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APPENDIX J

IMPLEMENTING QALY'S IN THE ANALYSIS OF AIR POLLUTION REGULATIONS

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Implementing QALYs in the Analysis of Air Pollution Regulations

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Quantifying and valuing improvements in health resulting from environmental regulation is a difficult and often thankless job. While economists and some policymakers see the necessity for such valuations in order to determine whether policies are an efficient use of societies resources, many other disciplines find cost-benefit analysis, and particularly the assignment of a dollar value to reductions in the risk of mortality, to be an "inherently flawed" process (Heinzerling and Ackerman, 2002). Even within the community of practitioners of cost-benefit analysis, there is broad disagreement over the appropriate methods by which improvements in public health should be quantified and valued.

One of the more recent controversies regards whether reductions in mortality risk should be reported and valued in terms of statistical lives saved or in terms of life years saved. A further complication in the debate is whether to apply quality adjustments to life years lost. Under this approach, individuals with preexisting health conditions would have a lower number of quality adjusted life years (QALY) lost relative to healthy individuals for the same loss in life expectancy. However, the QALY approach has some appealing characteristics, for example, it provides an alternative framework to cost-benefit analysis for aggregating quantitative measures of health impacts. As such, it provides an alternative method that can account for morbidity effects as well as losses in life expectancy, without requiring the assignment of dollar values to calculate total benefits. Whether this aggregation is appropriate for evaluating environmental regulations has still to be determined.

In recent analyses of air pollution regulations (U.S. EPA, 1999, 2000), the U.S. EPA has applied a standard damage-function approach to quantifying and monetizing health benefits of reducing air pollution. This approach has been used elsewhere in numerous applications (Kunzli et al., 2000; Levy et al., 1999). This approach quantifies reductions in individual health outcomes, such as premature mortality and chronic bronchitis, and assigns dollar values to those outcomes to obtain aggregate measures of monetized health benefits.

This paper examines the implications of an alternative approach, the quality-adjusted life years (QALY) method, which converts all health impacts (both mortality and morbidity) into changes in quality adjusted life years. Once the conversion to QALY has been accomplished, QALY can be aggregated across health outcomes and combined with costs to provide cost-utility ratios. Alternatively, a monetary value can be assigned to each QALY gained to provide an estimate of aggregate monetized benefits which can be compared with costs to calculate net benefits.

Within this paper, I provide an overview of the key issues involved in implementing a QALY based approach for evaluating the health impacts of air pollution regulations and illustrate these issues with an example based on the recent Heavy Duty Engine/Diesel Fuel regulations. Section 2 presents a review of the current benefit-cost framework and the motivations for exploring an alternative QALY based framework. Section 3 compares the assumptions embedded in willingness-to-pay based values with those embedded in QALY values. Section 4 outlines several different methods that may be used to integrate QALYs into a cost-benefit framework. Section 5 provides the results and discussion of the illustrative application of the QALY approach to the Heavy Duty Engine/Diesel Fuel regulations. Section 6 concludes with some thoughts on future research needs and policy considerations.

Cost-Benefit Methods and the Rationale for a QALY Based Analysis

EPA is required under Executive Order 12866 to evaluate the costs and benefits of major regulations, defined as those expected to have a cost of at least $100 million dollars (Clinton, 1993). The current interpretation of this directive is to provide estimates of economic benefits based on aggregations of individual willingness-to-pay (WTP), which reflects individual preferences for health and environmental improvements. EPA's current approach uses WTP applied to incidence of disease and premature death to calculate health-related benefits of air pollution reductions. Length of life lost and quality of life are not treated independently of WTP, although age-specific WTP for mortality risk reductions is considered in a sensitivity analysis (U.S. EPA, 2000).

Based on the current cost-benefit framework, the most important quantifiable health benefits associated with reduced air pollution are reduced risk of death and reduced risk of chronic illness. Monetized health benefits are dominated by the value of PM-related premature mortality benefits. The absolute size of mortality benefits is driven by two factors, the relatively strong concentration-response function, which leads to a large number of premature deaths predicted to be avoided per microgram of ambient $PM_{2.5}$ reduced, and the value of a statistical life, estimated to be about $6.3 million (2000$). The relative size of mortality benefits, i.e. the share of total health benefits accounted for by mortality, is driven by both the large absolute magnitude of mortality benefits and by the relatively low values placed on non-mortality effects.

In recent reports, the Office of Management and Budget, which reviews all regulations for compliance with E.O. 12866, has argued that "there are strong arguments that 'life-years' is a better measure than 'lives' of the effectiveness of regulatory alternatives" and that in cases where there are reductions in non-fatal risks, i.e. risks of disease, "OMB is considering the use of new effectiveness measures that combine information on mortality and morbidity." (U.S. Office of Management and Budget, 2001, 2002) Two such measures mentioned by OMB are QALYs and disability adjusted life years (DALY). OMB recommends such measures because 1) they allow for aggregation of mortality and morbidity without application of dollar values, 2) they provide more emphasis on morbidity impacts, and 3) QALYs have been widely adopted in the public health economics literature (U.S. Office of Management and Budget, 2002).

The EPA Science Advisory Board has also suggested that "EPA consider reporting some results in terms of implied cost-effectiveness (e.g., dollars per life-year)." They suggest that "EPA consider calculating the cost-effectiveness of the CAA and certain of its provisions for comparison with other interventions that improve health. In other areas of public health, cost-effectiveness is frequently characterized as cost per QALY gained." But they also note that "alternative measures, such as the value of a statistical life-year (VSLY) or the value of a QALY, are not consistent with the standard theory of individual WTP for mortality risk reduction" (U.S. EPA Science Advisory Board, 2001).

The recommendations of OMB and SAB are consistent with the recommendations by the National Academy of Sciences panel on cost-effectiveness. The NAS panel recommended the use of QALYs when evaluating medical and public health programs that primarily reduce both mortality and morbidity (Gold et al., 1996). The OMB, SAB and NAS panel recommendations motivate the following discussion of implementation issues for QALYs in assessing the benefits of air pollution reductions. However, the following discussion is predicated on the assumptions embedded in the QALY analytical framework. As noted in the QALY literature, QALYs are consistent with von Neumann-Morgenstern utility theory only if one imposes several restrictive assumptions, including independence between longevity and quality of life in the utility function, risk neutrality with respect to years of life, and constant proportionality in tradeoffs between quality and quantity of life (Pliskin, Shepart, and Weinstein, 1980; Bleichrodt, Wakker, and Johannesson, 1997) To the extent that these assumptions do not represent actual preferences, the QALY approach will not provide results that are consistent with a cost-benefit analysis based on the Kaldor-Hicks criterion. Even if the assumptions are reasonably consistent with reality, because QALYs represent an average valuation of health states rather than the sum of societal WTP, there are no guarantees that the option with the highest QALY per dollar of cost will satisfy the Kaldor-Hicks criterion, i.e. generate a potential Pareto improvement (Garber and Phelps, 1997).

Cost-benefit analysis based on WTP is not without potentially troubling underlying structures as well, incorporating ability to pay (and thus the potential for equity concerns) and the notion of consumer sovereignty. Table 1 compares the two approaches across a number of parameters. For the most part, WTP allows parameters to be determined empirically, while the QALY approach imposes conditions a priori. Noting these differences, the remainder of the paper takes an agnostic view of the two methods and investigates additional issues that arise in applying the QALY method to air pollution regulations.

QALY Implementation Issues

In designing a QALY-based analysis of the benefits of reducing air pollution, a number of important issues need to be addressed. These include (in no particular order of importance): treatment of non-health benefits, treatment of acute symptoms, assessment of baseline life expectancy and quality of life weights, assessment of loss in quality adjusted life years from mortality and morbidity due to air pollution, and integration of QALYs into cost benefit analysis, i.e. assignment of values to QALYs. There are potentially other issues, however, I will focus on this set as the most likely to substantially affect the evaluation of the QALY method.

Reductions in air pollution may result in a broad set of health and environmental benefits, including improved visibility in national parks, increased agricultural and forestry yields, reduced acid damage to buildings, and a host of other impacts. QALYs address only health impacts, and the SAB notes that "EPA should be careful to acknowledge that the costs per QALY or life-year would be overstated to the extent that there are other benefits of the pollution reduction." To address this issue, OMB suggests that agencies "develop a suitable measure of the effectiveness of disparate programs directed toward enhancing other [non-health] aspects of the nation's welfare" and in the construction of their league table in the 2002 Federal Budget, chose to "subtract the value of these benefits from the aggregate cost estimate to yield a net cost estimate." I will follow this same "net cost" approach in the illustrative exercise.

Health effects from exposure to particulate air pollution encompass a wide array of chronic and acute conditions in addition to premature mortality (U.S. EPA, 1996). While chronic conditions and premature mortality generally account for the majority of monetized benefits, acute symptoms can impact a broad population or sensitive populations, e.g. asthma attacks in asthmatic children. Bala and Zarkin (2000) suggest that QALY are not appropriate for valuing acute symptoms, due to problems with both the measurement of utility for acute health states, and application of QALY in a linear fashion to very short duration health states. Johnson and Lievense (2000) suggest using conjoint analysis to get healthy-utility time equivalences which can be compared across acute effects, but it is not clear how these can be combined with QALY for chronic effects and loss of life expectancy. There is also a class of effects which EPA has traditionally treated as acute, such as hospital admissions, which may also result in a loss of quality of life for a period of time following the effect. For example, life after asthma hospitalization has been estimated with a utility weight of 0.93 (Bell et al., 2001; Kerridge, Glasziou, and Hillman. 1995).

How should these effects be combined with QALY for chronic and mortality effects? One method would be to convert the acute effects to QALY, however, as noted above, there are problems with the linearity assumption, i.e. if a year with asthma symptoms is equivalent to 0.7 year without asthma symptoms, then one day without asthma symptoms is equivalent to 0.0019 QALY gained. This is troubling from both a conceptual basis and a presentation basis. An alternative approach is simply to treat acute health effects like non-health benefits and subtract the dollar value (based on WTP or cost-of-illness) from compliance costs in the cost-effectiveness analysis. However, this takes away one of the key comparative advantages of using QALY, the ability to aggregate morbidity and mortality effects without resorting to monetization. With that limitation in mind, I follow the latter approach in the illustrative exercise.

For air pollution regulations that result in gains in life expectancy (reduction in premature death), a critical variable in QALY analysis is the baseline life expectancy and health condition of the affected population. There is evidence that, at least for some of the mortality risks associated with short term exposure to elevated levels of air pollution, the susceptible population is comprised of individuals with chronic diseases (Goldberg et al., 2001). However, recent cohort analyses have found increased risk of all-cause mortality, as well as increased risks of cardiopulmonary and lung cancer mortality (Krewski et al., 2000; Pope et al., 2002). To the extent that the life expectancy of populations potentially affected by air pollution differs from that of the general population, QALY estimates of the benefits of air pollution reductions will be biased if general population life expectancies are used. However, there are some important issues to consider when evaluating the appropriate baseline health condition and life expectancy.

First, there is little information on life expectancy with many chronic diseases, and, QALY weights are available for some, but not all chronic health conditions. One of the more comprehensive collections of QALY weights can be found in the Cost Utility Analysis Database at the Harvard Center for Risk Analysis (Bell et al., 2001). This database lists QALY weights for many of the chronic diseases that may be preexisting risk factors for susceptibility to air pollution, including lung cancer, diabetes, congestive heart failure, cardiac disability, hypertension, and chronic obstructive pulmonary disease (COPD).

For many epidemiology studies, including most of the studies linking mortality with long-term exposure to air pollution, the distribution of causes of death within the populations is unknown except at the very broadest scale (i.e. all cardiopulmonary causes). And, for most time series analyses of mortality, age at death is also not known. Unless we know the distributions of age at death, causes of death from air pollution and the underlying health condition of those dying from specific causes, it is difficult to assign life expectancy and baseline quality of life.

An additional important issue in determining baseline life expectancy and health conditions is whether we have properly accounted for morbidity preceding premature mortality. There are a number of epidemiological and toxicological studies linking exposure to air pollution with chronic diseases, such as chronic bronchitis and atherosclerosis (Abbey et al., 1995; Schwartz, 1993; Suwa et al., 2002). If these same individuals with chronic disease caused by exposure to air pollution are then at increased risk of premature death from air pollution, there is an important dimension of "double-jeopardy" involved in determining the correct baseline for assessing QALY lost to air pollution (see Singer et al. (1995) for a broader discussion of the double jeopardy argument).

Analyses estimating mortality from acute exposures that ignore the effects of long-term exposure on morbidity may understate the health impacts of reducing air pollution. As shown in Figure 1, individuals exposed to chronically elevated levels of air pollution may realize an increased risk of death and chronic disease throughout life. If at some age they contract heart (or some other chronic) disease due to the exposure to air pollution, they will from that point forward have both reduced life expectancy and reduced quality of life. The benefit to that individual from reducing lifetime exposure to air pollution would be the increase in life expectancy plus the increase in quality of life over the full period of increased life expectancy. Now, because the individual has contracted a chronic disease, he or she is also more susceptible to short-term episodes of high pollution which can lead to immediate death (as picked up in the daily time series studies). If the QALY loss is determined based on the underlying chronic condition and life expectancy without regards to the fact that the person would never have been in that state without long term exposure to elevated air pollution, then the person is placed in double-jeopardy. In other words, air pollution has placed more people in the susceptible pool, but then we penalize those people in evaluating policies by treating their subsequent deaths from acute exposure as less valuable, adding insult to injury, and potentially downplaying the importance of life expectancy losses due to air pollution. If the risk of chronic disease and risk of death are considered together, then there is no conceptual problem with measuring QALYs, but this has not been the case in recent applications of QALY to air pollution (Carrothers, Evans, and Graham, 2002). The use of QALYs thus highlights the need for a better understanding of the relationship between chronic disease and long-term exposure and suggests that analyses need to consider morbidity and mortality jointly, rather than treating each as a separate endpoint (this is an issue for the current cost-benefit approach as well).

Once one has arrived at estimates of QALY gained (or lost) due to an air pollution reduction, the question arises at to how and whether to integrate these estimates into the cost-benefit framework in which other, non-health benefits are considered. The EPA SAB suggests that QALYs "are not estimates that conform with, or should be combined with, VSL estimates" (U.S. EPA Science Advisory Board, 2001). OMB is not quite as strong in their, statements, suggesting that there are several options, including: 1) don't place a dollar value on QALYs, just use them in cost-utility analysis; 2) apply a reference value from the health economics literature –

current literature suggests from $100,000 to $250,000 per QALY; or 3) apply a single value derived from the value of a statistical life (VSL), e.g. starting from a base VSL of $6.1 million, the discounted value of a life year (assuming 35 years of remaining life expectancy and a 3 percent discount rate) is $284,000. A recent QALY based analysis of mortality impacts of air pollution applies a value of $300,000 per QALY, constructed by applying an adjustment to the standard VSL-derived VSLY to account for differences in the contexts of air pollution risk and the risks on which the standard VSL is based (Carrothers, Evans, and Graham, 2002).

A fundamental problem with converting VSL into VSLY is the implicit assumption embedded in the VSLY approach that there is a linear relationship between the VSL and age. This assumption is not consistent with the current evidence on the age-VSL relationship. One potential alternative that may be more consistent with recent stated preference literature (Jones-Lee, 1989, 1993; Krupnick et al., 2000) is to use age-specific VSL to calculate age-specific value of life-years. The EPA Science Advisory Board in general agrees, noting that "inferring the value of a statistical life year...requires assumptions about the discount rate and about the time path of expected utility of consumption. The Committee agrees ....that the theoretically appropriate method is to calculate WTP for individuals whose ages correspond to those of the affected population, and that it is preferable to base these calculations on empirical estimates of WTP by age (U.S. EPA Science Advisory Board, 2000)." The VSL literature does not support additional adjustments to VSL or VSLY for health related quality of life (based on Krupnick et al, 2000). This is supported by the EPA SAB, which noted that "there are no published studies that show that persons with physical limitations or chronic illnesses are willing to pay less to increase their longevity than persons without these limitations. People with physical limitations appear to adjust to their conditions, and their WTP to reduce fatal risks is therefore not affected (U.S. EPA Science Advisory Board, 2000)."

Table 2 lists the derived value of statistical life year for different ages based on the Jones-Lee (1989, 1993) stated preference studies. Note that the Jones-Lee 1989 paper estimated a very steep quadratic relationship between age and WTP. The Jones-Lee 1993 estimated a much flatter relationship. Because of this, for the Jones-Lee 1989 estimates, during the younger years, the VSL is decreasing more slowly than the number of remaining life years (thus VSLY increases) but during older years, the VSL is decreasing more rapidly than the number of remaining life years, leading to reductions in VSLY. For the 1993 study, VSL is always decreasing more slowly than the number of remaining life years, so you see a steadily increasing VSLY.

Setup for Illustrative Exercises: EPA's Heavy Duty Engine/Diesel Fuel Regulations

To illustrate the issues raised above and to highlight some of the implications of those issues, I develop two illustrative exercises based on the benefits analysis conducted in support of the Heavy Duty Engine/Diesel Fuel (HDE) regulations promulgated by EPA in 2000. Both exercises are based on the same data and methods for generating QALYs. The first exercise illustrates the use of cost-effectiveness or cost-utility analysis with QALYs. The second exercise extends the use of QALY by demonstrating how QALYs might be integrated into benefit-cost analyses.

The HDE regulations are estimated to result in a population weighted reduction in $PM_{2.5}$

of 0.65 μg/m^3 in 2030, when the fleet of heavy duty vehicles is expected to be fully turned over. The benefits analysis was therefore based on projected populations in the year 2030. Although we typically adjust WTP to reflect growth in real income in the future, no adjustment is assumed in this exercise for simplification. In addition, the focus of this exercise is only on mortality and chronic bronchitis risk associated with fine particulate matter. Other health and environmental benefits total $3.8 billion (U.S. EPA, 2000). The estimated costs of the rule are $4.2 billion/year, representing the annualized costs of compliance over the period of implementation.

In this exercise, I develop estimates of the QALY gained from reductions in incidence of premature mortality and chronic bronchitis associated with reductions in ambient $PM_{2.5}$. For gains in life years resulting from reduced exposure to $PM_{2.5}$, QALYs are calculated as:

$QALY\,GAINED = \sum_i \Delta D_i \times w_i \times DLE_i$, where ΔD_i is the number of premature deaths avoided in age interval i, w_i is the average QALY weight for age interval i, and DLE_i is the average discounted life expectancy for age interval i, calculated as $DLE_i = \sum_{t=1}^{LE_i} \frac{1}{(1+r)^t}$, where r is the discount rate and LE_i is the average life expectancy in age interval i. For gains in quality of life resulting from reduced incidences of PM-induced chronic bronchitis, QALYs are calculated as $QALY\,GAINED = \sum_i \Delta CB_i \times DLE_i \times \left(w_i - w_i^{CB}\right)$, where ΔCB_i is the number of incidences of chronic bronchitis avoided in age interval i and w_i^{CB} is the QALY weight associated with chronic bronchitis. Following the literature, I discount QALYs over the period of life expectancy using a 3 percent discount rate (Gold et al., 1996). Using these QALY, I then develop examples of both cost-utility ratios and monetary estimates of benefits, by applying three different VSLY approaches. In addition to the age-dependent VSLY outlined in Table 2, I examine the impact of using QALY values from the health effects literature and VSLY derived from an age-independent VSL of $6.1 million.

The source of the concentration-response function for premature mortality is the reanalysis of the American Cancer Society cohort study of mortality and long-term exposure to fine particles, applied to adults aged 30 and over (Krewski et al., 2000). This study implies a relative risk of 1.003 for the HDE reduction in PM2.5 of 0.65 $\mu g/m^3$. Another recent QALY-based analysis (Carrothers, Evans, and Graham, 2002) suggests that mortality can be divided into acute exposure and long-term exposure risk, however, the HDE analysis focused on the risks from long-term exposure. This is consistent with recommendations from the EPA SAB and recent literature (Kunzli et al., 2001). Although there is no specific scientific evidence of a lag between reduction in PM and reductions in premature mortality, current scientific literature on adverse health effects associated with smoking and the difference in the effect size between chronic exposure studies and daily mortality studies suggest that all incidences of premature mortality reduction associated with a given incremental change in PM exposure would not occur in the same year as the exposure reduction. This literature implies that lags of a few years are plausible. Consistent with advice from the SAB, I have assumed a five-year distributed lag structure, with 25 percent of premature deaths occurring in the first year, another 25 percent in the second year, and 16.7 percent in each of the remaining three years (U.S. EPA Science Advisory Board, 1999).

Life expectancy at different ages was obtained from the Centers for Disease Control abridged life tables for 1999 (U.S. CDC, 2001). No information is provided in the Krewski et al. (2000) analysis to determine the distribution of underlying health status within the study population. As such, I had to make an assumption regarding the appropriate baseline quality of life for the affected population. Because the general population is likely to be on average at somewhat less than perfect health, I followed recent literature and assumed a QALY weight of w_i=0.95 for life years lost to air pollution (Carrothers, Evans, and Graham, 2002; Gold et al., 1996).

The concentration-response function for chronic bronchitis is taken from a cohort analysis of Seventh Day Adventist non-smokers, applied to adults aged 27 and older (Abbey et al., 1995). This study implies a relative risk of 1.0086 for the HDE reduction in PM2.5 of 0.65 $\mu g/m^3$. Prevalence rates were obtained from the Centers for Disease Control (Adams, Hendershot, and Marano, 1999, Table 57). There are no nationally representative estimates of the incidence of new cases of chronic bronchitis. Instead, we used an incidence estimate from Abbey, 1993, of 3.78 cases per thousand population, adjusted for age using the age distribution of the prevalence rates. I was not able to identify any literature estimating the life expectancy of individuals with chronic bronchitis. As such, I assumed that individuals with chronic bronchitis had the same age-specific life expectancy as the general population, thus chronic bronchitis is assumed to result in no loss in life years. Based on estimates reported in de Hollander et al. (1999), years of life with chronic bronchitis are assumed to have a QALY weight of w_i^{CB}=0.69. Years without chronic bronchitis are assumed to have the same weight as the general population, i.e. w_i=0.95. In the WTP based analysis, avoided incidences of chronic bronchitis are valued at $331,000 (1999$). This value is derived from the severe chronic bronchitis/cost of living tradeoff values reported in Viscusi, Magat and Huber (1991), adjusted to average severity chronic bronchitis using the elasticity of WTP with respect to severity of illness reported in Krupnick and Cropper (1992). For more details, see the technical support document for the HDE analysis (Abt Associates, 2000).

Results of Illustrative Exercise

Table 3 provides the results of the QALY analysis of mortality risk reductions. Based on the life table analysis, the average length of life lost by an individual dying due to causes related to long-term exposure to PM2.5 is around 15 years. The total discounted QALY gained from the HDE reduction in PM2.5 in 2030 for the population over 30 is 83,771.

Table 4 provides similar results for chronic bronchitis. Based on the life table analysis, the total discounted QALY gained from reductions in chronic bronchitis resulting from the HDE regulation for the population over 27 is 33,844. It is worth noting that most of this benefit (87 percent) is due to reductions in chronic bronchitis occurring in populations under 65 (i.e. the non-elderly population). This is due to the relatively long period of life that is lived with increased quality of life without chronic bronchitis.

The relationship between QALY gained and age is shown in Figure 2. Because the baseline mortality rate is increasing in age at a much faster rate than the prevalence rate for chronic bronchitis, the share of QALY gained accounted for mortality is proportional to age. At the oldest age interval, avoiding incidences of chronic bronchitis leads to only a few QALY gained, due to the lower number of years lived with chronic bronchitis. QALY gained from avoided premature mortality is low in the youngest age intervals because of the low overall mortality rates in these intervals, although the number of QALY per incidence is high. In later years, even though the QALY gained per incidence avoided is low, the number of cases is very high due to higher baseline mortality rates.

Placing these results in the context of a cost-utility analysis, based on the costs of the HDE rule of $4.2 billion, total cost per discounted QALY ignoring all other benefits, is $35,700. The HDE rule also resulted in $3.8 billion in other health and environmental benefits, or net costs of $0.4 billion. Net cost per discounted QALY is then $3,400. Even ignoring other benefits, the cost per QALY for the HDE rule compares favorably with many other health interventions reported in the Harvard Cost Utility Analysis database, and is well below the median cost per life-year saved for live-saving interventions of $48,000 (1993$) as reported by Tengs et al. (1995). With other benefits considered, the cost per QALY is very low relative to others in the literature.

There are several important assumptions I have made due to a lack of sufficient data. One key assumption is that chronic bronchitis does not result in reduced life expectancy. If this is not the case, then individuals will gain not only the lost quality of life, but the increased life expectancy in improved health. Another important assumption is the baseline utility weight for the population affected by long-term exposure to air pollution. I assumed that the average population affected by air pollution would have a utility weight of 0.95. However, some literature suggests that baseline quality of life is age dependent. For example, if we assume that individuals over 84 have a base utility weight of 0.81 (Tsevat et al, 1998), this reduces the QALY gained by 6 percent for reductions in premature mortality. Finally, the assumption of a 3 percent discount rate has a relatively large impact on the resulting QALY estimates. Assuming a zero percent discount rate would increase the QALY gained by 42 percent, while assuming a 7 percent discount rate would decrease QALY gained by 25 percent. Note that discount rates will have less of an impact on the overall cost-utility comparison if costs and QALY are discounted at the same rate, as both the numerator and denominator will be affected by any change in discount rate.

Based on the standard WTP method, the estimated 8,025 avoided incidences of premature mortality are valued at $6.1 million per statistical life, discounted over the 5 year cessation lag at 3 percent. This yields a total value for reduced mortality risk of $46.5 billion. Using age-dependent VSL as defined in Table 5, the total values for reduced mortality risk are $25.0 and $42.2 billion when using the Jones-Lee 1989 and 1993 adjustments, respectively. The 6,543 cases of chronic bronchitis are valued at $2.2 billion. The combined benefits of chronic bronchitis, mortality, and all other monetized benefits are thus $54.1 billion using the standard VSL, $32.6 billion using the Jones-Lee 1989 age-dependent VSL, and $49.8 billion using the Jones-Lee 1993 age-dependent VSL. When compared with costs of $4.2 billion, there are substantial net benefits regardless of which VSL method is employed.

Integration of QALY into the cost-benefit framework requires assigning a value per QALY to QALY gained from reductions in chronic bronchitis and premature mortality. Note that a QALY gained is considered the same, regardless of whether it arises from improvements in quality of life (from reduced chronic bronchitis) or improvements in quantity of life (gains in life expectancy from reduced premature death). Because of this, chronic bronchitis is not valued using a different valuation estimate. All QALY gained will be assigned the value, regardless of source. As indicated above, for this analysis, I examine five different values per QALY: two based on the medical cost-effectiveness literature, one based on the standard $6.1 million VSL, and two based on the Jones-Lee age-dependent VSL. The results of this analysis are presented in Table 6. The most striking result of this table is that when the QALY approach is used, the value of chronic bronchitis reductions is drastically increased relative to the value of reductions in mortality risk. All of the QALY based estimates of total benefits are lower than total benefits under the standard WTP based approach with age-independent VSL. However, when age-dependent VSL are used, the QALY approach actually results in larger total benefits because the value of QALY from chronic bronchitis reductions offsets the reduction in value from reduced mortality risk.

To further emphasize this finding, consider that in the standard WTP methodology, mortality risk reduction accounts for over 95 percent of combined benefits. In the direct QALY method, increase in life expectancy accounts for only 71 percent of the total QALY benefit. In the integrated assessment, this carries over, so that the value of mortality risk reduction now accounts for between 71 and 80 percent of total benefits, depending on which method is used to derive the value of a QALY. Even when age-dependent VSL are applied in the traditional WTP based analysis, mortality benefits still account for over 90 percent of combined benefits. Clearly, the QALY method provides greater emphasis on chronic diseases which reduce quality of life relative to reductions in mortality risk which have greater impacts on older populations with lower life expectancy.

An important qualification to this finding is the sensitivity of this result to the assumed dollar value of $331,000 per case applied to chronic bronchitis. I have applied values for mortality risk reductions and chronic bronchitis risk reductions that were derived from separate sources. However, Viscusi, Magat, and Huber suggest that it may be appropriate to use their risk-risk data to derive an implicit value of chronic bronchitis which is more consistent with the assumed VSL. Using this implicit value method, the value of an incidence of severe chronic bronchitis is 0.32*$6.12, or $1.95 million. The corresponding value for an average case of chronic bronchitis would be around $958,000 per case, or around three times the assumed value. This would bring the total value of chronic bronchitis in the cost-benefit analysis to $6.3 billion, or 12 percent of total benefits, which is much more in line with the QALY based results. However, the implicit value method is very similar in concept to the QALY method, i.e. both derive value per incidence by scaling VSL, so the result is not surprising.

Conclusions

As I have demonstrated in this paper, it is a relatively straightforward process to develop estimates of QALY gained from air pollution regulations for mortality and chronic disease. It is also numerically straightforward to monetize QALYs using a number of different methods. However, as I have discussed earlier in the paper, it is not necessarily appropriate to employ QALYs, monetized or not, in cost-effectiveness analysis, and may be especially inappropriate in benefit-cost analysis of environmental regulations. Depending on the method used to value QALYs, an integrated cost-benefit/QALY approach can result in either lower or higher monetized benefits than the traditional WTP approach. If one accepts the validity of applying dollar values to QALYs, then the additional value assigned to chronic disease in some cases more than offsets the loss in the value of a statistical life for older populations. As the value of a life year increases for older populations (the VSL falls at a less than proportional rate with age), the value of reduced mortality risk approaches the value using the VSL approach. The QALY valuation approach most consistent with the stated preference WTP literature is based on age-specific WTP. And in fact, these two methods (age-dependent VSL and age dependent value of a QALY) provide very similar values for reductions in mortality risk.

In considering the appropriateness of using QALYs in regulatory cost-benefit analysis, it is important to recognize that the QALY method requires additional data and assumptions about life expectancy, baseline health states for affected populations, life years impacted by chronic disease, and utility weights for chronic diseases which may not be appropriate for environmental policy analyses focused on maximizing net benefits. Derivation of dollar values for QALYs remains a controversial issue and adds additional uncertainty to a QALY based cost-benefit analysis. In addition, the QALY approach forces attention to the question “Does air pollution just cause death in already ill people, or does it cause the disease that leads to death?” Ignoring this question can lead to “double jeopardy” for those with chronic illnesses caused or exacerbated to any significant degree by long-term exposures to air pollution.

From an ethical standpoint, the QALY approach may be less desirable to decision makers because it explicitly places a lower value on reductions in mortality risk accruing to older populations with lower quality of life. On the other hand, the QALY approach enhances the perceived importance of chronic disease relative to premature mortality, especially when the mortality impact is on older populations, and so can be argued to give more equitable consideration to individuals who might suffer with chronic disease for a long period of life who might otherwise be undervalued if appropriate WTP values are not available. Under certain assumptions, the QALY approach can even give larger total dollar benefits than the current method because of the enhanced value of chronic disease reductions. This may or may not hold for other environmental scenarios, depending on the suite of health impacts considered. Finally, the issue of how to aggregate acute health effects for which QALYs do not seem well suited with QALY estimates for chronic diseases and premature death may prevent QALYs from being useful for policy analysis when there are a broad range of acute and chronic health outcomes from a regulation.

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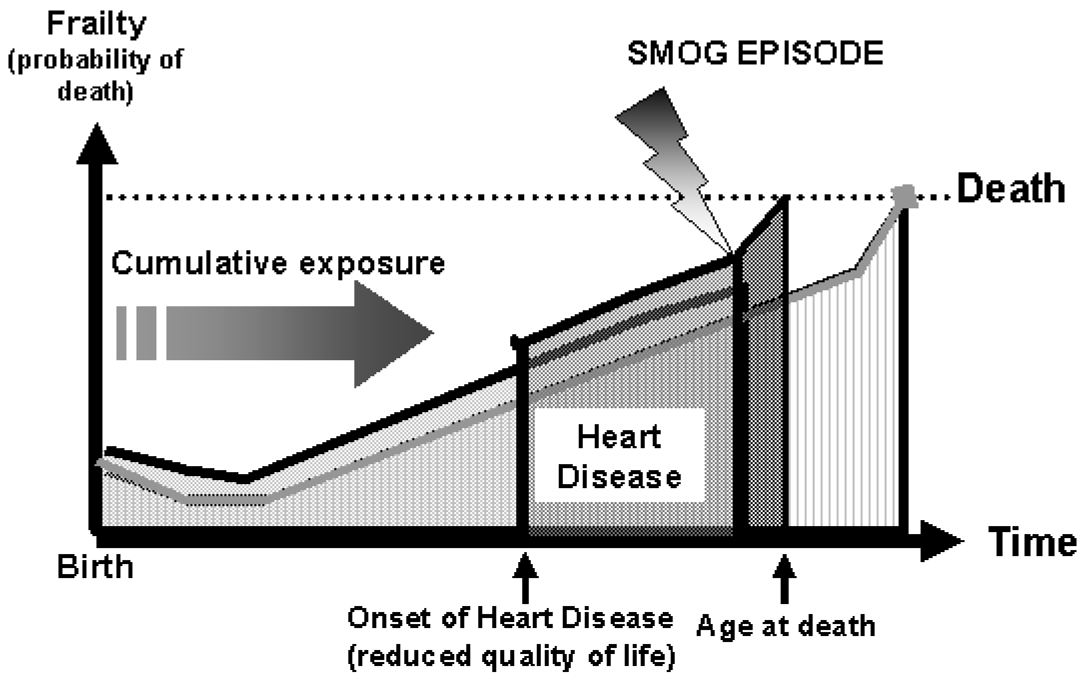

Figure 1. Relationship Between Long-term Exposure, Short Term Exposure, Chronic Disease and Death

(Source: Adapted from Kunzli, 2001).

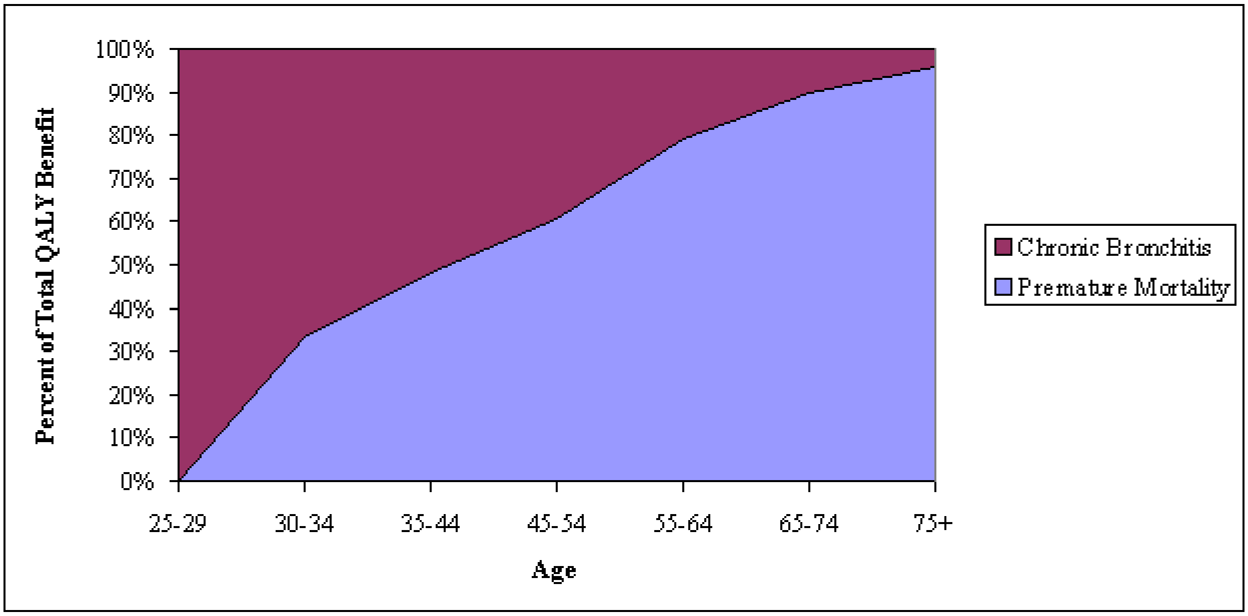

Figure 2. Age Structure of QALY Benefits

Table 1. Comparison of QALY and WTP approaches

Parameter	QALY	WTP
Risk Aversion	Risk neutral	Empirically determined
Relation of duration and quality	Independent	Empirically determined
Proportionality of duration/quality tradeoff	Constant	Variable
Treatment of time/age in utility function	Utility linear in time	Empirically determined
Preferences	Community	Individual
Source of preference data	Stated	Revealed and stated
Treatment of Income and Prices	Not explicitly considered	Constrains choices

Table 2. Derivation of Age-dependent Value of Statistical Life Year

Jones-Lee Age Group	Life expectancy	Discounted Life Expectancy (3% rate)	Adjusted VSL (J-L 1989)	Adjusted VSL (J-L 1993)	Implied Value of Life Year in Average Health for Age Group (J-L 1989)	Implied Value of Life Year in Average Health for Age Group (J-L 1993)
20-29	52	27.0	$4.00	$5.45	$152,869	$208,284
30-39	45	25.3	$5.45	$6.00	$222,149	$244,613
40-59	34	21.8	$6.12	$6.12	$289,610	$289,610
60-69	20	15.3	$5.26	$5.94	$353,770	$399,019
70-79	14	11.6	$3.86	$5.63	$341,322	$498,439
80-84	7	6.4	$1.71	$5.20	$275,044	$834,954
85+	5	4.6	$0.43	$5.02	$93,543	$1,095,791

Table 3. QALY Gained from Reductions in PM Mortality Risk

Age Interval	Reduction in PM-related Deaths in Interval (2030 Population)	Proportion of PM Deaths in Interval	Life Expectancy	Discounted Life Expectancy	Undiscounted Life years gained in interval	Discounted Life Years gained in interval
30-34	98	0.01	47.5	25.9	4,676	2,550
35-44	315	0.04	42.8	24.6	13,451	7,749
45-54	451	0.06	33.5	21.6	15,112	9,733
55-64	901	0.11	24.8	17.8	22,323	16,060
65-74	1,882	0.23	17.0	13.5	31,964	25,504
75-84	2,409	0.30	10.4	9.1	25,060	21,894
85+	1,969	0.25	5.0	4.7	9,847	9,290

Average length of life lost	15.26	11.56

	Undiscounted	Discounted
Total Gain in QALY (QALY weight = 0.95)	116,310	88,141
Discounted over 5-year distributed cessation lag:	110,544	83,771

Table 4. QALY Gained from Reductions in PM Chronic Bronchitis Risk

Age	Total 2030 Population (million)	CB Prevalence Rate (per 1000)	CB Incidence Rate (per 1000)	Reduction in CB Incidence	Discounted Life Expectancy (QALY weight = 0.95)	Discounted Quality Adjusted Life Expectancy with CB (QALY weight = 0.69)	Discounted QALY Gained per Incidence Reduced	Total Discounted QALY gained in age group
25-29	30.3	45.40	3.14	776	25.1	18.2	6.9	5,328
30-34	30.3	45.40	3.14	776	24.0	17.4	6.6	5,100
35-44	52.6	45.40	3.14	1,347	22.8	16.6	6.2	8,406
45-54	35.2	59.10	4.09	1,155	19.9	14.4	5.4	6,287
55-64	29.4	59.10	4.09	965	16.4	11.9	4.5	4,318
65-74	25.2	60.70	4.20	850	12.4	9.0	3.4	2,878
75+	18.2	67.30	4.65	675	8.3	6.0	2.3	1,526

	Undiscounted	Discounted
Total Gain in QALY (QALY weight = 0.69)	56,951	33,844

Table 5. Age-Dependent VSL Analysis of Reductions in Premature Mortality

Jones-Lee Age Group	Jones-Lee (1989) Ratios	Jones-Lee (1993) Ratios	J-L 1989 Adjusted VSL (million $)	J-L 1993 Adjusted VSL (million $)	# of Lives Prolonged	Non-Age-Specific VSL Benefits (billion $)	Jones-Lee (1989) Mortality Benefits (billion $)	Jones-Lee (1993) Mortality Benefits (billion $)
30-39	0.89	0.98	$5.45	$6.00	256	$1.5	$1.3	$1.5
40-59	1.00	1.00	$6.12	$6.12	1,059	$6.1	$6.1	$6.1
60-69	0.86	0.97	$5.26	$5.94	1,392	$8.1	$6.9	$7.8
70-79	0.63	0.92	$3.86	$5.63	2,146	$12.4	$7.8	$11.4
80-84	0.28	0.85	$1.71	$5.20	1,205	$7.0	$2.0	$5.9
85+	0.07	0.82	$0.43	$5.02	1,969	$11.4	$0.8	$9.4
Total Mortality Benefits						**$46.5**	**$25.0**	**$42.2**

Table 6. Comparison of Total Monetized Benefits Across Life Year Valuation Methods

Valuation Approach	billion (1999$) Chronic Bronchitis	Premature Mortality	Total
Health Cost-Effectiveness Literature ($100,000 - $250,000 per QALY)	$3.4 - $8.5	$8.4 - $20.9	$11.8 - $29.4
Standard $6.1 million VSL Basis			
Statistical Lives Saved	$2.2	$46.5	$48.7
QALY	$9.6	$23.8	$33.4
Age-Adjusted VSL Basis			
Statistical Lives Saved, J-L 1989	$2.2	$25.0	$27.2
QALY, J-L 1989	$8.5	$24.4	$32.9
Statistical Lives Saved, J-L 1993	$2.2	$42.2	$44.3
QALY, J-L 1993	$10.9	$42.7	$53.6