ESTIMATING ENVIRONMENTAL COMPLIANCE COSTS FOR INDUSTRY: ENGINEERING AND ECONOMIC APPROACHES

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I. Introduction

The U.S. economy has changed in a number of ways over the last ten years. One of the important changes has been the extent to which certain kinds of activities have come to be circumscribed by federal regulations. These regulations extend from limitations on the discharge of air and water pollutants and permissible concentrations of harmful substances in workplaces to requirements governing the hiring and firing of employees. In both breadth and intensity, federal regulation has become more pronounced.

But how much more pronounced? This is a difficult question to answer because we often do not know how much regulation costs affected individuals, firms and governmental units. These costs of regulation are one -- but certainly not the only -- important measure of the scope and impact of regulation on the economy. One reason we lack such a measure of the cost of federal regulation is that the expenditures necessitated by regulation do not pass through the federal budget. That is, EPA does not install flue-gas scrubbers on electric power plants or build cooling towers at these facilities to ease thermal water pollution. Rather, they require these expenditures of private firms and there is very little *federal* accounting of the expenditures made by regulatees, either public or private.

This paper is concerned with the estimation of the costs incurred by the private sector in complying with federal environmental regulation. Its purpose is not to develop new estimates of these costs or to critique in great detail existing methodologies. Rather, our primary purpose is to discuss briefly the pros and cons of existing approaches to compliance cost estimation, outline several new and more comprehensive methodologies, and discuss the problems that would be encountered in trying to put these approaches into practice.

In the following section we indicate several reasons why compliance cost information is important, and draw several semantic distinctions it is important to bear in mind when thinking about such costs. Following that, we discuss a number of ongoing attempts to estimate the expenditures in previous years on environmental regulation; we also discuss several new ways in which inferences can be drawn about prior pollution control spending. Next, we take up the ex ante estimation of industrial compliance costs. That is, we look at ways in which prospective rather than existing regulations can be expected to affect the private sector. In this section we discuss the current method of forecasting compliance costs (which we refer to as the "input cost accounting approach"), as well as several more sophisticated methodologies to determine these costs. A final section touches on the practical prospects for improving compliance cost estimation in the ways we have suggested.

II. Why Estimate Compliance Costs?

Given the difficulties in identifying and quantifying them, one might be permitted to question the need for more accurate estimates of environmental compliance costs. There are three reasons these costs are important to know. First, and most simply, cost-benefit analyses of federal regulatory programs are impossible without accurate estimates of environmental compliance costs.

These cost-benefit analyses are in turn important because, when properly done, they can assist in identifying areas where additional regulation may do more harm than good, and areas where additional regulation will improve the allocation of resources resulting from the unaided private market. Efficiency in the allocation of resources is not the only economic goal of government, of course. Economic policy is designed to address both macroeconomic stability as well as the distribution of income. Nevertheless, efficiency in resource allocation is one very important goal, arguably the principal reason for the creation of federal regulatory agencies.

Accurate compliance cost estimates can do more than contribute to sound benefit-cost analysis, however. They can also be used to make inferences about the macroeconomic consequences associated with environmental regulation.[1] That is, compliance cost estimates can be used in a number of ways to help determine the effects of regulation on the price level, the unemployment rate, the rate of economic growth, the balance of trade, the levels of investment and productivity, and other indicators of aggregate economic activity. Thus, compliance cost estimates are essential to understanding both the allocative as well as the cyclical or counter-cyclical effects of environmental regulation.

Finally, accurate estimates of environmental compliance costs are essential if the costs imposed by regulatory agencies are ever to be subject to the same kinds of controls imposed on the direct spending of the various departments of the federal (and other levels of) government. To elaborate, some students of regulation have proposed that EPA and other regulatory agencies be subjected to a "regulatory budget" that would limit the annual total expenditures each could require public and private regulatees to make (in much the same way each of these agencies is currently limited in what it can spend for salaries, rent, travel, consultants, etc.).[2] Since no such limit now exists, some critics of regulation argue, agencies have no incentive to limit their regulatory appetites and establish priorities among and within programs — in short, have no incentive to think about new regulations in a way that is useful to society.

But if such a regulatory budget were ever to be considered seriously, one thing is clear: it would fail if there were no way to assess with some confidence the costs that regulated parties were forced to bear as a result of agencies' regulations. For it is only by adding up these costs that one could determine whether or not an agency had exceeded its regulatory budget for the year. Unlike the direct expenditure budget, there are no cancelled checks that can be tallied at the end of the year to check on total, on-budget spending. Absent an accounting system maintained by the regulatory agencies, an oversight body, and/or regulatees themselves, such an accounting would be impossible and the regulatory budget virtually unenforceable.

Thus, for a number of reasons it is important to have accurate information about the costs of complying with environmental regulation. Not only is such information essential to the analysis of the allocative, distributive, and macroeconomic effects of regulation; it is also a precondition for any type of new mechanism to control the costs that regulatory agencies impose on private and public parties.

Before turning to ways these costs have been examined in the past, it is useful to discuss briefly the kinds of compliance costs referred to throughout this paper.[3] The concept of costs appropriate to a benefit-cost analysis of environmental regulations is of course social opportunity cost. That is, all the productive opportunities that are foregone throughout the economy as a result of a regulation (not just those foregone by the regulatee) must be included as costs of the regulation. These will generally be greater than, but may sometimes be less than, the expenditures made by firms in response to regulation.[4] Nevertheless, for the purposes of this paper the terms "pollution control expenditures," "pollution control costs," and "compliance costs" will be used more or less interchangeably.

We also distinguish in this paper between direct and indirect costs. By the former we mean those associated with regulation that would show up in an accounting statement -- purchases of capital equipment, expenditures for the materials and energy to run the equipment, labor to operate and maintain it, and resources devoted to the recordkeeping and other administrative requirements arising from regulation. Indirect costs are also very important consequences of environmental and other regulation, but generally do not show up in the same way as direct costs. They include the diminished productivity that *may* result when regulations are imposed on private firms, the reduction in innovative activity perhaps induced by regulation, the losses that result when regulation induces "upstream" or "downstream" changes in factor mixes that inhibit production, and so on.

All these kinds of effects will not appear on a balance sheet across from an entry indicating a regulatory requirement. Nonetheless, they are very important, so important, in fact, that one of us has argued that econometric simulations of the effect of regulation on the economy cannot be taken too seriously for the very reason that they exclude these indirect costs.[5] It is because of the importance of these costs that we suggest in a later section the use of more complicated models to determine compliance costs than have been used in the past.

III. Ex Post Estimates of Environmental Compliance Costs

The most important use of compliance cost estimates is probably to determine, *in advance of regulation,* what would be the allocative and macroeconomic effects of the proposed rule. Nevertheless, we begin with a discussion of ex post estimates of the costs of complying with existing rules and regulations. There are a number of ways of determining past compliance costs; the problems encountered in these approaches foreshadow the difficulties that will arise in estimating the expected costs of proposed rules. Most of the ex post estimates are made using surveys of affected firms.

III.1. Survey Estimates of Expenditures[6]

Considering their importance, there are surprisingly few comprehensive estimates available of past expenditures for pollution control. Sometimes the information that is available is conflicting or disparate. For example, both the Bureau of Economic Analysis (BEA) and the Bureau of the Census (BOC) within the Department of Commerce conduct annual surveys to determine expenditures on pollution control. Similarly, McGraw-Hill Incorporated also surveys businesses annually to determine pollution abatement expenditures. Table 1 compares estimates from these three sources of actual capital investment in pollution abatement control for 1978, and estimates from McGraw-Hill and BEA of planned capital expenditures for 1980.

As columns 1, 2, and 3 of the table indicate, there are considerable differences between estimates, even with respect to actual or historical capital expenditures. For example, McGraw-Hill's estimate of pollution control investment in the machinery industry in 1978 is three times that of the Census Bureau, and more than twice that of BEA. On the other hand,

Table 1. Estimated Capital Expenditures for Pollution Control
(millions of dollars)

	1978 ACTUAL			1980 PLANNED	
	(1)	(2)	(3)	(4)	(5)
Industry	McG-Hill[a]	BEA[b]	Census[c]	McG-Hill[d]	BEA[b]
Iron and Steel	$425	$441	$793	$1069	$638
Nonferrous metals	293	247		285	285
Other primary metals	-	54		-	87
Electric machinery	134	130	75	238	126
Machinery	243	111	82	196	97
Autos, trucks, parts	193	198	140	162	311
Aerospace	45	23		30	34
Fabricated metals	137	-		189	-
Instruments	58	-		146	-
Stone	207	164	127	125	176
Other durables	190	181	186	116	199
Total durables	1935	1561	1402	2559	1956
Chemicals	547	565	842	762	476
Paper/Pulp	274	239	342	473	300
Rubber	100	58	28	201	58
Petroleum	834	1294	420	1525	1536
Food/Beverage	309	172	185	181	150
Textiles	81	29	60	110	36
Other nondurables	67	32	37	97	27
Total nondurables	2212	2389	1914	3450	2583
Total manufacturing	4147	3950	3316	6009	4540
Mining	511	206		109	171
Railroads	54	36		53	32
Airlines	20	15		97	13
Electric utilities	2791	2472		3615	2558
Gas utilities	60	35		61	44
Commercial	423	220		512	243
Commercial & Other Trans.				93	
	3859	2974		4539	3161
ALL BUSINESS	8006	6924		10,548	7699

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[a] 12th Annual McGraw-Hill Survey of Pollution Control Expenditures, May 14, 1979.

[b] Gary Rutledge and Betsy O'Connor, "Capital Expenditures by Business for Pollution Abatement, 1978, 1979, and Planned 1980," Survey of Current Business, June 1980.

[c] Pollution Abatement Costs and Expenditures, 1978, U.S. Bureau of the Census, MA-200(78)-2, U.S. G.P.O., Washington, D.C., 1980.

[d] 13th Annual McGraw-Hill Survey.

the Census estimate for investment in pollution control by the chemical industry is about 50 percent greater than the estimates of either McGraw-Hill or BEA. BEA's estimate for petroleum refining is more than three times that of the Census Bureau, and is 50 percent higher than McGraw-Hill's reported total. Other differences in both individual industry and total estimates are clear.

Given the discrepancies among estimates of historical expenditures for pollution abatement capital, one might expect even more divergent estimates of planned future expenditures. Columns 4 and 5 of Table 1 confirm this suspicion. According to McGraw-Hill, total planned capital expenditures for pollution abatement for all business in 1980 were $10.5 billion. This was 37 percent more than BEA projected based on its survey of manufacturing and nonmanufacturing firms. For the electric utility industry alone, the McGraw-Hill and BEA estimates of 1980 investment in pollution control differed by nearly a billion dollars.

There are two major reasons why these three sets of estimates diverge so. First, the Census Bureau surveys establishments or plants, while the BEA survey goes to firms. Hence, if a multidivision firm has operations in several different industries, *all* of its pollution control expenditures across all operations are attributed by BEA to its primary product. Thus, expenditures for pollution control in U.S. steel's paintmaking operations are recorded under "steel works" in the BEA survey. This accounts for some of the difference between BEA and Census. Second, the sample sizes used by BEA, Census, and McGraw-Hill differ. The Census Bureau surveys 20,000 plants to estimate pollution control investment in the manufacturing sector. The Bureau of Economic Analysis surveys about 15,000 firms to prepare its estimate. McGraw-Hill, like BEA, bases its estimates on a sample of firms, yet they sample only 346 -- less than 3 percent of BEA's sample size. Hence, all three sources are trying to estimate national totals based on different sample sizes, composition, and definitions.

Several factors point toward possible upward bias of all three sets of estimates. Although the response rates for the McGraw-Hill and Census surveys are unknown, it is about 60 percent for BEA, of which at least some responses no doubt prove unusable. It is not unreasonable to expect that the firms that do respond to the survey are those that are spending considerable amounts on pollution abatement. If their experience is generalized to all firms in an industry, the resulting estimates will be high. This will be particularly true in industries with both large firms and small firms. Since many regulations exempt firms below a certain size, the effect of environmental rules on all small firms taken could be negligible. Yet, if a number of small firms are treated as one big firm, estimates of their expenditures may be large.

Second, some respondents can be expected to have difficulty determining which portion of capital and operating expenditures is due to pollution abatement and which portion is made to improve normal operations and increase profitability. This joint cost problem is especially difficult when new facilities are constructed or existing ones are modified. The temptation in such cases is to err in the direction of large pollution control expenditures, creating a possible further upward bias to the estimates. Finally, although there is little evidence to support such a supposition, some firms may deliberately report erroneously high numbers in an attempt to cast regulation in a bad light.

There is another problem with the BEA, Census Bureau and McGraw-Hill estimates. Not only are they of questionable value in estimating what they attempt to estimate, that which they do estimate may not be what we are after. This is because the totals reported in the three surveys discussed above encompass pollution control spending that arises not only as a result of federal environmental regulation, but also spending necessitated by state and local controls, and spending voluntarily undertaken (as for good will). In terms of the distinction drawn by the Council on Environmental Quality, the surveys discussed above report total pollution control spending but do not separate out *incremental* spending (due to federal regulation). This extends not only to estimates of annual capital expenditures but also to estimates of annual operating costs.

The Census Bureau does try to eliminate one type of pollution control spending from their totals -- that which results in the profitable recovery of by-products. Their survey, reproduced as Appendix A in this report, makes allowance for and deducts this offsetting revenue (see Item 5 in the survey and its explanation in the "specific instruction"). Nevertheless, even the Census Bureau survey lumps together pollution control expenditures made in response to local, state or federal regulations and those expenditures made for good will. Thus, neither it nor the BEA or McGraw-Hill surveys are particularly useful in identifying pollution control costs that arise exclusively as a result of federal environmental regulation.

Even if the three surveys did isolate expenditures made in response to federal regulation, they would not be ideal for the tasks at hand. This is because the surveys lump together all air pollution spending, all water pollution spending, and all spending on solid waste. That is, there is no way to differentiate the effect of air pollution controls in State Implementation Plans (SIPs), for example, from those arising from new source performance standards, or from controls to prevent emissions into the atmosphere of hazardous air pollutants. Although survey estimates of aggregate spending necessitated by federal regulation would facilitate macroeconomic analyses, they would still not be useful in evaluating the allocative effects of specific regulations. For this, estimates would be needed on a regulation by regulation basis. It is unlikely that large scale surveys of the sort discussed here will ever provide such detailed information.

Even when firms have been surveyed in considerably more detail, this latter problem has remained. The analysis performed by Arthur Andersen and Company for the Business Roundtable (AA/BR) is a case in point.[7] This study was billed as the most comprehensive analysis to date of the economic effects of federal regulation on 48 major U.S. corporations. It included not only environmental regulation, but also occupational safety and health controls, affirmative action requirements, energy regulations, federal pension and retirement restrictions, and consumer protection requirements mandated by the Federal Trade Commission.

Perhaps the most significant aspect of the AA/BR study is the methodology it employed. A conscious effort was made to isolate for the year in question, 1977, these expenditures that arose *solely* as a result of federal regulation. According to AA/BR, for example, the study excluded air and water pollution control expenditures that the reporting firms would have made even had these expenditures not been required by regulation. This should make their estimates very conservative. For instance, suppose no law prohibited the discharge of substance X into the air. A law is then passed which prohibits this discharge.

One would assume that any costs associated with the control of X would be counted as incremental control costs. Not so in the AA/BR study. If a firm was controlling substance X to some degree prior to regulation, those costs are netted out of total control costs in calculating the incremental cost of complying with the regulation. (Figure 1 illustrates the AA/BR methodology).

There are several observations to be made about the AA/BR approach. First, it does improve in a couple of ways on the survey approach taken by BEA and the Census Bureau. Not only are incremental costs distinguished from other pollution control expenditures; also, it is somewhat easier to link incremental costs to specific regulatory requirements. For instance, the report targets particulate removal under State Implementation Plans as being expensive (especially in relation to the amount removed). It also identifies the national ambient air quality standard for ozone as being expensive for the firms surveyed to comply with.[8]

Second, the AA/BR study is bedeviled by a problem that always crops up in attempts to isolate regulation-induced spending from that which would take place anyway. This problem arises because it is always difficult if not impossible to determine what a firm would have spent in the absence of a particular regulation. Since this varies from firm to firm -- some would voluntarily remove much more pollution than others, for instance -- it is very difficult to extrapolate from a small sample of firms (48 in the AA/BR study) to the economy as a whole. For this reason and several others, no economy-wide estimates of regulatory burdens in 1977 were hazarded by AA/BR.

While understandable, this failure to generalize the findings from the 48 firms involved to the whole economy limits the usefulness of the AA/BR study. It makes it impossible, for example, to compare the BEA, Census Bureau, and McGraw-Hill estimates of new investment in pollution control with the figures in the AA/BR study. This is unfortunate because of the careful and conscious focus in the latter on incremental effects. This in turn makes it difficult to use the AA/BR study as a basis for any analysis of the macroeconomic effects of regulation on the economy.

What can we conclude about the use of surveys to make inferences about pollution control expenditures? Two observations seem warranted. First, while they provide some useful information, the BEA, Census, and McGraw-Hill surveys will not be useful either for micro- or macroeconomic analyses until they distinguish between expenditures necessitated by federal regulation and those arising for other reasons. Second, since all the surveys are based on extrapolations from a sample of firms or establishments to the industry as a whole, it is important to treat the overall estimates cautiously. In fact, the problems of extrapolation were so great with the AA/BR study that no attempt was made to generalize the findings from the 48 firms involved to the economy as a whole. Some of the same problems exist with the other three surveys, of course. Finally, we should remember that even perfect surveys will only give us information about past expenditures for environmental quality management. Useful as this information may be, it does not help in ex ante analyses of regulatory impacts.

III.2. Other Checks on Pollution Control Spending

One disadvantage to all survey approaches is that they rely on firms for accurate information on pollution control spending. When firms misunderstand survey instruments, when samples are unrepresentative of the entire population, or when firms strategically mis-state true spending, economy-wide estimates of pollution control spending based on surveys may be misleading. In this section we discuss briefly two means which might be used to check on the accuracy of firms' reported estimates of pollution control spending.

As a result of the Revenue and Expenditure Control Act of 1968, the use of tax-exempt industrial development bonds (IDBs) was sharply curtailed. One use of these bonds for which their tax-exempt status could be retained was for investment in pollution control equipment. These IDBs are issued by quasi-public agencies and the proceeds of the bond sale are used by private firms to install end-of-pipe pollution control equipment.[9] The firm repays the bond holders in much the same way it would if it floated the bonds privately. Since fairly good statistics are kept on the size and composition of the market for tax-exempt pollution control bonds, it is possible to compare survey estimates of pollution control spending with actual data on the use of tax-free bonds. Tables 2-4 below compare estimates based on the BEA survey of capital investment for pollution control from 1975-1980 with data on the actual use of IDBs on both an aggregate and industry basis.

Several interesting observations can be drawn from the tables. First, even after eliminating investment in process change -- which does not qualify for tax-exempt financing -- IDBs have only been used for 43 percent of all BEA-estimated investment in end-of-pipe pollution control since 1975. In 1980, only 39 percent of end-of-pipe investment in pollution control was financed with tax-exempt IDBs. In addition, according to BEA surveys, although new investment in end-of-pipe control equipment rose every year but one from 1975-1980, the volume in the tax-exempt market has fallen in four of those years, the last three consecutively. Although the total number of issues has

Table 2.

	1975	1976	1977	1978	1979	1980	TOTAL
1. Total Volume of Tax Exempt Pollution Control Bonds ($$10^6$)	$ 2,134	$2,056	$2,982	$ 2,793	$ 2,466	$ 2,463	$ 14,894
2. Number of Issues	193	168	221	155	163	170	1,070
3. Average Issue Size ($$10^6$)	$ 11.1	$ 12.2	$ 13.6	$ 18.0	15.1	14.5	13.9
4. New Investment in Pollution Control Plant and Equipment	6,549	6,762	6,939	6,924	7,143	7,699P	42,016
5. New Investment in End-of-Pipe Plant and Equipment (including solid waste)	5,419	5,524	5,609	5,549	5,826	6,376P	34,301
6. Total capital expenditures (corporate)	113,489	121,232	137,017	153,090	176,371	195,673P	896,872
7. IDBs as a percent of end-of-line pollution control expenditures	39.4	37.2	53.2	50.3	42.3	38.6	43.4
8. IDBs as a percent of total capital expenditures	1.9	1.7	2.2	1.8	1.4	1.3	1.7
9. Total Tax Exempt Financing (adjusted by CBO study on IRBs)	30,126	34,914	46,860	49,115	48,061	53,282	262,358
10. Corporate Bonds	42,756	42,380	42,015	36,872	40,139		
11. IDBs as a percentage of tax exempt financing	7.1	5.9	6.4	5.7	5.1	4.6	5.7
12. IDBs as a percentage of corporate bonds	5.0	4.9	7.1	7.6	6.1		

Sources: Lines (1) - (3): Weekly Bond Buyer, Jan. 26, 1976, Jan. 31, 1977, Jan. 23, 1978, Jan. 22, 1979, Jan. 21, 1980, and Jan. 19, 1981.
Lines (4) - (6): Survey of Current Business, June 1978 and June 1980.
Line (9): Weekly Bond Buyer, Jan. 8, 1979 and Jan. 12, 1981; Small Issue Industrial Review Bonds, CBO, April 1981, p. 14.
Line (10): Federal Reserve Bulletin, April 1979, December 1980.

Table 3.

	1975	1976	1977	1978	1979	1980^p	Total
Pollution control cost -- capital expenditures for end-of-line methods plus solid waste							
Electric Utilities	1336	1735	1907	1912	2183	2264	11,157
Petroleum	963	932	859	1027	1150	1296	6,227
Metal processors	889	799	791	622	724	892	4,717
Chemicals	561	577	544	476	387	398	2,943
Paper	463	411	364	215	260	234	1,947
All other	1205	1070	1144	1277	1122	1292	7,110
Total	5,417	5,524	5,609	5,549	5,816	6,376	34,301
IDB Financing							
Electric Utilities	628	1027	1919	1558	1579	1429	8,140
Petroleum	220	261	142	83	59	117	882
Metal Processors	529	276	373	647	246	263	2,334
Chemicals	253	208	244	189	181	137	1,212
Paper	224	121	155	98	141	159	928
All other	280	163	149	218	260	328	1,398
Total	2,134	2,056	2,982	2,793	2,466	2,463	14,894
IDB Financing as a Percent of Pollution Control Costs							
Electric Utilities	47.0%	59.2%	100.0%	80.6%	72.3%	63.1%	71.7%
Petroleum	22.8	28.0	16.5	5.1	5.1	9.0	14.2
Metal Processors	59.5	34.5	47.2	104.0	34.0	29.5	49.5
Chemicals	45.1	36.0	44.9	39.7	46.8	34.4	41.2
Paper	48.4	29.4	42.6	45.1	54.2	80.8	47.7
All other	23.2	15.2	13.0	17.1	23.2	25.4	19.7
Total	39.4%	37.2%	53.2%	50.3%	42.3%	38.6%	43.4%

Table 4. Total Use of IDBs and Percent Distribution of Use by Industry Type (1975-1980)

	Total IDBs Used ($ million)	Percent Distribution (%)
Electric Utilities	$ 8,140	54.7%
Petroleum	882	5.9
Metal Processor	2,334	15.7
Chemicals	1,212	8.1
Paper	928	6.2
All other	1,398	9.4
TOTAL	$14,894	100.0%

risen slightly for the last two years it is still below its level in 1975, and considerably below 1977 when 221 new tax exempt issues were brought to the market.

Equally interesting are the figures on individual industry use of IDBs. As Table 3 shows, certain industries rely to a much greater extent than others on tax-exempt financing. For instance, during 1975-1980, the electric utility industry financed with IDBs nearly 72 percent of the investment BEA estimated it made in end-of-pipe plant and equipment. By contrast, the petroleum refining industry used IDBs to finance but 14 percent of its pollution control investment. The average for the other industries for which data is available is about 45 percent. In addition, Table 4 indicates that the electric utility industry accounted for more than half, 55 percent, of all IDBs issued between 1975-1980. This is in spite of the fact that it accounted for less than a third of all investment in end-of-pipe pollution control during this same period according to BEA.

In 1980, the average IDB carried a net interest cost of about 9.5 percent. By contrast, the average yield on long-term corporate bonds issued in 1980 was 13.5 percent. On an average-sized issue of $15 million, this means interest costs are lower by about $0.6 million per year on the tax exempt bonds. In view of the significantly lower interest firms have to pay on tax-exempt bonds, why is it that less than half of all estimated investment in end-of-pipe pollution control in 1980 was financed by IDBs? Could this be a sign that firms exaggerate when responding to the BEA capital expenditure survey? Do the IDB figures give a more accurate picture of investment in pollution control? In spite of the temptation to draw such a conclusion, there are several reasons to believe that tax-exempt bonds would never be used to finance all end-of-pipe investments in pollution control.

First, the tax code restricts the use of IDBs to air and water pollution control -- they cannot be used to finance investments that will reduce the generation of solid waste. Thus, from line 5 in Table 2 would have to be subtracted solid waste expenditures before one could get an accurate picture of actual IDB use relative to maximum possible use. The solid waste expenditures to be deducted, however, are small in comparison to end-of-pipe capital spending for air and water pollution control -- in 1980 they amounted to $566 million, or about 9 percent of end-of-pipe spending. Thus, one must look elsewhere to explain the large amount of capital spending on pollution control that does not make use of the tax-exemption for IDBs.

Of course, firms may elect to finance capital expenditures (for pollution control or otherwise) in many different ways. For instance, one reason why the petroleum industry may have relied very little on tax-exempt bonds to finance pollution control (only 14 percent between 1975-80) may have been their favorable profit picture over this period, particularly during 1977-1980 when they financed only about 7 percent of pollution control investments with tax-exempt bonds. This may also explain the relatively intensive resort to the IDB market by electric utilities, since they have not done well as a whole over the last five years.

Finally, there are other impediments to the use of tax-exempt bonds that limit their use. In some cases, it may simply be that a pollution control investment is too small for a firm to go to the trouble and expense of securing an underwriter for the bonds, helping the authorized pollution control financing agency to put together the package and marketing the bonds. Rather, it may find it expedient to install the equipment and skip the favorable tax advantage.

In other cases additional limitations on the use of IDBs may reduce their use. For instance, the Internal Revenue Service forces firms to deduct from the amount of the investment to be financed the value of any materials that may be recovered in the waste stream, but IRS does not allow the costs of this recovery to be subtracted from this value. Thus, if sulfur will be recovered when a scrubber is installed, the market value of the sulfur must be deducted from the capital cost of the scrubber even though it may not be economic to recover the sulfur from the scrubber sludge. Similarly, IRS requires firms to deduct from the amount of investment to be financed the interest earned on the capital which is saved when bonds rather than retained earnings are used to finance pollution control. In other words, if the assumed rate of interest is 12 percent, IRS automatically reduces the amount that can be financed via

IDBs by 12 percent. This provision also has an obvious effect on the volume of tax-exempt financing and drives a wedge between investments that would *appear* to qualify and those which are actually made using IDBs.

All this is not to deny the possibility that firms knowingly or unknowingly exaggerate investment in pollution control when they respond to the BEA, Census Bureau, McGraw-Hill or other surveys. They may, and this would explain some of the difference between the BEA estimates and the volume observed in the market for tax-exempt IDBs. Nevertheless, as we have pointed out there are other important reasons why we would never expect all investment in pollution control equipment, or even all qualifying investment, to be financed using tax-exempt IDBs.

The preceding discussion raises an interesting issue. If firms currently have little or no incentive to accurately reveal pollution control expenditures, might they be given one? In other words, could a mechanism be devised that would at least bound the apparent incentive of firms to exaggerate pollution control spending?[10] The final "check" on estimates of pollution expenditures we discuss goes to this point.

To understand this approach it is important to note the potentially conflicting motives which a firm may face. On the one hand it may wish to exaggerate the current and future costs it will incur to comply with environmental regulations. By doing so, the firm may give impetus to efforts to "reform" regulation so as to diminish its burden on the public and private sector. At the same time, this firm may have an incentive to understate to a different group -- its stockholders -- the compliance costs it will face in the future. If future compliance costs were thought to be large, after all, the firm would not be as good an investment as it would be if these future burdens were small.

In fact, upcoming liabilities that may reasonably be expected to result from environmental and other regulations must be identified in the 10K report that each firm must file with the Securities and Exchange Commission each year. Several prominent firms have been penalized by the SEC for failing to report accurately these liabilities.[11] It is reasonable to inquire, then, whether these 10K reports might provide useful information on pollution control spending. The answer would appear to be that while such reports may be of some use in determining future (or ex ante) compliance costs, they will probably be of little use in determining past spending. It is not their purpose to present information on prior environmental expenditures -- this information will be available from the firm in other forms. And the firm would appear to have the same incentive to exaggerate prior environmental spending in reporting to stockholders as it has when responding to surveys.

The SEC reporting requirement might be used in an attempt to create "incentive compatibility" in estimating future costs, however. Suppose a firm were required to report on its 10K filing to the SEC the same estimates of future environmental compliance costs it provides to EPA during the period a proposed regulation is being considered. This might temper somewhat a firm's inclination to exaggerate those expected compliance costs. The larger the estimate they made, the less good the firm would look to current and potential stockholders. While such a consistency requirement has problems of its own,[12] it might help to reduce any exaggeration that currently takes place in responding to surveys on environmental control expenditures. As suggested above, however, such an approach is more relevant to the ex ante estimation of control costs than it is to estimates of spending in previous years. It is to these methods of ex ante cost estimation that we now turn.

IV. Ex Ante Estimates of Compliance Costs

As we indicated above, it is just as important to have accurate estimates of the expected costs of proposed regulations as it is to know how much is being spent as a result of existing rules. In this section we turn our attention to methods of ex ante estimation of environmental compliance costs. Here we try to do more than discuss the current methods of ex ante estimation, the most important of which we refer to as the "input cost accounting approach." We also discuss in some detail the way that two additional methodologies could be applied fruitfully to the estimation of expected compliance costs. The first methodology involves the use of what are referred to as engineering process models; the second makes use of neoclassical econometric models of the production process.[13]

IV.1. The Input Cost Accounting Approach

One way to determine the expected costs of proposed regulation is to ask the firms, individuals, and governmental units likely to be affected by it. Alternatively, one could rely upon the regulatory agency (EPA in the case of environmental regulation) or its contractors to provide such estimates. Since both regulators and regulatees generally use the same approach to estimate costs (although often with different assumptions), it is discussed in some detail here.

As its name implies, the "input cost accounting approach" (or ICAA) consists of two steps. First the estimator determines what additional inputs will be required by the regulation under consideration. Typically those will include capital (as in a flue gas scrubber or electrostatic precipitator), labor (to conduct tests of new chemicals, for instance), natural resources (limestone to inject into flue gases in a scrubber), and energy (which is required to operate all capital intensive pollution control equipment). Alternatively, if a regulation required a source to burn low - rather than high - sulfur coal, the additional cost of the cleaner coal would be entered as a cost of the regulation. The second stage involves the attribution of costs to these added input requirements, both now and in the future, since at least one concern is with the present discounted value of all future incremental costs attributable to the regulation in question.

Not only must these costs be projected for all existing sources under the ICAA, also a projection must be made about new sources that eventually will be subject to regulation. In the case of chemical regulation, of course, some estimate must be made of the number of new chemicals that will be introduced and hence subjected to pre-manufacturing notification and testing. The number of chemicals making it through the process times the cost per chemical would provide an estimate of the increased direct input costs arising from certain chemical regulations.

In some cases -- typically in EPA cost estimates -- a "model plant" approach is followed. That is, rather than attempt to estimate what will be required in the way of additional inputs at each existing facility by some proposed regulation, one or more model plants are selected which are taken to be representative of other plants in an industry. The ICAA is then used to determine compliance costs at this plant(s), and this cost is then multiplied by the number of average or model plants in the industry to arrive at total incremental cost. While this saves time and money during the cost estimation stage, it can easily create other problems.

The most obvious of these problems comes in determining what is a model plant. This choice has in the past led to both under- and overestimation of actual compliance costs. In some cases, the model plant has been taken to be one of the most modern and advanced in the industry. It is occasionally the case, in fact, that this plant will have already installed some pollution control equipment prior to regulation. This means that additional input requirements at this facility may be small; however, to generalize these small additional incremental costs to other plants in the industry where "pro bono" or anticipatory pollution control has not taken place can lead to substantial underestimates of actual compliance costs.

On the other hand, the model plant variant of the ICAA can lead to overestimates of compliance costs as well. This can result from the same circumstances described above. For in that case, the pollution control equipment installed prior to the regulation should *not* be counted among the incremental costs attributable to regulation. Only the additional costs, if any, of meeting the regulation are relevant here. Yet in the case of certain industry responses to the BPT effluent guidelines EPA apparently included in their cost estimates even the equipment that had been installed prior to the regulations. That clearly leads to an overestimate of true environmental compliance costs.

There are other problems with the ICAA as well. Even though an attempt is often made to foresee new technological advances in pollution control, this foresight can never be perfect. Hence, when a new innovation makes pollution control less expensive, actual compliance costs will fall relative to the original estimates. For example, some now believe that fluidized-bed combustion now has or soon will have the ability to lower considerably the costs of sulfur removal from coal-fired industrial and utility boilers. If so, the estimates of the costs of meeting the performance standards for new sources which EPA established in 1979 may be exaggerated.

In addition to technological innovation, compliance cost estimates may exceed actual costs because of what one of us has elsewhere called regulatory innovation.[14] These regulatory innovations are best exemplified by EPA's so-called "bubble" and "offset" policies under which one source of pollution in a plant or area can increase its pollution provided that another source makes an equivalent or greater reduction in its discharges of that same pollutant. Such regulatory innovations are significant because they enable polluters to meet given discharge goals in the least expensive way possible. This means that compliance cost estimates based on clean-up at all sources will exaggerate true costs so long as sources can "buy up" equivalent reductions elsewhere at less expense. Thus, these kinds of flexibility-enhancing reforms will reduce compliance cost estimates based on the ICAA.

A final difficulty with the ICAA is the open-endedness of some of the regulations for which cost estimates must be made. Consider the example mentioned above of new source performance standards for coal-fired utilities. After it was decided how much the new standards would cost a "typical" plant, it was also necessary to estimate how many new plants would be built. Yet this is no simple matter. First, this depends on the rate of growth (or decline) of demand for electricity, something which the utilities themselves have proved to be less than prescient in estimating. Not only are tastes and prices variant, estimating future demand is also difficult because the rate of adoption of energy conservation practices and alternative sources of energy is difficult to foresee.

Moreover, the number of new plants is not only dependent on exogenous factors like those below. It may also depend to some extent on the very regulations being analyzed. That is, if environmental controls on new plants are significantly more stringent than those on existing sources, new plants may cost so much more that there are fewer of them. Thus new source controls may affect both cost-per-plant and the number of plants. While important, this effect is very difficult to estimate because we cannot observe the plant construction activity that would take place in the absence of new source controls.

For all these reasons, then, the ICAA is flawed. It is understandable as a first order response to the new task of compliance cost estimation, and will continue to be used for quick approximations of compliance costs. But its obvious and subtle limitations point toward the need for a more sophisticated method of estimating compliance. Ideally, such a method would not only provide information about direct compliance costs -- that is, additional labor, capital, natural resources and energy -- but would also make possible the identification of at least certain of the indirect costs, as well. These latter costs may include changes in the optimal use of factors both upstream and downstream from the point at which regulations have their initial impact.

The two approaches we discuss next, in more technical detail than in the discussion so far, have the characteristic that they can shed some light on both the direct and indirect costs of regulation. Each of these approaches employs well established modeling methodologies to examine the impact of federal regulation on production activities. The first approach relies exclusively on engineering data and the physical laws of energy and material transformation. The second approach is founded on the neoclassical-economic theory of the firm and employs this theory in conjunction with economic data and econometric techniques to analyze characteristics of production activities. Neither of these approaches has been extensively employed to examine compliance cost; however, in the following sections we show how these approaches can be developed into useful compliance cost tools, potentially superior to those previously discussed.

IV.2. Engineering Process Models

IV.2.1. Overview of the Model

One strictly engineering approach to modeling a production activity, and the impact upon that activity which a proposed environmental regulation can have, is the engineering process model.[15] As the name implies, this approach decomposes a specific production activity (e.g., the production of iron and steel) into identifiable engineering processes -- each process associated with a specific well-defined task. Normally, each task can be accomplished by a variety of process configurations which are differentiated on the basis of inputs and the engineering efficiency of the process. The process modeler first determines the sequence of tasks to be performed as required by a particular production activity and then assembles the alternative processes capable of accomplishing each task. Naturally, the output of one task becomes the input of a succeeding task; thus, internal consistency among the process alternatives must be maintained to insure that a fully specified configuration of process alternatives is capable of accomplishing the overall production activity.

The set of interrelated process alternatives depicts the menu of *blue-prints* from which the complete production activity is assembled. We shall term this set of blue-prints the *technology* for a specific production activity. We define the set of all potential inputs to the technology by the vector x and all outputs by the vector y; we then define the technology as the set of feasible input and output combinations. Formally, we define the technology set T as:

$$T = \{(x,y) \mid (x,y) \text{ is a feasible production choice}\} \qquad (1)$$

Once the technology set is established the process modeler chooses an optimization rule which serves to identify that set of process alternatives, drawn from the technology set T, which optimizes a specific objective function. For example, if the optimization rule was the minimization of total factor cost, subject to the constraint that a given level of outputs be produced, then the process alternatives chosen, combined with the scale of production, would determine the optimal demands for factors of production and the unit cost of producing the specified level of outputs. Formally, the optimization problem appears as (2).[16]

$$\begin{aligned} &\underset{x}{\text{Minimize:}} && p'x \qquad (2)\\ &\text{S.T.} && y \geq y^0 \\ & && (x,y) \in T(x,y) \\ & && p \geq 0 \end{aligned}$$

where: p = the vector of input prices

y^0 = specified level of outputs

$'$ = vector transposition

and: $y \geq y^0$ requires a given level of output to be produced

$(x,y) \varepsilon T(x,y)$ constrains the optimal set of process alternatives to be contained (elements of) within the established technology

$p \geq 0$ requires input prices to be nonnegative

If the process model depicted in (2) is to be used to analyze compliance cost, special care must be exercised in the construction of the process alternatives. Specifically, we are concerned with mass balance and to a lesser degree energy balance. Since the environmental regulation of an industry is generally concerned with the emission of industrial by-products, i.e., pollutants, (henceforth termed *residual outputs*) all such products must be accounted for in the process model at each stage of production. Simply stated everything which enters the model as an input must be traced through its physical transformations to a final output. The maintenance of *materials balance* in the process model permits the influence of a regulation pertaining to one or more residuals to be traced through the entire sequence of production.

The completed process model will be employed to mimic a firm or industry's response to a given federal regulation. Naturally what we are concerned with is the marginal impact (incremental cost) of the regulation; thus, if an industry is already treating its waste water streams to recover valuable by-products, for example, we will want to be sure that our process model incorporates that fact in the pre-regulation *base case*. Therefore, in addition to the important properties of process consistency and materials balance, the process modeler will also strive to construct a model which depicts actual production practices, especially in the area of pollutant generation, abatement and treatment.

Before proceeding further into the discussion of the process model approach a few characteristics of the process model methodology need to be highlighted.

- First, and foremost, the process model is frictionless, i.e., it does not permit less than instantaneous adjustment to relative factor price changes and environmental relation
- Second, the model is purely static and does not permit technological change nor the impact of new technology diffusion
- Third, the optimization rule provides the mechanism for choosing process alternatives, it is not intended as an explanation of process choices actually made by firms. Moreover, the model always chooses the ideal configuration or processes in a world of perfect certainty; therefore, it does not allow for the adoption of sub-optimal process alternatives as a special case
- Fourth, the ex ante - ex post distinction with regard to the analysis of a proposed regulation vis-a-vis an inplace regulation is not meaningful in the process model context since the model has no time dimension. All compliance cost estimation is essentially ex ante.

IV.2.2. Process Models and Specific Classes of Environmental Regulations

We shall not attempt in this section to discuss the analysis of specific environmental regulations using a process model; but rather, to examine the broad range of generic regulations amenable to analysis and to depict how the process model would be configured for each class of regulations. Five classes of environmental regulations are given below, each class is characterized by the variables of the process model which are impacted.

- Regulations which alter relative input prices
- Regulations which limit input quantities
- Regulations which restrict residual emissions
- Regulations which tax residual emissions
- Regulations which restrict process choice

The first class of regulations we shall discuss are those which affect the relative prices of factor inputs. Such regulations could take the form of subsidies with respect to the purchase of treatment equipment or taxes placed upon the use of particular inputs such as fresh water. Regulations which affect input prices are the simplest to model in a process framework and merely involve the substitution of the old input price vector with the new vector incorporating the affected prices. The optimization problem (3) depicts how the stylized process model of (2) is redesigned to analyze this first class of regulations.

$$\begin{aligned} \text{Minimize:} \quad & \bar{p}'x \\ \text{ST} \quad & y \geq y^0 \\ & (x,y) \in T(x,y) \\ & \bar{p} \geq 0 \end{aligned} \qquad (3)$$

where: $\bar{p}$ = the vector of input prices which now reflect the presence of an environmental regulation

For the purpose of analysis the model (3) is solved once using the vector p prices (pre-regulation input prices) and once using the vector $\bar{p}$ prices (post-regulation prices). Given the two solutions, several aspects of the regulation's effect can be ascertained. First, the difference in the value of the objective function provides an insight to the regulation's impact on the *private cost* of production to the firm or industry. We use the term private cost since the regulation has distorted the market for inputs and thus the firm's cost of production will not necessarily bear directly on social cost. Second, we can examine the optimal demands for factors of production in the pre-regulation and post-regulation states of the world. This is clearly an important aspect of the analysis since an environmental policy may affect a factor of production which is the target of an unrelated but important government policy. Certainly we would want to determine the impact of the regulation on the demands for labor and energy.

In addition to the simple cost and factor demand analyses suggested above, the process model allows one to view the intricacies of the engineering adjustments made in response to a regulation. Given the base case solution of the model at p prices, we are able to determine the specific set of processes adopted and the scale at which each process is operated. When the model is run at $\bar{p}$ prices the model adjusts its optimal configuration of processes and their scales. While not relevant to the present class of regulation (i.e., those which affect input prices) some types of regulations can alter the overall engineering efficiency of the production activity. This engineering efficiency, which we shall term *technical efficiency*, will often be disguised in the objective function due to simultaneous changes in process alternatives, but may be perceived from a direct examination of the optimal processes chosen.[17]

Finally, the process analysis model permits the investigation of *residual switching* in response to a specific regulation. Residual switching would occur if regulations on waterborne residual discharges were in place while airborne discharge regulation was absent. In the case of iron and steel production, waterborne residuals generated in the finishing section could be piped back to quench coke and thus the residuals would be discharged through evaporation into the air mantel. Since all residuals are tracked through the production activity, residual switching can be directly perceived.

Summarizing briefly we have identified four ex ante analyses of compliance cost which can be conducted with the use of process models. The first, termed *private cost analysis*, focuses on the incremental private compliance cost associated with a particular regulation. Such analysis, based on the change in per unit production cost, captures both direct and indirect effects and is properly defined as incremental if the base case analysis (model (2)) is constructed according to our guidelines.[18] The second, *factor demand analysis*, concerns the potential for altered factor intensities and thus individual factor rewards and productivities. The third, *efficiency analysis*, deals with overall productivity of the production activity and the fourth, *residual analysis*, concerns the effect of a regulation designed to alter the emission of one residual on the emission of all residuals.

The second class of regulations has the effect of limiting the inputs of certain factors of production. Again one could imagine limitations on the quantities of fresh water consumed or regulation banning the burning of high sulfur coal. In all cases this class of regulations merely imposes an additional set of constraints on the model. If x_c is a subset of the input vector x and x_c are those inputs constrained by regulation, the process model appears as (4).

$$\begin{aligned} &\underset{x}{\text{Minimize:}} && p'x && (4) \\ &\text{S.T.} && y \geq y^0 \\ & && (x,y) \in T(x,y) \\ & && p \geq 0 \\ & && x_c \leq x_c^0 \end{aligned}$$

where: x_c^0 = vector of constraining input levels.

The same types of impact analyses discussed with regard to (3) can be performed on (4). Those analyses are: 1) private cost analysis, 2) factor demand analysis, 3) efficiency analysis, and 4) residuals analysis.

The third class of regulations are those which directly restrict the discharge of residuals. This is clearly the most popular form of environmental regulation and one which is readily handled within the process model framework. Partition the output set y into two subsets, y_q which are the desired market oriented outputs and y_r which are the residual outputs. Bear in mind that this partitioning is a function of market prices and particular outputs can move between the two subsets as these market prices change. Consider regulations on the residuals subset which place upper limits on their disposal. The process model incorporating this class of regulations is given in (5).

$$\begin{aligned} &\underset{x}{\text{Minimize:}} && p'x && (5) \\ &\text{S.T.} && y_q \geq y_q^0 \\ & && (x,y) \in T(x,y) \end{aligned}$$

$$y = \begin{pmatrix} y_q \\ y_r \end{pmatrix}$$

$$p \geq 0$$

$$y_r \leq y_r^0$$

where: y_q^0 = specified level of market outputs

y_r^0 = maximum level of residual discharges

Comparing the optimal value of the objective function from (5) with the value generated by the unconstrained technology (2) provides an estimate of the full private cost of the regulation $y_r \leq y_r^0$. The cost differential resulting from the regulation is a composite of direct and indirect impacts on the production activity in question. The direct impacts are those closely associated with the reduction of discharges; for example, the cost of treatment and abatement capital, and the labor, energy and materials necessary for its operation. The indirect impacts are less easy to identify since they emanate from efficiency gains or losses that have resulted from the reorganization of the process activities in an attempt to reduce discharges. While these indirect impacts may be hard to identify individually (such identifications require the type of efficiency analysis discussed above), they are accurately accounted for, along with the direct impacts, in the value of the objective function.

The fourth class of regulations we shall consider are those which act as a tax or fee on the discharge of residual outputs. Let the vector t represent the schedule of per unit taxes or fees applied to the discharge of residual outputs y_r. In the absence of other environmental regulations the discharge-tax model appears as (6).

$$\underset{(x,y_r)}{\text{Minimize:}} \quad p'x + t'y_r \tag{6}$$

$$\text{S.T.} \quad y_q \geq y_q^0$$

$$(x,y) \in T(x,y)$$

$$y = \begin{pmatrix} y_q \\ y_r \end{pmatrix}$$

$$p \geq 0$$

$$t \gtreqless 0$$

where: t = a vector of taxes on y_r if $t > 0$ or subsidies if $t \leq 0$.

Analysis of the above regulation is quite straightforward. Following the analysis methodology discussed previously, one would examine: private cost (objective function), factor demands, process efficiencies, and residuals discharges.[19]

A modification to (6), which would reduce the private compliance cost of discharge-tax regulation and bring the model closer to reality, would be to permit the sale of usable by-products captured by the residual discharge treatment equipment. An example is the spent sulfuric acid used in the finishing sections of steel plants. Taxing the discharge of the spent acid induces the firm to treat the finishing section waste streams and capture the acid. The recovered acid is then sold in the market at a positive price, thus offsetting the cost of recovery.[20] To incorporate the effects of by-product recovery induced by regulation one can modify the objective function of (6) or (5) by subtracting the by-product sale revenue. The modified objective function is given in (7).

$$\underset{(x,y_r,y_{qr})}{\text{Minimize:}} \quad p'x + (t'y_r - p_r'y_{qr}) \tag{7}$$

where: p_r = a vector of market prices for recovered by-products

y_{qr} = a vector of marketable recovered by-products

The term $t'y_r - p_r'y_{qr}$ represents the net direct private cost of discharge-tax regulation. Evaluating the objective function (7) relative to a base case of no regulation such as (2) provides an estimate of the direct and indirect private cost of regulation.

The last class of regulations we will discuss are those which require the adoption of particular processes, e.g., scrubbers. This type of regulation normally augments the technology set T by including processes which are tangential to the production activity. Let us denote this augmented technology by $\hat{T}$. We further define individual process within the set $\hat{T}$ by $(\overline{x},\overline{y})$. With this added notation in hand we may proceed to the process model and define the appropriate constraints.

$$\begin{aligned} &\underset{x}{\text{Minimize:}} && p'x && (8)\\ &\text{S.T.} && y \geq y^0 \\ &&& (x,y) \ \varepsilon \ \hat{T}(x,y) \\ &&& (\overline{x},\overline{y}) \ \varepsilon \ (x,y) \\ &&& p \geq 0 \end{aligned}$$

where: $(\bar{x},\bar{y})$ is the process which must be adopted and the subscripts on y have been dropped since we are no longer directly concerned with residuals.

The first constraint, $y \geq y^0$ is the usual output requirement; the second, $(x,y) \in \hat{T}(x,y)$ merely requires that the chosen set of process alternatives be elements of the augmented technology $\hat{T}$; the third constraint requires that a particular process, e.g., scrubbers, be an element of the set of optimal process alternatives, (x,y), and the fourth merely requires that input prices be non-negative. The analysis of this class of regulations proceeds through the steps as those outlined earlier, i.e., cost analysis, factor demand analysis, efficiency analysis, and residuals analysis.

The six models discussed above (2)-(7) have all assumed that the firm or industry facing a particular environmental regulation will continue to produce a given vector of marketable outputs. In the case of iron and steel, used in illustrations above, this required level of output would include a menu of steel ingots, semi-finished shapes, plate, strip and wire products. In reality, environmental regulations impact the output decisions we have arbitrarily held constant. To capture the impact of regulation on these output decisions we cast the process model in a profit maximizing mode. In such a mode the model chooses simultaneously both the levels of output and factor demands. In the absence of regulation the model would appear as (9).[21]

$$\underset{(x,y)}{\text{Maximize:}} \quad p_q'y - p'x \tag{9}$$

$$\text{S.T.} \quad (x,y) \in T(x,y)$$

$$p_q, p \geq 0$$

where: p_q = a vector of prices for the market outputs

$p_q'y$ = total revenue from the sale of y

$p'x$ = total factor cost

The model depicted by the optimization problem (9) makes a stronger assumption about the production activity it seeks to represent than does the earlier model (2). In (2) cost minimization was chosen as the optimizing rule which served to select from the technology set those process alternatives which were least cost. Presumably (2) mimics the selection of process alternatives actually made by firms and industries. In (9) the optimizing rule is profit maximization; and the model determines not only the least cost process alternatives but also the mix and quantities of outputs to produce. To link the results of (9) to actual firm or industry decisions we must assume that the firm seeks to maximize profit.

Given we are content with the profit maximizing assumption, (9) provides the basis for the same regulatory analysis as the preceding cost minimization models. In addition, (9) permits us to examine the impact of regulation on the firm's output decisions and provides us with some insight as to the regulatory effect on profitability. The model given in (9) is thus richer in its analytic power than the previous cost minimization models.

IV.3. Neoclassical-Econometric Models of Production Activity

IV.3.1. Overview of the Model

The contemporary econometric model of production is similar to the process model in several respects, but is fundamentally different in its methodology. The econometric model is constructed as a tool of explanation, designed to explain the behavior of economic agents controlling production activities. Unlike the process model, the econometric model cannot be used as an aid to production management nor can it supply information concerning optimal process configurations. The reason behind these inabilities lies in the structure of the model, which infers characteristics of the underlying technology from observable economic phenomena (factor prices and demands) emanating from the decisions of economic agents. In contrast, the process model infers the decisions of the economic agents (process choices and factor demands) from the characteristics of the technology.

Underlying the econometric model of production is the neoclassical theory of the firm. The firm is composed of a set of economic agents (decision makers) who purchase factors of production and organize those factors to produce a set of intended, i.e., marketable, outputs. The firm is a dynamic enterprise, which exists through time and is assumed to optimize some intertemporal objective function, e.g., profit, sales, revenue, growth, etc. Optimization of the objective function subject to the constraints imposed by the technology determines the optimal demands for factors of production and the optimal mix and scale of outputs to produce. The actual process alternatives adopted to produce the intended outputs are *observable* in the neoclassical-econometric model.

Let us consider a version of the econometric model which might be compared to the process model depicted by the optimization problem (2). We shall assume that the firm, whose production activity we are investigating, is minimizing total cost subject to an output constraint. Employing the notation of the previous section we would model the firm's decision making problem as the simple optimization problem displayed below.

$$\underset{x}{\text{Minimize:}} \quad p'x \tag{10}$$

$$\text{S.T.} \quad y \geq y^0$$

$$(x,y) \in T(x,y)$$

$$p \geq 0$$

Given some minimal regularity conditions on the set T, the necessary conditions for a cost minimum are also sufficient.[22] Solving the necessary conditions in terms of the input vector x gives rise to a system of optimal factor demand functions of the form (11).

$$x^* = h(p,y) \tag{11}$$

These demand functions express the optimal quantities of factors to be employed by the firm as a function of factor prices and the level of output.

At this stage of development the neoclassical-econometric model appears quite similar to the engineering process model. We have identified the optimal input demands x^* by using knowledge of $T(x,y)$ and an optimization rule (cost minimization) -- a procedure quite analogous to the process model. However, if we reverse the problem and use knowledge of x^* we can indirectly determine the properties of $T(x,y)$.

To infer the technology from the factor demands we introduce the notion of the cost function. At a cost minimum, total cost is given by (12).

$$c = p'x^* \tag{12}$$

If we substitute the factor demand equations (11) into (12) we obtain an expression for minimum total cost as a function of input prices and output. The resulting minimum *cost function* is given in (13).

$$c = c(p,y) \qquad (13)$$

A significant property of cost functions was discovered by Ronald Shephard and published in 1953.[23] The result followed from Shephard's investigation of duality properties inherent in economic optimization problems and has since been termed Shephard's lemma. We merely provide Shephard's result without derivation.[24] Shephard's lemma states, given certain regularity conditions on T, the first derivatives of the cost function with respect to input prices generate the optimal factor demands as described by (14).

$$\frac{\partial c(p,y)}{\partial p} = x^* = h(p,y) \qquad (14)$$

Thus, we can derive an expression for optimal factor demands by differentiating the cost function rather than deriving and solving the first order conditions of (10). Since we no longer need to deal directly with (10) we do not require explicit information concerning $T(x,y)$; indeed, characteristics of $T(x,y)$ can be approximated from $c(p,y)$.

We have undertaken this rather formal presentation of the cost function since it is the standard analytical tool in the contemporary neoclassical-econometric model of production. It is hoped that our presentation has also highlighted the fundamental difference between the engineering process model and the econometric model; namely, the process model requires explicit knowledge of the engineering character of production to assemble the technology set $T(x,y)$, whereas, the econometric model only requires information on the observable economic variables x^*, p, and y.

So far, our discussion of the neoclassical-econometric model has made no reference to the purely econometric issues associated with the model, and we intend no detailed discussion of these issues since such a discussion would take us beyond the scope of this paper. However, we do need to highlight some characteristics of the model which are derived from its econometric nature. First, the model is only as good as the data (observations on x^*, p, and y) used to estimate it. Second, ex ante analyses which push the model beyond its range of experience are less reliable than those analyses performed within the range of experience. The *range of experience* is defined by the observed variation in x^*, p, and y which was used to estimate the model originally. If a particular environmental regulation forces firms to use new and untried technologies, ex ante econometric analyses of the regulation will push beyond the model's range of experience and will force the model to extrapolate its results to these unexperienced regions. Finally, if we intend to draw from the model analyses of regulations which involve the interactions of factor demands x^*, intended outputs y_q, and discharged residuals y_r, the data used to estimate the model must contain sufficient orthogonal variation in these variables. That is, we must be able to observe variation in discharges which are moderately uncorrelated with variations in intended output and factor demand.

These caveats expressed with regard to econometric models are not unique to these models but hold with equal force with respect to engineering process models. Clearly, the process model is only as good as the engineering data used to construct it. Moreover, the process model has a fixed range of experience given by its set of process alternatives and the model is incapable of extrapolating beyond its range of experience.

V.3.2. Econometric Models and the Analysis of Environmental Regulations

During our discussion of process models we examined five broad classes of environmental regulations and showed how the process model could be employed to analyze the impact of these regulations on firms or industries. We begin our examination of the econometric model by reconsidering four of these five classes of regulations. Specifically we shall consider:

- Regulations which alter relative input prices
- Regulations which limit input quantities
- Regulations which restrict residual emissions
- Regulations which tax residual emissions

For each class of regulations we will illustrate how an ex ante analysis of the regulatory impact would be conducted.[25]

We assume as given, the existence of a neoclassical-econometric model of the production activity in question. The model we will be working with has the following form.

$$\text{Cost Function:} \qquad c = c(p,y) \tag{15}$$

$$\text{Input Demand Functions:} \qquad x^* = h(p,y) \tag{16}$$

where: c = total minimum cost of production
p = a vector of factor prices
y = a vector of outputs
x^* = a vector of optimal factor demands

In addition, we assume analytical forms have been assigned to the functions $c(p,y)$ and $h(p,y)$, and the parameters of these forms have been previously estimated.

An examination of the first class of regulations, those which effect the price of one or more inputs, is easily carried out within the context of the econometric model. Assume the regulations have altered the pre-regulation price vector p and denote the new post-regulation price vector $\overline{p}$. The pre-regulation econometric model is represented by equations (15) and (16). When the pre-regulation prices are inserted into the model we are able to calculate the total cost and factor demands in the pre-regulation environment. We use these calculations as the base case in our ex ante analysis of the regulations. Inserting $\overline{p}$ into (15) and (16) provides estimates of the post-regulation total cost $\overline{c}$ and factor demands $\overline{x}^*$. The post-regulation equations are given below.

$$\overline{c} = c(\overline{p},y) \tag{17}$$

$$\overline{x} = h(\overline{p},y) \tag{18}$$

The total direct and indirect impacts of the regulation are found through a comparison of c and $\overline{c}$; while a comparison of x^* and $\overline{x}^*$ provides a measure of the factor demand effect. Since this form of regulation has only an effect on relative input prices, one would again not expect a loss in technical efficiency to occur. Finally, we are unable to analyze the pattern of residual discharges in this regulatory environment since there are no economic or institutional (regulatory) forces acting on the firm to control its discharges.[26]

The ex ante analysis of regulations which in some sense limit input quantities is more interesting than those regulations which affect input prices since limitations on factor inputs force the firm to be *allocatively inefficient.*[27] Allocative inefficiency occurs when the first order conditions for a cost minimum are violated. For the sake of illustration let us assume that the production technology we are concerned with employs only two inputs x_1 and x_2 and provides a single intended output y. In the pre-regulation environment the econometric cost function and factor demand functions appear as follows:

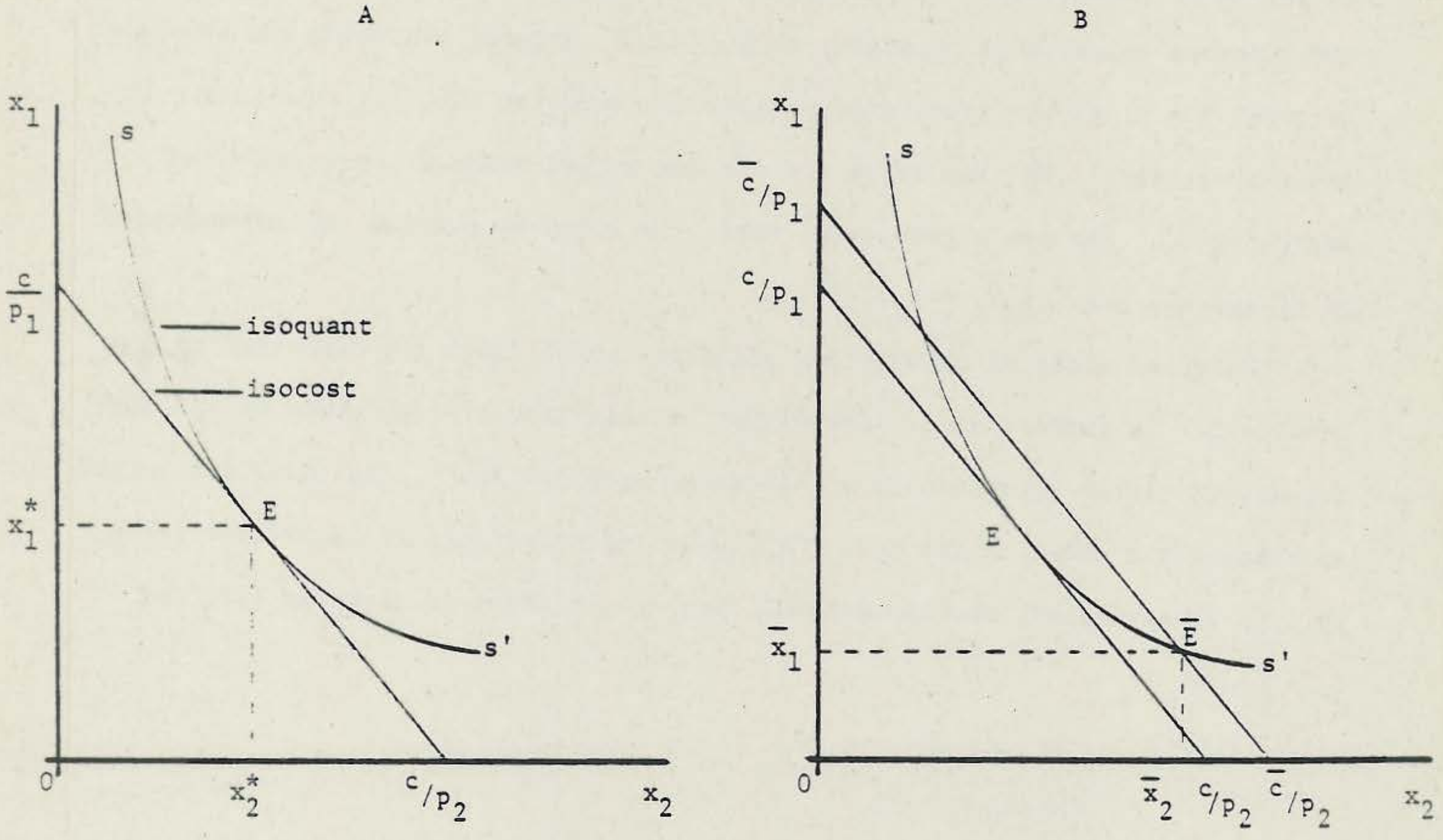
$$c = c(p_1,p_2,y) \tag{19}$$

$$x_1^* = h_1(p_1,p_2,y) \tag{20}$$

$$x_2^* = h_2(p_1,p_2,y) \tag{21}$$

The cost minimizing equilibrium of the firm characterized by equations (19) - (21) is depicted graphically in panel A of Figure 1. The curve ss' is the isoquant corresponding to output level y for this production activity and the isocost line corresponds to a total cost of c. The tangency between the isoquant and the isocost at point E determines the cost minimum and the optimal factor demands x_1^* and x_2^*. Now consider a proposed regulation which

Figure 1


A

B

x1
s
c/p1
isoquant
isocost
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E
s'
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x2*
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E
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s'
0
x̄2
c/p2
c̄/p2
x2

limits the quantity of input x_1 to a maximum of $\overline{x}_1$. Given this regulation the firm is forced to move from point E to point $\overline{E}$ (panel B) on the isoquant. The new total cost at $\overline{E}$ is $\overline{c}$ and the difference between c and $\overline{c}$ is the cost of allocative inefficiency brought about by the regulation.

The determination of $\overline{c}$, $\overline{x}_1$, and $\overline{x}_2$ from the econometric model (19) - (21) is not as straightforward as it appears from the diagram and involves the simultaneous solution of equations (19) - (21). Briefly sketching the solution, we first fix x_1 at its constraint level $\overline{x}_1$ in equation (20) but allow its price p_1 to vary. We then solve for the new $\overline{p}_1$ and using $\overline{p}_1$, p_2, and $\overline{x}$, we solve for $\overline{x}_2$. The new higher total cost $\overline{c}$ is found by summing the expenditures on x_1 and x_2, i.e., $p_1\overline{x}_1 + p_2\overline{x}_2$.[28]

The third class of regulations are those which limit the discharge of residuals. To perform an ex ante review of this type of regulation we utilize the output vector partition in y_q (intended outputs) and y_r (residual discharges). An econometric model of the form (15), (16) incorporating the output partition (y_q, y_r) is estimated, and the general form of the model is given in (22) and (23) below.

$$c = c(p, y_q, y_r) \tag{22}$$

$$x^* = h(p, y_q, y_r) \tag{23}$$

After the parameters of the model have been estimated the regulated level of residual discharges $\overline{y}_r$ is substituted in (22) and (23) along with the specified level of intended outputs and the price vector of inputs. The model is then simulated to predict post-regulation $\bar{c}$ and factor demands $\bar{x}^*$. The remainder of the ex ante analysis proceeds as usual.

The ex ante analysis of regulations which impose a tax on the discharge of residuals must employ indirect econometric techniques. These indirect methods are employed since the ex ante, pre-regulation environment provides no economic or institutional forces which would motivate the firm to control residual discharges. Without such forces an economic model seeking to explain the pattern of discharges cannot be constructed. In such a world the best we can do is explain cost and factor demand from a model like (22), (23) which is conditioned upon a given level of residuals discharge and intended output production.

In order to measure the ex ante impact of a residuals discharge tax on a firm's production activity we analyze the *shadow cost* to the firm of a reduction in its discharges. Since, in the pre-regulation world, the price of discharges to the firm is zero, one would expect the cost minimizing firm to discharge residuals up to the point where the discharges no longer had a beneficial impact (positive marginal product) on the production of intended outputs. If the firm is forced to discharge less than this optimal amount, the cost of producing the same level of intended output will be higher in the presence of discharge constraints. This additional cost can be termed the shadow cost of the discharge constraint. If a tax on discharges was levied equal to the shadow cost mentioned above, the firm would voluntarily limit its discharges to the point coincident with the aforementioned discharge constraint.

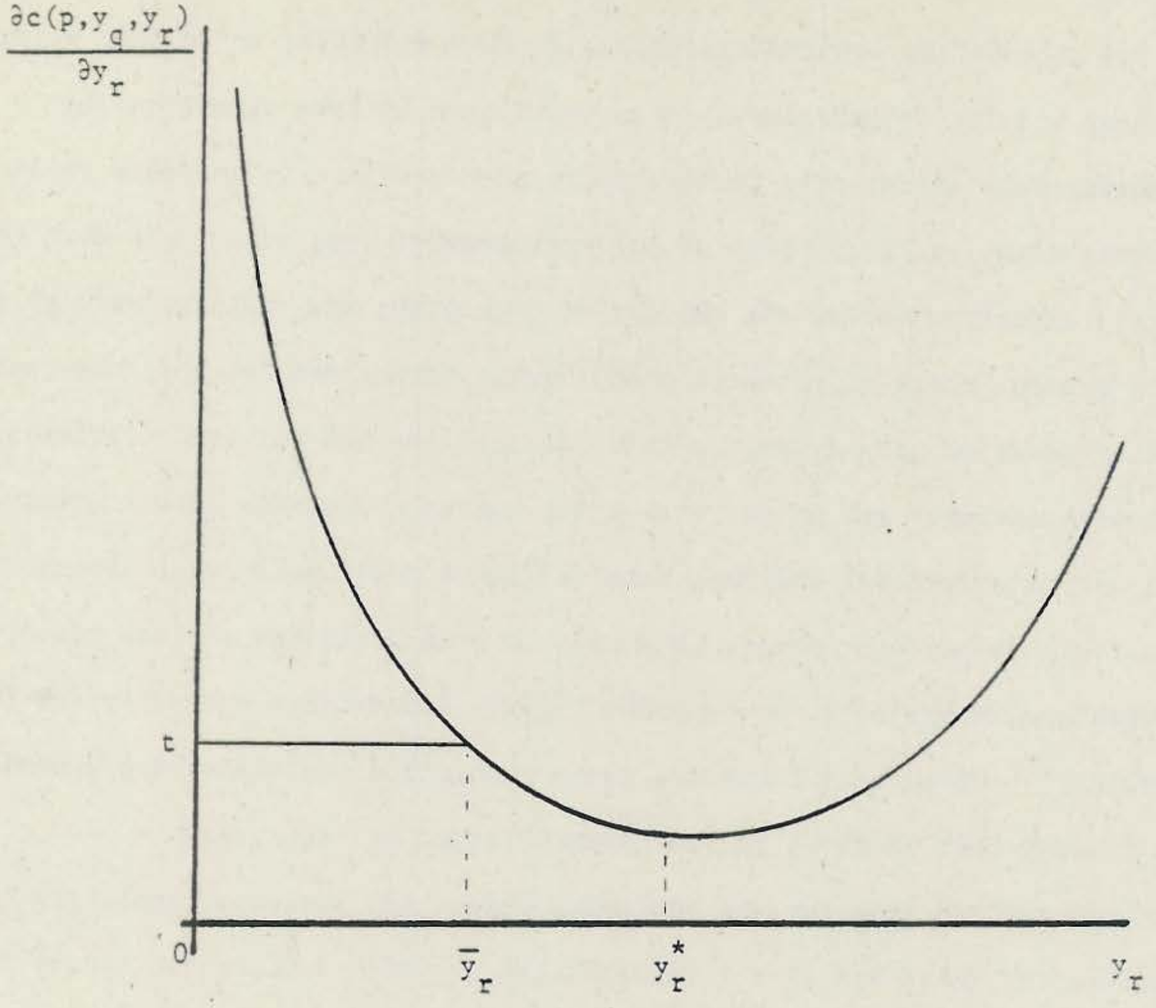
Implementing this indirect econometric approach, using the previously discussed model (22), (23), merely requires differentiating the cost function (22) with respect to the levels of discharge y_r. The resulting functions state how the cost of producing a given level of intended output changes as discharges change. One might expect these functions to be U-shaped, as displayed in Figure 2. The unconstrained, untaxed firm would fix its discharges optimally at y_r^*. If we now institute a tax of t on per unit discharges, the firm will reduce its discharges to $\overline{y}_r$. To actually compute $\overline{y}_r$ from (22) we differentiate (22) with respect to y_r and set this derivative equal to t as given by (24) below.

$$t = \partial c(p, y_q, y_r) / \partial y_r \tag{24}$$

Solving (24) for y_r in terms of the exogenous variables p, y_q, and t provides estimates of $\overline{y}_r$. Inserting $\overline{y}_r$ into (22) and (23) generates estimates of $\overline{c}$ and $\overline{x}^*$ which are used in the ex ante analysis.

Some concluding remarks are in order with respect to ex ante regulatory evaluation using the framework of the econometric model. First, the analyses focus on the private costs of production and the demand for productive factors. The analysis of production costs captures both the direct and indirect impacts of regulation and thus considers both technical and allocative inefficiencies which may spread throughout the production process as the result of regulation. The analysis of factor demand also reflects the direct and indirect impact of regulation but in this case the impact is realized through altered factor proportions. Since the post-regulation proportions may run counter to other governmental policies (e.g., energy conservation), may inhibit productivity, or may lead to redistributions of income through altered factor shares, the factor demand impacts can be quite important and not fully realized through an analysis of total cost alone.

Figure 2



IV.3.3. Some Often Overlooked Regulatory Costs: Dynamic Impacts

The process and econometric models we have discussed up to this point have been static, frictionless models which have no time dimension and instantaneously adjust from one equilibrium to another, in response to an exogenous stimulus in the form of an environmental regulation. In this static, smoothly adjusting world, the impacts of regulation are realized through the static private costs of production and static factor demands. In the real world, production is a dynamic affair, factors are not adjusted costlessly and instantaneously but adjust with a lag and at a positive cost. Moreover, firms are intertemporal and must make decisions today which will affect their operation in subsequent years. Examples of such decisions include research and development projects, and optimal capital maintenance and scrappage schedules.[29] Given that firms and their production activities are dynamic, some thought must be given to the dynamic impact of regulation.

Let us first consider the short-run versus the long-run regulatory impact. We define the short-run as a time dimension in which a subset of factor inputs are variable and the remaining inputs are quasi-fixed (i.e., not variable in the short-run); in the long-run all factors are variable. Quasi-fixed variables are usually composed of capital stocks but may also include such things as fixed labor contracts. Since some variables are incapable of adjustment in the short-run, the firm is not able to move directly to a least cost equilibrium in response to an imposed regulation. This limited adjustment ability will lead to a greater short-run regulatory impact on total cost than on long-run costs. Consequently, static process and econometric models will tend to underestimate the short-run impacts since they are essentially long-run models.[30]

Fortunately, short- and long-run econometric models do exist and can be easily adapted to the problem of regulation analysis, unfortunately no such process models exist. A simple but powerful dynamic econometric model is the *partial static equilibrium* model.[31] The model permits a subset of the factor inputs to costlessly adjust to an equilibrium conditioned on a set of quasi-fixed inputs which do not adjust. In this context the firm's cost minimization leads to a *restricted cost* function of the following form.

$$c = c(p_v, y, \hat{x}) \tag{25}$$

where: c = minimum variable cost

p_v = a vector of variable factor prices

y = a vector of outputs

$\hat{x}$ = a vector of quasi-fixed factors

In essence (25) is a short-run cost function associated with a set of short-run variable factor demand functions given in (26).

$$x_v^* = h(p_v, y, \hat{x}) \tag{26}$$

where: x_v^* = a vector of optimal variable factor demands

The short-run model represented by equations (25) and (26) can be used to examine the short-run impacts of all four classes of regulation discussed in the previous section.

To find the long-run cost function corresponding to (25) we make use of the *envelope theorem* in economic theory. For any given level of output and variable input prices there is a unique level of $\hat{x}$ that will minimize all costs. If $\hat{x}$ is set at this equilibrium level, denoted $\hat{x}^*$, then the firm is in full long-run equilibrium with respect to all factors of production and the corresponding long-run cost function is given by (27).

$$c^* = c(p_v, y, \hat{x}) + p_{\hat{x}}\hat{x}^* \qquad (27)$$

where: c = minimum total cost

$p_{\hat{x}}$ = a price vector for the quasi-fixed inputs

If we allow all input prices (both variable and quasi-fixed) and output to vary we can generate a set of short-run cost functions. The envelope of all these short-run functions, which traces the locus of minimum long-run total cost, is the long-run cost function depicted by equation (27). The long-run cost function (27) is associated with a set of long-run factor demand functions for both variable and quasi-fixed inputs, enabling a companion long-run examination of regulatory impacts.

In the partial static equilibrium model the short- and long-run equilibriums are two distinct states of the dynamic production activity; and the transition between these two states is neither explained nor observed. There exists a second class of dynamic models which explicitly considers the adjustment from a short-run partial equilibrium to a long-run full equilibrium. This model explains the process of adjustment on the basis of internal adjustment costs.

Paralleling the partial static equilibrium model, the internal cost of adjustment model also dichotomizes inputs into variable and quasi-fixed categories. The variable factors can be adjusted at zero cost to the firm while the quasi-fixed factors can only be adjusted at positive cost. The faster the rate of adjustment, the greater the cost.

The internal cost of adjustment model depicts not only short- and long-run equilibriums but also the dynamic path of quasi-fixed factor adjustment and an expression for the adjustment costs themselves. In general, adjustment costs are found to be a function of the changes in quasi-fixed factor stocks, the levels of output, the level of quasi-fixed factor stocks and the prices of variable inputs as depicted by equation (29).

$$\tilde{c} = \tilde{c}(\hat{x}, \Delta\hat{x}, y, p_v) \tag{29}$$

where: $\tilde{c}$ = the cost of a given change in the levels of quasi-fixed factors per unit of time

$\Delta\hat{x}$ = the change in quasi-fixed factor stocks per unit of time

$\hat{x}, y, p_v$: as previously defined

If a dynamic internal cost of adjustment industry model was estimated, impacts on adjustment costs of regulations which affect levels of quasi-fixed stocks could be determined. It is important to point out that these adjustment costs are incurred in addition to the static direct and indirect costs discussed previously. The lower the speed of optimal quasi-fixed stock adjustment the greater will be internal adjustment cost of a change in quasi-fixed stocks mandated by regulation. Industries with typically low speeds of adjustment include: textile mill products, lumber products, stone clay and glass products, electrical machinery, nonelectrical machinery, petroleum refining and primary metals.

Probably the most important dynamic impact a regulation can have would be to affect technological advance and innovation diffusion. Since firms must make research and development decisions in a world of imperfect foresight and uncertainty, it is not clear whether such an impact would result in a private (or social) loss or gain. It is quite conceivable that a particular regulation could serve to speed-up the adoption of a highly efficient innovation or could just as conceivably forestall such adoptions. Unfortunately, the neoclassical-econometric model can provide little useful information in this regard since it does not presently incorporate a well-developed theory of technological advance or innovation diffusion.

V. Practical Problems with Ex Ante Compliance Cost Estimation

In the preceding sections we have discussed three approaches to the problem of ex ante compliance cost estimation; these are: 1) the input cost accounting approach, 2) the engineering process model, and 3) the neoclassical econometric model. The practical problems associated with the input cost accounting approach have already been discussed in some detail and we shall not elaborate further on them. Our intention in this section is to examine the problems associated with the process and econometric model approaches to compliance cost and to suggest some avenues of future research.

There can be no doubt that the engineering process model is an extremely useful tool for the ex ante analysis of environmental regulation. The model's ability to identify and accurately account for indirect costs and the phenomena of residual switching serve to distinguish it from the more crude input cost accounting methods. However, the model does have some inherent weaknesses and problems of implementation.

The major weakness of the process model is its lack of a time dimension. This timeless character of the model implies that all production activities occur instantaneously and that alterations in these activities (i.e., process changes resulting from regulation for example) also occur immediately and costlessly. Moreover, the model is poorly equipped to deal with technological change and the diffusion of innovation; thus, it is largely unsuitable for analyses of regulatory impacts on the process of innovation.

The major implementation problem associated with the process model is cost. At the present time only a handful of process models exist which are capable of undertaking the types of compliance cost estimation suggested in section IV. The small number of such models is a direct result of the enormous effort which must be undertaken to construct a credible model. Upon completion of the model there still exists the cost associated with model maintenance which would include periodic updates of the technology matrix to incorporate new processes and changes in the structure of the industry the model is designed to depict. Finally, the high degree of specificity in a credible model implies that the model construction, maintenance and results are not easily generalizable to other production activities; and thus, numerous, self-contained models must be constructed to encompass the industrial sector of a modern economy.

The practical problems of process models are fairly well understood since we have experience (albeit, minimal experience) in the construction and use of such models for the analysis of environmental regulation. On the other hand, the neoclassical econometric approach to compliance cost estimation is still in its formative stages, and thus we have little practical experience with the methodology. Two studies do exist which employ the formal neoclassical model in the analysis of environmental regulation. The first, Kopp [1980], studied the relationship between levels of residuals discharges and measures of technical efficiency in the U.S. electric power industry; the second, Pittman [1981], examined the impact of environmental regulation on the cost structure of paper mills. Unfortunately, the limited nature of these studies provides only a partial understanding of the problems to be faced if the econometric model approach is to be employed on a large scale to estimate ex ante compliance cost.

One practical limitation of the econometric modeling approach is clear -- it is data-intensive. The quantity of data required will depend upon the level of technological disaggregation (i.e., 4, 3, or 2-digit SIC designations and plant, firm or industry organization) dictated by the analysis. But regardless of the aggregation, the model will require the prices and quantities of all inputs consumed and marketable outputs produced plus estimates of residual discharges. Collecting the input and output data will be a costly task in itself; however, such data does exist and has been routinely collected and used by econometricians to study production activities for some time. The task of collecting the residual discharge estimates poses a more uncertain cost. For some sectors of the economy the task will be quite straightforward since residual discharge estimates are readily available; the obvious example is U.S. steam electric generation where residual discharge estimates have been collected for several years. For other industrial sectors EPA estimates may have to be employed.

The potential advantages of the econometric approach make it a reasonable alternative to the process model for ex ante compliance cost estimation. Aside from the initial data collection effort, the cost of econometric model construction, estimation and maintenance is miniscule when compared to that of the process model. Moreover, the econometric model can be given a time dimension permitting one to examine the adjustment cost associated with a regulation in a dynamic setting. Finally, properly designed econometric models of industrial activity mesh well with other economic models used for policy analysis, such as large scale macro-econometric models.

The major practical problem associated with the econometric approach is its reliability. Past experience with process models has shown that they provide reasonably good approximations to actual engineering activities and can be expected to perform adequately in the complex analysis of compliance cost. Econometric models, on the other hand, do rather well in depicting factor demand but can they reliably forecast compliance cost? The results of econometric models are sensitive to technological and input aggregation and to model misspecification, but even under ideal aggregation conditions and proper specification it is unclear whether the complexity of firms' adjustments to regulation can be adequately captured and predicted by a model which is intended only as a summary of major causal forces. Unfortunately, we have little practical experience with econometric models incorporating discharge data upon which to base a judgement concerning the usefulness of the underlying econometric methodology.

Some Topics for Research

In the body of this paper we have asserted that the ex ante analysis of compliance cost can be improved if process models and/or econometric models are used instead of, or in conjunction with, the input cost accounting approach. Given our claim, a logical research strategy would be to establish an empirical test of the assertion. Such a test would simultaneously provide insight regarding the credibility of our proposals and would also generate experience in using process and econometric models which may uncover previously unknown practical problems or advantages.

Considering first the process model approach, it seems reasonable to circumvent the construction stage and use one of the currently available off-the-shelf models as a guinea pig. The research plan would involve choosing a particular regulation or a set of regulations to be analyzed. The process model would then be configured in a pre-regulation base case environment and solved. Next the model would be re-configured in the post-regulation environment and resolved. The types of compliance cost analyses discussed in section IV would then be executed. As a test of the model's validity one could choose a regulation already in place where the ex post cost data on hand is assumed to be of high quality. Using the process model we would then perform an ex ante analysis and determine how well the ex ante estimates compared to the actual ex post cost.

A test of the econometric approach is considerably more complicated than the process model. Since high quality econometric models of the kind required for ex ante estimation do not currently exist, a test methodology similar to the process model would first require the construction of a suitable econometric model. The cost of this initial construction, including data collection, can be expected to be quite high. Moreover, even if such a model were constructed and tested, we would not be able to determine the differential impact on the quality of the results emanating from poor model construction or from an underlying inadequate methodology. As we stated above, it is the econometric methodology which is really at issue and which we seek to test, not a specific model. Thus before any wholesale testing of econometric models begins a plan to evaluate the econometric methodology must first be devised.

FOOTNOTES

[*] The authors are, respectively, Fellow, Quality of the Environment Division, Resources for the Future, and Visiting Assistant Professor of Economics, University of North Carolina; and Senior Fellow, Quality of the Environment Division, RFF. The authors wish to acknowledge the very helpful comments of Margaret Slade and William Vaughan on an earlier draft of this paper. Jeff Kolb of the Environmental Protection Agency graciously made available the data on use of tax-exempt pollution control bonds, which facilitated our analysis. Kopp acknowledges the support of the Andrew W. Mellon Foundation in conjunction with this work.

1. For a review and discussion of the macroeconomic effects of environmental regulation, see Peskin, Portney, and Kneese [1981].

2. See DeMuth [1980] for the most comprehensive discussion of the pros and cons of the regulatory budget.

3. For a fuller discussion of these issues see Peskin, Portney, and Kneese [1981].

4. See Portney [1981].

5. Ibid.

6. This section draws largely on material presented in Portney [1981].

7. See Andersen [1979].

8. Ibid., p. 26.

9. For a discussion of the allocative inefficiencies that result from tax-exempt financing of pollution control, see Peterson and Galper [1975].

10. For an analysis of such mechanisms, see Sonstelie [1981].

11. For instance, see the Securities and Exchange Commission Administrative Proceeding File No. 3-5936. See also Salpukas [1979].

12. See Sonstelie [1981].

13. For a discussion of other possible uses of these kinds of approaches, see Vaughan [1978].

14. See Portney [1981].

15. An excellent description of the process model approach and its applicability to environmental regulation can be found in Russell and Vaughan [1976].

16. We have taken some liberty with the notation used to describe the process model in order to utilize one set of notation consistently throughout the paper.

17. Technical efficiency is a concept attributed to Farrell [1957]. Its only known application to the environmental regulation is found in Kopp [1980]. A full description of Farrell's early contribution and several generalizations to it are found in Kopp [1981].

18. A methodology for analyzing both direct and indirect impacts of environmental regulation using an econometric model is found in Kopp and Smith [1981].

19. In this case we would subtract from the value of the model (6) objective function the value of the tax $t'y_r$, in order to perceive how the actual costs of production net of the tax were altered by the imposition of the tax. Naturally, if we were concerned with total private compliance cost including the tax $t'y_r$ would remain in the calculated value of the objective function.

20. If in the pre-regulation environment it was profitable to recover marketable by-products we would want to make sure that the base case objective function of model (2) included $p_r'y_{qr}$.

21. We should point out that if the process model is characterized by constant returns to scale and further that it can utilize any quantity of inputs at a fixed price without limit, it will tend to expand production infinitely. In actual applications one would normally restrict the quantity of capital the model can employ.

22. These conditions are found in Diewert [1974].

23. See Shephard [1953].

24. A formal and most useful proof is contained in Diewert [1974].

25. Unfortunately, the econometric model is incapable of examining the regulatory impact of a required process adoption, since it does not identify individual processes.

26. Since in the pre-regulation and post-regulation environments there are no costs to a firm for its pollution, the firm faces no constraints on its polluting behavior. Without such constraints the economic model of production is incapable of determining how the residual discharges will change with a given change in the price of factor inputs.

27. Discussions of allocative efficiency can be found in Farrell [1957] and Kopp [1981].

28. A full solution to this problem can be found in Kopp and Diewert [1981].

29. See Kopp and Smith [1980] for a theoretical discussion of these issues.

30. Of course, if the econometric model was estimated with short-run data then they will tend to overestimate the long-run effects.

31. The model is fully described in Brown and Christensen [1981].

32. See Berndt, Fuss, and Waverman [1977] for a more detailed discussion.

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