allowances. At least in a competitive market situation the allowance value is folded into electricity prices just as fuel or other inputs and passed on to consumers. So you can have a very massive resource transfer to the owners of the power plants if all the allowances are grandfathered. Dallas [Burtaw] has done some work that shows, if I have interpreted it correctly, that CO2 allowances can be worth 10 to even 13 times more than the impact on the power industries' assets from the control costs. In other words if you figure out by how much power industries' assets are reduced if they have to absorb all the control costs, and then you ask yourself how many of the allowances would you have to give them to make them whole but not enrich them, the answer is something on the order of 7.5% (according to Dallas' work). Other estimates I've seen show 10 –15% of the allowances going to the power sector's asset owners in order to offset the impact of the controls. If you give them more, they end up with tens of billions of dollars in what can only be described as an unjust enrichment.

Most of the ideas of auctioning are variations on these themes that the allowances to pollute or the use of the atmosphere is a publicly owned resource and it should be used to the benefit of consumers—in this case to counter the wealth transfer that might otherwise be occurring with admittedly economically efficient tool of cap and trade.

So, we favor using the slices of the allowance pie to accomplish different public purposes, such as protecting consumers or promoting such initiatives as efficiency renewables, clean generation, and carbon capture and sequestration. This is implicitly done through another one of the allocation formulas called output-based standards. Basically, the idea is that if you give renewables, or clean generation, or even efficiency an award of allowances for each kilowatt-hour that they produce or save, then their cost is being bought down and you'll get more of those "incentivized" technologies more rapidly than you would otherwise.

Another use that can be made of part of the allowance pie is to take care of the communities and employees and even some businesses who may be adversely or disproportionately affected by the transitional costs of this program.

So here's one hybrid example and we support this bill—we support the concept in this bill—because we think that in the end any allowance allocation system for carbon, and for other pollutants too, will not likely be a pure system. The administration has already proposed a hybrid that goes from grandfathering to auctioning. Carper has his proposal on the table, which is a pure output-based approach—and there may even be other approaches—but you will see a hybrid.

[The speaker goes off into a story about how he was the only representative of an interest group allowed into the room where the House Energy and Commerce Committee was meeting to mark-up the final version of the Acid Rain bill in 1990. Remarking that he was led past a drooling pack of well-dressed lobbyists, who were being held at bay, he was led into the room where the legislators were "carving up the sulfur pizza—over pizza." As they sat around trading favors—securing each other's votes on various issues—sculpting the Acid Rain Program, they were literally carving up and eating dozens of pizzas. He concludes the story by commenting that any eventual carbon allowance allocation system will undoubtedly go through the same process, and he continues--]

There is going to be some constructive constituency work and deal-making to come up with a package that meets needs. Some of those needs will include the needs of the power generators but, as I said, they can be made whole for a relatively small slice of the carbon allowance pie. There's a need to take care of the mine workers and others who feel a need for transition assistance. From our vantage point, it's very desirable to incentivize some of the cleaner technologies that we need to get over the hump that has come from the fact that carbon has been zero-priced for so long. And we need to take care of the consumers who should not have to bear the wealth transfer that would come if the allowances were otherwise given over to the owners of the power plants.

So these slices can grow, and they can shrink, and there are other colors in the rainbow for other slices if people have other proposals to add. It obviously must add up to no more than 100% of the allowances, but there's a lot of room to work with.

Those are some thoughts about what's going on from our vantage point.

May 2, 2003 4:15 PM
Question and Answer Session

Q: Bill Jaeger, Oregon State University
I have a question related, Sam, to your comment that maybe the auction idea is ahead of its time because firms aren't in favor of it and coal miners aren't in favor of it. Seems to me that those people will never be in favor of it, because you're asking them to give up some money or give up some jobs. Until we identify the constituency that will benefit from the revenues from an auction, I'm not sure how we can build political support. If we were able to link the auction to what those revenues from the auction would be used for and who would benefit from them, then it seems to me you could identify a group that would say, 'Hey I'm in favor of auctions.'

A: David Doniger: I can understand why it's not particularly attractive to the mine workers to look at an auction in which only 20% of the value, or less, is actually captured and 80% or 90% is grandfathered. It's not substantially different. So to walk over the edge and support this without knowing that there's significant money involved and that it's going to come to them, which is partly your point, is to expect too much. When a carbon program is no longer avoidable, the mine workers are going to be there with a demand to be in some way made whole—taken care of. One can evaluate how much it's just that they should receive or other claimants should receive, but unless you have a structure that does something like this with the allowances, there's no revenue, there's no value to meet that need with. Put another way, there's a real opportunity if you approach it this way.

A: William Pizer:
Two things: One is that I think you do see firms that are not actually in favor of grandfathering if they don't think they are actually going to be the ones at the table getting it. I mean it could be people who perceive themselves as new entrants in the future, for example new gas-fired facilities—it could be large energy consumers, but they're not necessarily pushing for an auction—they're maybe pushing for something else—but they probably don't like standing up for the grandfathering. The other thing that is interesting about what David just said (about once the mine workers see that a carbon policy is inevitable)—I think one thing that struck me about this problem, because CO2 is so pervasive in the economy and so pervasive in electricity generation too, it's going to have to start out small. I think that's something that is hard sometimes to grasp, just because the consequences for the mine workers are going to be huge; the consequences for the communities are going to be huge. I think expecting a large sudden reduction is kind of putting the cart before the horse. It's interesting, David, in your presentation you talked about how hard it gets as we delay, and certainly that's true to some extent, but a certain amount of delay is certainly reasonable because the future gives us time to turn around the capital stock, gives us time to invest in new technologies. Who knows, maybe in 30 years we'll actually have some solutions to problems that right now seem somewhat intractable. That isn't an excuse for not doing anything, but it may be a reason to think about a more gradualist approach. I had to slip this in—you mentioned the MasterCard commercial about some things being priceless. I am

wondering whether you were referring to the value of the thing you were getting or the price you were paying. It seemed like there was a big difference if we could get the priceless environmental benefit for some reasonable cost. On the other hand, if we're spending an infinite amount of money to get the environmental benefit, I think it has a slightly different punch line.

A. Sam Napolitano
Adding to it, I thought the way we went about doing the auction in the Clear Skies Bill was about as clever as you could be in terms of gradually phasing it in, in that it doesn't come into being a complete state that you've totally turned over until about 50 years out. An amazing amount of the wealth sits with those people who are now getting the grandfathered allowances as we speak, but basically there is not a company that has come out. In a flip way, I can remember talking to Capitol Hill staffers who called over and asked about the auction and why we did this. They said something along the lines of, 'Do you have any supporters for this?' I said, 'Well, environmental and welfare economists throughout the country.' They said, 'Well, how many votes do they have?' That's almost the way it's being treated even though it's an elegant idea. You have the idea, I know when you talk about the revenue coming back to people, but there's a little bit of "the check's in the mail" aspect to this when it comes to actually seeing that revenue coming into the treasury and that there would be any tax change that possibly could happen. It's kind of the attitude that exists.

A. David Doniger
Actually, that's why the Jeffords structure is interesting for people to study. Most economists who approach this say the clean way to do this is to auction out of the treasury, bring the money into the treasury and then disperse it through tax reductions or other kinds of spending, so it's a revenue and spending thing. When you think about that politically, it has a lot of hurdles. I will not go into all of them, but one of them is that you involve three committees in each body of Congress instead of one. You involve the Environmental Committee, obviously that's the constant, and you involve the Finance Committee and you involve the Appropriations Committee. Well, the Jeffords Bill concept is that the allowances are what are being allocated. Think about the chart that I gave as all grandfathering—the question is to whom are they going to be grandfathered?—Who are they going to be given to? The first cut, which is what the bill represents, is to create a trustee who receives the allowances on behalf of certain targeted beneficiaries and then outside the federal budgetary machinery conducts the sale. If you read the bill, you will not find the word "auction"—instead, it says the trustee "liquidates" the allowances he has been allocated, and the proceeds go to the beneficiaries. You can achieve the economic benefits of the normal auction model without using the word and without using the usual structures. That may be more doable in a political context.

A. William Pizer:
One thing I didn't bring up here that we talked about actually in our earlier discussion about allocations is it is actually significant that the revenue under the Jeffords Lieberman is not going into the treasury. A lot of the advantages . . . well, it is under the

Clear Skies—it's just not very much money. If you're attuned to auctions because of the revenue recycling, the Jeffords Lieberman approach is not really getting at that. As David just explained, it's grandfathering in a different way. There's really no way to achieve the kind of auctioning results that economists like without involving all these committees, which is kind of a mess.

Q. Bill Shobe, Virginia Department of Planning and Budget:
I wanted to ask whether we know enough about the science of NOx and SOx to allow trading between the two. I heard some talk of inter-pollutant trading, but it seems here are two that seem likely candidates. Is there much discussion about that?

A. William Pizer:
I know Randy Lutter actually wrote a paper on that, but I don't know where it is. He was at the American Enterprise Institute and he's a big advocate of that.

A. Sam Napolitano:
At one point, that was actually posted on our website when Randy did some looking at the relationship. You could have two ways to do it: One way is you could set up that relationship and allow for trading in terms of setting up the different values for each of the pollutants where they can be traded against each another. Or alternatively, what you can grossly do is try to set up cap-and-trade programs that effect roughly the same thing—i.e., take more SO2 out of the air than NOx. In a crude sense, that's what we think Clear Skies is actually doing.

Q. Bill Shobe continued:
I'm sorry, I just want some clarification. In these bills is there going to be trading across pollutants or is it just trading within each pollutant?

A. Sam Napolitano:
I think each one can trade with each pollutant. But I think each one of the bills makes a more substantial reduction in SO2. So, in a gross sense each one of them has it right about which pollutant is greater and more cost-effective to tackle.

A. William Pizer
It also varies by zones. Clear Skies has two zones for NOx and I think the Jeffords Lieberman has two zones for SO2. So for various reasons there have actually been further regional bifurcations of the pollutants.

Q: Robert Hearne, North Dakota State University:
Has there been any thought about what would happen if we gave state and local governments these permits to allocate as they would like—kind of a decentralized market without the auction? Any thought on that?

A. William Pizer
I know that when about 3 or 4 years ago a group of us at RFF talked about an economy-wide carbon program, in that program we envisioned a system somewhat like you just

said—namely that a large chunk of the revenue from the sales of these CO2 allowances or greenhouse gas allowances would be given back to the states, basically as block grants to assist the states with whatever transitional needs they had. The allocation to the states would be based on a mixture of what their emissions were as well as what their energy consumption was. So we tried to balance production and consumption of carbon intensive goods. That was the idea—admittedly, at the time it was because we really didn't have a good idea of how to structure a transitional program.

A. Sam Napolitano:
Actually, for what you are talking about from the NOx and NOx SIP Call we have, that's exactly what we have. We have allocations of allowances, but the state of Virginia will decide how those are given out to its sources, and that's what's happening throughout the states that are involved in that. I have not heard it discussed at all to let the states particularly be the solution at the federal level what we're talking about for multi-pollutant bills.

Q. William Pizer:
The SIP Calls, also, not just power plants, right?

A. Sam Napolitano:
Yes, it's got some industrial sources in some cases.

Q. Richard Dixon, Government of Alberta:
We just finished on Friday and I am not sure when it will be released, but there is a major feasibility study where we're looking into emissions trading for the province. We have our three P's--carbon, SO2 and NOx--and a bit of a different type of regime we have with Hg.

What we found though in our feasibility study, and it wasn't discussed here, is that the relationship with the 3P trading system is very important in terms of the tradeoff of technologies that we use for abatements given whether it's electricity . . . or this kind of thing. So it's quite different--it's not the science that's of interest so much as it is the technologies--and then the drive on the technologies and innovation. So that's where we're heading with that.

Q. Andy Patterson, Environmental Business International:
I wanted to ask you about the nuclear provisions in the new Dominici Bill since that's a big difference from last year. Particularly what impact it might have on the outlook for carbon trading if you included new nuclear production, not running the current fleet better, but new nuclear production because some of the utilities are weighing that option now. One of the interesting elements that Dominici put in the bill was financial incentives for construction of conventional nuclear but then threw in another provision for hydrogen production from gas-cooled nuclear. So you have two, in essence, public policy pushes for nuclear that would have an impact (a) possibly on reducing carbon reduction from coal plants by replacing them with convention nuclear; (b) you can move over to the transportation sector of your pie, Bill, by producing hydrogen. How do you

see the debate going on whether nuclear gets included going forward for offsets or not if it's new nuclear rather than just running the current fleet better, particularly since it's in the Dominici version of the energy bill now.

A. William Pizer

I don't think any of the bills . . . I mean the Jeffords Lieberman . . . obviously Clear Skies doesn't have carbon, and the Jeffords Lieberman I don't think has off-system credits, so there's really no way you get . . . I know Jeffords Lieberman you can put any price on carbon so you would be favoring nuclear by some amount. Coupled with those other incentives you might make nuclear competitive with gas or something. It would obviously help. My impression is that with nuclear the problem is siting, it's not just the cost.

Andy Patterson:

It's actually not the siting, you could build 20 to 30 more reactors.

William Pizer: . . .on the current existing sites, yeah.