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MEMORANDUM

March 31, 1994

TO: Jim DeMocker

FROM: James E. Neumann, Mark T. Dickie and Robert E. Unsworth

SUBJECT: Linkage Between Health Effects Estimation and Morbidity Valuation in the Section 812 Analysis -- Draft Valuation Document

INTRODUCTION

In previous memoranda IEC recommended a methodology for using existing value of morbidity avoidance estimates in the Section 812 retrospective benefit-cost analysis (IEC 1993). EPA's Science Advisory Board reviewed IEC's recommendations and requested that additional effort be devoted to ensure that valuation measures selected for the Section 812 analysis correspond to the types of morbidity effects predicted by available air pollution/health effects concentration-response (CR) functions (Schmalensee 1993). Consistency between definitions of health effects in the health science and economic valuation literatures is required to ensure a valid transfer of benefits estimates from the existing economics studies to the Section 812 analysis.

A draft document specifying the CR functions to be used in the Section 812 analysis has recently been completed by EPA's Office of Policy, Planning and Evaluation. The draft document provides descriptions of the endpoints assessed in the relevant health effects estimation literature. As a result, it is now possible to assess the consistency of descriptions of health endpoints in these CR functions and those evaluated in existing economic studies. This memorandum provides IEC's analysis of this issue and our recommendation for using existing economic estimates within the Section 812 study.

Our major conclusions are as follows:

- There are nine health endpoints for which both a CR function and an economic benefit estimate are available. Our recommended values for these endpoints are summarized in Exhibit 2 of this memorandum. For other health effects, either a CR function is not recommended or available, or economic estimates are not available.

- For six of the nine health endpoints, there is close correspondence between the effect described by the CR function and the relevant economic value. For these six, we recommend a damage function approach (i.e., using the product of the estimated incidence of the health effect and the unit economic value) for primary benefits estimation within the Section 812 study.
- For three health effects there is a poor correspondence between the descriptions in the health effects and economics studies. For these endpoints, we recommend a "bounding" approach for benefits estimation, but we suggest the results be used only in sensitivity analyses of the total benefits from avoided morbidity.
- Even in cases where there is a close correspondence in the definition of effects, there are other factors in the transfer of benefit estimates from existing economic estimates that bias the results. Information needed to adjust benefits estimates to account for these biases is generally not available. However, we suggest that the Section 812 study include discussion of these factors.

The remainder of this memorandum consists of three parts. First, we summarize the availability of CR functions and describe the health endpoints assessed. Second, we provide an overview of important economic issues that should be considered in performing and interpreting the results of a benefits transfer of values for avoided morbidity effects. Finally, we compare on an illness-by-illness basis the descriptions of health effects in the health science and economics literatures and recommend methods for ensuring consistency in the Section 812 analysis.

HEALTH EFFECTS ASSESSED IN CONCENTRATION-RESPONSE FUNCTIONS

The Section 812 retrospective analysis includes several key components: emissions estimation; emissions modeling; health, environmental and welfare effects estimation; and economic valuation. Estimation of health, environmental and welfare effects from ambient pollutant concentration estimates will rely on CR functions developed from the relevant literature. In the case of health effects, the relevant literature includes both laboratory-based controlled exposure studies and epidemiological studies of the effects of ambient concentrations of specific pollutants. The laboratory-based studies examine the physiological response in subjects exposed to one or more concentration levels for a given pollutant. This approach is well-suited for more moderate symptomatic responses, although in some cases these studies suffer from small sample sizes. The epidemiological studies use measures of health effects observed in a geographic area over some period of time and fluctuations in pollutant concentrations to estimate a statistical correlation between concentrations and response. This approach is used for more severe effects, including mortality. While sample size is not usually a problem for these epidemiological studies, the approach is limited in that the pollutant can never be conclusively proven to be the cause for the observed response.

EPA representatives from the Office of Policy, Planning and Evaluation, the Office of Air and Radiation, and the Office of Research and Development met in mid-February of this year to discuss the status of the health effects literature and to decide which effects could be estimated reliably using CR functions. Based on the results of this meeting, the Office of Policy, Planning and Evaluation has developed a revised draft document summarizing the basis behind the selected CR functions. The document includes a listing of the CR functions by pollutant. Because the most recent draft of this document has not been reviewed and finalized by EPA, the conclusions are subject to revision.

Exhibit 1 provides a description of the health effects for which CR functions have been or might be developed for use in the Section 812 analysis. The descriptions reflect IEC's understanding of the draft health effects estimation document, EPA criteria documents used in the development of the health effects methodology, and the relevant health effects literature. In addition, we have discussed the status of the health effects estimation effort with several of the authors of the CR methodology. Using the symptom descriptions in Exhibit 1, we can evaluate the potential for use of existing economic values. The last column of Exhibit 1 includes a list of potentially relevant economic values for each health effect that will be estimated, based on endpoints evaluated in IEC's previous memorandum (IEC 1993).

As indicated in Exhibit 1, there are several categories of effects for which economic valuation is not likely to be possible. First, effects for which a CR function is not available, or for which a CR function is available from the literature but is not recommended for use, cannot be evaluated. These effects include asthma attacks, bronchial reactivity, emergency room visits and respiratory hospital admissions resulting from ozone exposure; short and long-term morbidity resulting from sulfur oxide exposure; decreased time to onset of angina resulting from carbon monoxide exposure; and respiratory illness resulting from nitrogen oxide exposure. For two of these effects (asthma attacks and emergency room visits associated with ozone exposures), a CR function and a closely matching economic benefit estimate are available, but the CR function is not considered reliable. For these two effects, it may be possible to use the available CR function for sensitivity analysis. If the status of these CR functions change, these effects could be incorporated in the primary benefits estimate developed for the Section 812 study. However, for the other effects in this group lacking a CR function, no closely matching economic estimate is available. Even if a CR function is developed for these other effects it is unlikely that benefit valuation based on transfer of existing economic values would be possible.

Second, economic valuation is not possible for two other categories of effects because no benefit measure exists in the literature. These health effects include decreased lung function resulting from particulate matter, ozone, and sulfur oxide exposure; and chronic effects resulting from ozone exposure (e.g., lung lesions). These effects are clinically significant, but do not necessarily result in an observable impact on behavior that can be evaluated in economic terms. For example, there is some evidence that decreased lung function affects athletic performance, although it does not prevent participation in athletic activities or lead to other symptoms. It is plausible to assume a positive willingness to pay to avoid restriction of participation in athletic activity; however, it is not clear that avoiding decreases in athletic performance would substantially improve the welfare of those participating in these activities. As discussed by Cropper and Freeman (1989), an

Exhibit 1

**STATUS OF CONCENTRATION-RESPONSE FUNCTIONS
RECOMMENDED FOR USE IN THE SECTION 812 ANALYSIS**

Pollutant	Effect	Description of Effect	Status of CR Function	Potentially Corresponding Economic Value
Particulate Matter	Alterations in pulmonary function	Decreased peak expiratory flow	Available	None
	Acute bronchitis	Cases of acute bronchitis among children	Available	Several days of lower respiratory symptoms and/or several MRRADs
	Chronic obstructive pulmonary disease (COPD)	Cases of chronic bronchitis only (no mention of other forms of COPD)	Available	Cases of chronic bronchitis
	Cough and lower and upper respiratory symptoms	Composite index of the presence of any of the following symptoms: cough, trouble breathing, wheezing, phlegm, and/or chest pain	Available, but exact specification not finalized	Composite of cough, shortness of breath, and pain on deep inspiration
	Emergency room visits (ERV)	Emergency room visits for respiratory illnesses and/or asthma symptoms	Available	Cost of illness measure for ERV
	Respiratory hospital admissions (RHA)	Hospital admissions for all types of respiratory problems	Available	Cost of illness measure for RHA
Ozone	Alterations in pulmonary function	Decreased expiratory volume and forced vital capacity, and/or increased airway resistance	Available	None
	Cough	Two estimates of acute coughing spells; one from two hour and one from eight hour exposure	Available	Cough
	Pain upon deep inspiration (PDI)	Two estimates of acute PDI and chest discomfort; one from two hour and one from eight hour exposure	Available	Pain upon deep inspiration

Exhibit 1				
STATUS OF CONCENTRATION-RESPONSE FUNCTIONS RECOMMENDED FOR USE IN THE SECTION 812 ANALYSIS (continued)				
Pollutant	Effect	Description of Effect	Status of CR Function	Potentially Corresponding Economic Value
Ozone (continued)	Shortness of breath	Two estimates of acute shortness of breath; one from two hour and one from eight hour exposure	Available	Shortness of breath
	Aggravation of respiratory disease	Increase in asthma attacks	Available but not recommended	Asthma attack
	Chronic effects	Lung structure damage - mild and moderate lesions in the centriacinar region of the lung	Available	None
	Bronchial reactivity and inflammation	Airway responsiveness in the form of inflammation	None recommended	None
	Emergency room visits and respiratory hospital admissions	As described above for particulate matter	May be available but none currently recommended	Cost of illness measures
	Worker productivity	Lost daily income among farm laborers	Available	CR function measures welfare effect directly
Sulfur Oxides	Alterations in pulmonary function	Decreased forced expiratory volume and increased airway resistance	Available (for exercising asthmatics only)	None
	Asthma symptoms	Percentage of exercising asthmatics with "at least noticeable" and "at least moderate" symptoms, including: chest tightness, shortness of breath, and/or wheeze (see attached for more detail)	Available	Composite of chest tightness, shortness of breath, and wheeze, or estimate for a "bad asthma day" for asthmatics

Exhibit 1

**STATUS OF CONCENTRATION-RESPONSE FUNCTIONS
RECOMMENDED FOR USE IN THE SECTION 812 ANALYSIS
(continued)**

Pollutant	Effect	Description of Effect	Status of CR Function	Potentially Corresponding Economic Value
Sulfur Oxides (continued)	Short and long-term morbidity	Any respiratory symptomatic response	Available but not recommended	None
Carbon Monoxide	Pulmonary morphology	Broadly defined pulmonary effects	None recommended	None
	Angina	Decreased time to onset of angina	Available but not recommended	None (cannot convert existing values for increased angina incidence)
Nitrogen Oxides	Alterations in pulmonary function	Increased airway resistance, decreased pulmonary function	None recommended	None
	Respiratory illness	Increase in lower respiratory illness in children 12 years or younger	Availability uncertain	Coughing, chest tightness, MRRAD

Source: Draft Methodology for Estimating Human Health and Welfare Benefits of the Clean Air Act for the Section 812 Analysis, USEPA Office of Policy Analysis, March 1994.

Key to abbreviations:

- MRRAD - Minor respiratory restricted activity day
- COPD - Chronic obstructive pulmonary disease
- PDI - Pain upon deep inspiration
- ERV - Emergency room visit
- RHA - Respiratory hospital admission

economic value can be placed on impairments of pulmonary function or structure only to the extent that the impairments are recognized by individuals or increase risks of other recognizable illnesses. It is not clear that either of these criteria is satisfied for these health effects.

For the remaining effects, there is both a CR function and a corresponding benefit estimate. We discuss these categories of effects in greater detail below.

TRANSFERRING EXISTING ESTIMATES OF THE VALUE OF AVOIDING SYMPTOMS

In this section, we discuss issues that arise in transferring existing economic benefit estimates for use in valuing health effects. The damage function approach for estimating the aggregate benefits of avoiding morbidity consists of multiplying unit values per case or per symptom-day of morbidity by the expected number of cases or symptom-days avoided. Before applying this approach to specific illnesses, it is useful to consider whether any general conclusions may be reached concerning the sources of potential errors introduced through the transfer process and their signs and magnitudes.

One type of benefit transfer error occurs when the unit value applied is not an estimate of *ex ante* willingness to pay (WTP) for reduced risk of illness. Specifically, symptom valuation studies have estimated WTP for risk-free reductions in symptom-days, and the cost of illness approach generally measures *ex post* direct and indirect costs rather than *ex ante* WTP. This issue was highlighted by the EPA Science Advisory Board as a potentially important source of error in the application of existing benefit estimates. This issue has been discussed in a previous memorandum (IEc 1993) and is not pursued further here.

A second error occurs when the unit economic value and/or health effect does not match the actual health effect occurring in the population. This issue may arise because health and economic studies may not use descriptions that reflect the "average case" of an effect experienced from a particular pollutant exposure. This issue may also arise if the cause of the risk presented to subjects in the economic valuation studies differs from the cause evaluated in the Section 812 analysis (i.e., air pollution). For example, in our earlier memorandum summarizing important issues in the transfer of mortality values, we identified differences in the risk scenario as an important bias (IEc 1992). In the case of mortality, the bulk of the economic values are based on trade-offs of mortality risk for wages in the labor market, but in the Section 812 study the values will be applied to assess air pollution-induced mortality risks. Air pollution-induced risks differ from risks in the workplace in that workplace risks are for the most part borne voluntarily and the nature of workplace risks may be more familiar and better understood by the affected population.

Studies cited in our previous memorandum (IEc 1993) that assess the value of avoided morbidity risk are not based on wage-risk studies, but on contingent valuation or risk-risk studies. Two of these contingent valuation studies, Loehman et al. (1978) and Rowe and Chestnut (1986), explicitly present air pollution to subjects as the cause of the symptoms or medical conditions they are attempting to value. The other three studies, Dickie et al. (1987), Tolley et al. (1986), and

Viscusi et al. (1991), however, do not specify the cause of the health effects in the valuation scenarios presented to subjects. For these three studies, it is not possible to determine if subjects believed air pollution was the cause of these symptoms. As a result, it is difficult to determine whether this factor causes our estimates to overstate or understate the benefits of air pollution control. We can conclude that air pollution exposure is for the most part an involuntary act and that air pollution risks are not familiar to or well-understood by the general public. In our earlier memorandum (IEc 1992), we conclude that avoidance of risks with these characteristics may be more highly valued by society than risks with more "typical" causes. We therefore conclude that potential differences in the risk scenario are more likely to cause the morbidity values from the Dickie et al., Tolley et al., and Viscusi et al. studies to understate the benefits of air pollution-induced morbidity risk reduction.

Another important example of this type of inconsistency may involve neglecting latency periods. Most of the morbidity effects considered in this document represent acute incidences that are nearly concurrent responses to short-term fluctuations in pollution. In the case of chronic bronchitis, however, both the CR function and the valuation estimate address cases per year. If air pollution increases bronchitis incidence only after a latency period, then the aggregate benefit estimates should be discounted.

A third type of error occurs because of an imperfect match between health effects valued in the economics literature and those effects predicted by CR functions. As illustrated in Exhibit 1, even in cases where CR functions predict health effects similar to those valued by economists, the match may be inexact. For example, CR functions may predict joint increases in a group of symptoms, while contingent valuation studies value symptoms individually. It appears that professional judgment applied on an illness-by-illness basis is the best available way to minimize errors caused by mismatches between CR function results and economic benefit estimates.

In a similar vein, it is difficult to assess how closely the severity of effects predicted by CR functions resembles the severity of effects valued in the economics literature. In most cases the CR functions reported in Exhibit 1 do not distinguish effects according to severity and so presumably should be taken to represent cases of average severity. In contrast, the valuation estimates in several studies appear to reflect symptoms of greater than average severity. Viscusi, Magat and Huber (1991) indicate that the description of chronic bronchitis given to respondents in their survey represents a relatively severe case of this morbidity effect. It is somewhat more difficult to assess the severity underlying contingent values for symptoms. For example, the descriptions of some of the symptoms given to respondents in the Tolley et al. (1986) survey appear to represent rather severe cases (e.g. headache, sinus congestion, eye irritation), while other descriptions seem to imply symptoms that are less severe. Dickie et al. (1986) did not describe symptoms to respondents but instead allowed respondents to value symptoms similar to those they experienced. Nonetheless, two aspects of the sampling procedure in the Dickie et al. study suggest that the symptoms valued were probably more severe than average. First, respondents valued only those symptoms which they had experienced. If the probability of experiencing (and recalling) a symptom is positively correlated with its severity (i.e., those experiencing it most frequently also experience it most severely), then the symptoms valued would be more severe than average symptoms. Second, respondents valued only their three "worst" symptoms. Thus, those respondents experiencing more than three symptoms were almost surely valuing symptoms of greater than average severity.

Based on the above discussion, it appears that valuation estimates largely correspond to relatively severe effects, while health effects predicted using CR functions correspond to effects of average severity. Considering this effect alone, the benefits transfer procedure will tend overstate actual benefits. Unfortunately, there is little reliable information to support quantitative adjustment of valuation estimates for differences in severity. The Loehman et al. (1978, 1979) study presents values for both mild and severe symptoms, but the severity distinction given to respondents is vague. In addition, the Loehman severity descriptions do not adequately distinguish symptom severity from the economic decision of whether to restrict daily activities. In light of these considerations we recommend comparison of severity between health effects predicted by CR functions and effects valued by contingent valuation studies on an illness-by-illness basis.

Finally, a fourth set of errors may arise if individual characteristics cause unit values to vary. The damage function approach assumes that all affected individuals hold the same WTP to avoid a symptom-day (or incidence) of a given effect. Factors which may produce variation in unit values include: the duration of illness avoided; the number of symptom-days currently experienced and baseline risk; concurrent reductions in several related symptoms; selection bias arising from respondent choice of residential location; and other determinants of unit values such as income, information, and incentives for averting or mitigating action. Each of these factors is discussed below.

Duration of Illness Avoided

Several contingent valuation studies (Loehman et al. 1978, 1979; Rowe and Chestnut 1986; and Tolley et al. 1986) provide evidence that WTP per symptom-day avoided declines as the number of symptom-days avoided increases. This result, which is expected on the basis of convexity of preferences, raises two important issues for benefits transfer. The first issue arises even if all individuals are alike, provided the representative individual avoids more than one symptom-day. Multiplying marginal WTP for a single day by the number of symptom-days avoided plainly overstates WTP for avoidance of multiple symptom days in the presence of declining daily values. To estimate the magnitude of this error or to attempt to correct for it requires an estimated relationship between daily WTP and duration of symptoms avoided. Hall (1989) estimated this relationship by pooling data from several contingent valuation studies. In Appendix A to this memorandum we extend and test the robustness of Hall's approach. We find the conclusion that WTP is overstated in the case of multiple symptom-days to be strongly supported under plausible assumptions regarding the incidence of symptom days across the population.

The second issue arising from declining daily WTP occurs when benefits are aggregated across individuals who experience different reductions in symptom days. To illustrate, suppose the population consists of N individuals who differ in the number of symptom-days reduced, but who are otherwise identical. In other words, each individual's valuation is determined by the same function relating WTP to symptom-days avoided, but individual WTP differs because of variations in the number of symptom-days avoided. Suppose the i th person experiences a reduction of t_i symptom-days, for which this person is willing to pay some sum of money. Aggregate WTP is therefore the sum of individual values. The question at issue is, what error is made if aggregate WTP is estimated by assuming that all N individuals experience the same magnitude of reduction

in symptom days? In Appendix A to this memorandum, we derive a general expression for the magnitude of this error. We conclude that, for a given population size, the magnitude of error resulting from the assignment of average reductions in symptom-days to individuals whose actual reductions vary rises with the estimate of the variance of symptom-day reductions over individuals, and with the curvature of the WTP-duration function. The combined effect of duration on individual values (the first effect described above) and on aggregation of individual values (the second effect) is to cause the total benefits estimate to be overstated.

These two issues may also affect chronic bronchitis valuations. Although there is limited empirical evidence, we would expect WTP for reduced risk of chronic bronchitis to decline with age, because incidence among older individuals would imply fewer years in which the disease would be endured. If this is true, then errors will be introduced if the decreased cases of chronic bronchitis predicted by health effects studies are concentrated in age groups unrepresentative of those from which the valuations were derived. Similarly, aggregation errors will occur if age affects chronic bronchitis valuations nonlinearly. Attempting to assess whether these errors in fact arise and how large they might be would be extremely difficult, however, in light of the limited empirical evidence on how chronic bronchitis valuations vary with age.

For example, Krupnick and Cropper (1992) did not find a statistically significant effect of age on rates of trade-off between chronic bronchitis risk and dollars, but their sample was quite small. Moreover, Krupnick and Cropper did not find a significant effect of age on trade-offs between chronic bronchitis risk and fatality risk. The latter result suggests that age may affect valuations for chronic bronchitis risk and fatality risk similarly, and a number of studies have shown that age reduces WTP for fatality risk reductions. In light of this weak evidence, we are reluctant to go beyond pointing out the possibility that chronic bronchitis valuations may be affected by the age at which the effect is first experienced, and thus, the duration of this effect.

Number of Symptom-Days Currently Experienced and Baseline Risk

Both Loehman et al. (1986) and Tolley et al. (1986) report that estimated WTP for avoiding a given number of symptom days increases with the number of days the symptom is currently experienced. These results are derived from regressions in which income (as opposed to utility) is held constant. Implicitly, an individual moves to a lower indifference curve as symptom-days experienced increases while income is held constant. Thus this effect is separate from the effect of duration on daily WTP, which concerns movements along a given indifference curve.

The direction and magnitude of the resulting error in estimated WTP can be assessed in a manner paralleling the discussion above. Assume that individuals differ in the number of symptom-days currently experienced but are otherwise identical (including experiencing identical reductions in symptom-days). Then the bias caused by assuming that everyone currently experiences an equal number of symptom-days depends on the product of (1) the second derivative of WTP with respect to current symptom-days and (2) the variance of baseline symptom-days in the population. Tolley et al. used a linear functional form where the second derivative must be zero (thus, these results are not applicable to this discussion). Loehman et al., however, report constant elasticities of median WTP with respect to symptom-days experienced that exceed unity. In other words, WTP

to avoid symptoms of a given duration appears to increase more than proportionately with increases in baseline symptom-days. This result would imply that the second derivative is positive and that WTP is underestimated if all individuals are assumed to have the same baseline number of symptom-days.

A complete assessment of the magnitude of error introduced by this factor would require estimates of the distribution of current symptom-days in the population. In addition, the estimates generated by Loehman et al. appear to provide the only evidence on the economic parameter involved in the error. In short, the available evidence bearing on the size of this error is limited; nevertheless it is unfortunate that the error works in the opposite direction as the effect of duration avoided. If both the number of symptom-days currently experienced and the number of symptom-days avoided vary independently in the population, it is not clear whether to expect WTP to be over- or under-estimated. In addition, there is no evidence that these factors cancel each other. Even more information is required if the level of baseline symptoms is correlated with symptom reductions caused by air quality improvements.

Similar considerations may affect chronic bronchitis valuations. Several studies have examined how health risk valuations vary with baseline risk; most of the evidence favors the idea that individuals at higher risk are willing to pay more for a given risk reduction (see Viscusi 1992). Thus, baseline risks may affect values for reducing risk of chronic illness in the same way as baseline symptom frequency affects symptom avoidance values. There is no direct evidence, however, regarding whether these effects occur with respect to chronic bronchitis.

Avoidance of Multiple Symptoms

Improved air quality may reduce several related symptoms concurrently. If daily WTP to avoid a given symptom depends on the number of symptom days avoided, it is natural to question whether WTP to avoid one symptom varies with joint reductions in other symptoms. Does WTP for a joint reduction in several symptoms equal the sum of the individual symptom values? There is evidence in other valuation contexts that WTP is subadditive (i.e., WTP for joint changes is less than the sum of WTP for separate changes). Tolley et al. report WTP to avoid individual symptoms as well as WTP to avoid groups of three and five symptoms jointly, for durations of one and thirty days. In each case, the sum of mean WTP values for individual symptoms slightly exceeds the mean WTP for avoiding the group of symptoms. Unfortunately Tolley et al. do not report the covariances between the individual symptom values which would support a statistical test of the difference. We conclude that the limited evidence available suggests that the bias caused by summing WTP for separate symptoms to estimate values for joint symptom reductions is small.

Selection Bias Arising from Respondent Choice of Residential Location

Each of the economic studies we recommend as sources for unit values drew respondents from relatively small geographic areas; none is based on a national random sample. The most striking examples of this are the Dickie et al. and Rowe and Chestnut studies. Both Dickie et al. and Rowe and Chestnut drew respondents from Glendora, while Dickie et al. include additional

subjects from Burbank. These are heavily polluted areas east of Los Angeles, with Glendora in particular experiencing severe ozone pollution. If individuals living in Glendora differ from similar individuals living elsewhere in terms of preferences for health, then errors will occur when extrapolating results from these two studies to the national population.

This issue becomes important if preferences for health vary across individuals, individuals perceive health effects from air pollution, and people have at least some discretion in choosing where to live. Under these conditions, a randomly chosen person from a heavily polluted city such as Glendora is less likely, other things equal, to place a high value on health than is a similar individual from a less-polluted area. In other words, we would expect that persons with the lowest values for avoiding health effects would "self-select" the areas with the lowest level of environmental health amenities. Therefore, all else equal, WTP estimates from the Dickie et al. and Rowe and Chestnut studies may be drawn from individuals who place a lower than average value on respiratory health improvements. This factor may explain why the Dickie et al. estimates tend to be relatively low, despite our conclusion that the symptoms respondents valued in this study were more severe than average.

Other Determinants of Unit Values

The damage function approach is prone to error whenever unit values vary significantly over the population, if illness reductions are concentrated among individuals with high or low values, or if the factors causing unit values to vary affect utility in a nonlinear fashion. Potentially relevant factors not discussed above include income, health information, and incentives for averting or mitigating action. For example, if illness reductions are concentrated among low-income groups, WTP estimates based on average income may be too high. Changes in air quality may affect incentives to acquire information about health effects or to undertake averting/mitigating action. Since neither health effects nor valuation estimates typically control for these incentives, the resulting behavioral changes could produce errors in both the health effects predicted and the estimated unit values. Based on information available from health effects and valuation studies, however, we are unable to speculate on the importance of these factors.

Summary

There are several important factors associated with the transfer of existing economic values for use in the Section 812 analysis that could cause the aggregate benefits estimate to differ from the true value. Our analysis indicates that two of these factors, caused by inconsistencies in the duration and severity of effects, are likely to cause the economic values we recommend to overstate the true value. On the other hand, several attributes of the subjects in the relevant economic studies, including the influence of their choice of residence, their baseline risk level, and their perception of the attributes of the risk scenario, may cause the values we recommend to understate the true value. Unfortunately, given currently available information we are unable to recommend a quantitative adjustment to correct these biases, or to assess the cumulative effect of all of these factors together. In the next section we consider qualitatively the possible effect of these factors in our discussion of specific symptoms and illnesses.

ILLNESS-BY-ILLNESS CONSIDERATION OF HEALTH EFFECTS

We recommend applying some form of benefits transfer to nine of the health effects for which CR functions are available. The manner in which these estimates are used in the Section 812 study, however, should reflect different levels of confidence in the accuracy of the transfer. Specifically, for six of the effects, there appears to be a reasonably close match between the health effect predicted by the CR function and the effect valued in the economics literature. The six health effects with closely corresponding unit values, and the associated pollutants, are:

- chronic bronchitis (PM);
- respiratory or asthma-related emergency room visits (PM);
- respiratory hospital admissions (PM);
- cough (ozone);
- pain on deep inspiration (ozone); and
- shortness of breath (ozone).

Descriptions of three of the remaining health effects correspond less closely to available unit values. These health effects are:

- cough with lower and upper respiratory symptoms (PM);
- symptoms among exercising asthmatics (sulfur oxides); and
- acute bronchitis among children (PM).

We recommend a benefits transfer methodology for each of these health effects below. We have more confidence in the outcome of the procedure for the six health effects more closely tied to estimated economic values. Therefore, for these six, we recommend inclusion of the benefits generated using the damage function approach in the primary estimate of benefits of avoided morbidity. For the remaining three, we recommend use of the estimates generated for purposes of sensitivity analysis only.

Health Effects with Close Matches to Unit Values

Chronic Bronchitis

We recommend valuing cases of chronic bronchitis with unit values derived from Viscusi et al.'s risk-risk study and a suitably chosen value of a statistical life. The median rate of tradeoff

between chronic bronchitis risk and fatality risk estimated by Viscusi et al. is 0.32. The plausible range for the value of statistical lives is \$600,000 to \$13.5 million, with a mean estimate of \$4.8 million (1990 dollars, see IEc 1992). We recommend applying a unit value of 0.32 times \$4.8 million, or \$1.5 million per case of chronic bronchitis avoided for the mid-range estimate. Using the range of values for a statistical life, we generate a range of values for avoiding a case of chronic bronchitis of \$190,000 to \$4.3 million.

Based on information currently available, there are two reasons to believe that the \$1.5 million per case of chronic bronchitis may be at the high end of the range of plausible values. As discussed previously, Viscusi et al. indicate that the survey description of chronic bronchitis underlying the risk-risk tradeoffs represents a relatively severe case of this morbidity effect. The risk of a typical case of chronic bronchitis may therefore be worth somewhat less than 32 percent of fatality risk, although there is no information available to support a quantitative adjustment. The second reason would apply if air pollution increases chronic bronchitis risk after a latency period. The value of a statistical life corresponds to the risk of immediate death, and recent results suggest that mortality or morbidity that occurs after a latency period is discounted (Cropper and Sussman 1990, Viscusi 1991). If information becomes available on latency periods for chronic bronchitis, we recommend that non-current-year incidences be appropriately discounted.

Respondents in the Viscusi et al. survey were not aware of the cause of the risk they were valuing, however. We believe that, based on available information on the importance of the cause of risks, if the risk scenario presented air pollution as the cause of the chronic bronchitis risk, respondents may have indicated a higher value for avoiding this risk. In addition, if income, age or baseline risk of chronic bronchitis affect valuations, and if chronic bronchitis risk reductions are concentrated among individuals whose incomes, ages or baseline risks are different from the Viscusi et al. sample, this per case value of chronic bronchitis may be unrepresentative.

Respiratory or Asthma-Related Emergency Room Visits

We recommend applying the cost of illness per emergency room visit to the expected reduction in emergency room visits in order to quantify this effect. The major qualifications associated with the resulting benefit estimate are (1) it is not a measure of WTP (see discussion in our earlier memorandum, IEc 1993) and (2) to the extent that emergency room visits occur because of illnesses valued elsewhere in the Section 812 analysis, some benefits may be double-counted. For example, if a large portion of the emergency room visits are associated with new cases of chronic bronchitis, then adding benefits estimates for these two categories will lead to double-counting. Recent analysis of the cost-of-illness for chronic obstructive pulmonary disease, including chronic bronchitis, indicates the cost of emergency room visits and respiratory hospital admissions is at least a significant portion of the total cost of illness for this disease (Abt Associates 1991).¹

¹ In our previous memorandum, we did not recommend specific values for ERV or RHA, but instead recommended the use of available cost of illness measures. We cite one of the available measures, from Abt Associates (1991), in Exhibit 2. These values, although prepared under contract to EPA, have not been reviewed for their appropriateness for the Section 812 study.

Respiratory Hospital Admissions

We recommend applying the cost of illness per respiratory hospital admission to the expected reduction in respiratory hospital admissions to quantify this component of the benefits of the Clean Air Act. The major qualifications are the same as those discussed for emergency room visits.

Cough

As shown in Exhibit 1, two CR functions are available for cough, representing two- and eight-hour exposures to ambient pollutants. Contingent values for cough are reported in Dickie et al., Loehman et al. and Tolley et al. The Tolley et al. survey describes a chest cough which recurs twice each hour for an entire day. Therefore, a high estimate could be obtained using Tolley et al.'s median value of \$13.84. If it is important to have a great deal of confidence that the true value is below the upper bound, Loehman et al.'s \$56.91 median could be used in place of the Tolley et al. estimate. Conversely, a low estimate could be obtained using Dickie et al.'s median value of \$1.26. To construct a mid-range estimate, we recommend applying the mid-range estimate of the unit value of cough of \$7.00 per day of reduced coughing using the results of both CR functions (i.e., for both exposure levels).

The major qualifications to this methodology concern the possible effects of severity, duration, or baseline symptoms experienced not adequately controlled by the bounding procedure above. For example, it is not clear from the health effects literature that the effects predicted from the two-hour and eight-hour exposure times are appreciably different. If subsequent work indicates a significant difference in the severity of these effects, it may be necessary to modify our recommended values to reflect those differences.

Pain on Deep Inspiration

Only Dickie et al. report values for pain on deep inspiration (PDI). Dickie et al. report a median of \$4.41 (1990 dollars) for PDI, and medians of \$6.30 and \$1.26 for the related symptoms of chest tightness and "could not breathe deeply." Ten percent trimmed means are respectively \$28.04, \$22.71, and \$268.63 for these symptoms. We recommend using \$1.26, \$4.41 and \$28.04 as low, mid-range and high estimates, respectively. The major qualifications here are the same as for cough, with the additional concern that the absence of corroborating evidence from other contingent valuation studies implies that less confidence should be placed in PDI values than those for other, more extensively studied symptoms.

Shortness of Breath

Dickie et al. and Loehman et al. provide estimates for shortness of breath. We recommend rejecting the Dickie et al. median of \$0 as a lower bound estimate in favor the median of \$1.26 for the related symptom "could not breathe deeply." We recommend a high estimate of \$10.57 per symptom day (the Loehman et al. median), and if it is necessary to have great confidence that the

true value is below the upper bound, \$104.86 (the Loehman et al. mean). For a mid-range estimate, we recommend the \$5.00 figure derived in our previous memorandum (IEc 1993).

Health Effects That Match Unit Values Less Closely

For those health effects that match the unit economic values less closely, we estimated a range of values that could be used for the purposes of sensitivity analysis. Although we constructed estimates that we believe provide high and low estimates of the economic value of avoidance of these health effects, there is little information to rely on to calculate a mid-range or best estimate. If EPA prefers to conduct the sensitivity test with only one value, using the midpoint of the ranges we present will provide a reasonable mid-range estimate.

Cough and Lower and Upper Respiratory Symptoms

As shown in Exhibit 1, this health effect refers to the presence of any of the following symptoms: cough, trouble breathing, dry cough, wheezing, phlegm, and/or chest pain. One immediate difficulty is that we do not know whether individuals would typically experience only one of these symptoms, and if so which one, or if they would typically experience several at once. A lower bound estimate can be constructed by assuming that only the one symptom with the lowest estimated unit value would be experienced. Several symptoms valued by Dickie et al. are potentially related to "trouble breathing," including shortness of breath, could not breathe deeply, chest tightness, and pain on deep inhalation. Dickie et al. also report values for cough, wheezing and coughing up phlegm, sputum or mucous. Excepting the zero median estimates for shortness of breath and phlegm, the lowest reported median value among this group of symptoms is \$1.26 for "could not breathe deeply."

A somewhat higher but still low-end estimate would be obtained by applying a mid-range unit value while still assuming only one symptom is experienced. To illustrate, notice that in the previous memorandum, mid-range estimates on average exceed the Dickie et al. estimates by a factor of two to three. Applying a conversion factor of three gives an estimate based on mid-range values but low-end health effects (i.e., only one symptom) of \$3.72 per day. We recommend use of this value as a low estimate for this health effect.

Conversely, a high estimate for this health effect can be constructed by assuming that all of the symptoms are experienced, that WTP is additive over symptoms, and using mid-range values for the symptoms. Thus we sum the following values from the Dickie et al. study: \$4.41 (median for PDI, the value of which falls in the middle of the values for symptoms associated with "trouble breathing"), \$6.30 (median for chest tightness, to represent "chest pain" in this list of symptoms), \$2.52 (median for wheezing), and \$2.75 (10 percent trimmed mean for coughing up phlegm, which has a zero median). We multiply the resulting sum of \$15.98 by three to account for Dickie et al. values typically being one-third of mid-range estimates to arrive at \$47.94. To this we add our mid-range estimate of the unit value of cough (\$5.00), yielding a high estimate of \$54.94 per day for this group of health effects.

The process recommended to transfer benefits in this case is far less straightforward than the process used for valuing single health effects with closely related unit values. Because of the uncertainty in applying groups of symptom-day effects to represent the value of a "composite" measure of health effects, we suggest that the values derived for this effect (a range of \$3.72 to \$54.94 per day) be applied with care and only for purposes of sensitivity analysis in the Section 812 study.

Asthma Symptoms for Exercising Asthmatics

As shown in Exhibit 1, this health effect consists of two severity levels of symptoms ("at least noticeable" and "at least moderate") including chest tightness, shortness of breath and wheeze. In a parallel manner to the procedure described above, we can compute a low estimate by assuming that only the one symptom with the lowest estimated unit value would occur, and applying a low estimate for this symptom. Excluding the zero median value for shortness of breath reported in Dickie et al., this would yield a value of \$2.52 corresponding to the Dickie et al. median for wheeze. A more realistic low estimate could be obtained by multiplying this value by three as a rough conversion to a mid-range value estimate for a low-end health effect, yielding \$7.56 per day. We recommend use of this value as a low estimate for this health effect.

Again, a high estimate can be computed by assuming that all three symptoms are experienced, WTP is additive, and applying mid-range values for each of these symptoms. Thus we sum \$5.00 (shortness of breath), \$6.30 (chest tightness), and \$7.56 (wheeze) to generate an estimate of \$18.86. The range of values calculated using the symptom definitions (\$7.56 to \$18.86) could be used to value avoidance of "at least noticeable" effects, assuming "at least noticeable" implies some definable symptoms. Again, because of the uncertainty associated with using groups of symptoms to value a health effect, we recommend use of these values in sensitivity analyses only.

A second method for valuing asthma symptoms is to use Rowe and Chestnut's (1986) estimate of the value of avoiding a bad asthma day. This estimate, while not as specific as a definition that relies on a set of symptoms, was elicited from a group of asthmatics, the response group identified in the CR function. However, in order to standardize responses Rowe and Chestnut first asked subjects to rate the worst day they typically experience that they would not classify as a bad asthma day, with options ranging from no symptoms to moderate symptoms. The mean "baseline" response was somewhere between mild and very mild symptoms. The range of values reported for avoiding a single bad asthma day was from \$11.81 to \$53.80, with a mean about \$36.00. If we assume the composite measure "bad asthma day" roughly corresponds to "at least moderate" symptoms, then a range of values from \$11.81 to \$53.80 would be reasonable for this effect. Again, because of the uncertainty associated with using groups of symptoms to value a health effect, we recommend use of these values for the purposes of sensitivity analysis only in the Section 812 study.

Acute Bronchitis

Acute bronchitis in children is particularly difficult to value for several reasons. First, there is a lack of detail regarding the description of this health effect in the underlying health studies. The clinical definition of acute bronchitis apparently refers to an infection of the lower respiratory system. Second, this effect is described in the CR function as cases of acute bronchitis. A case may imply the incidence of more than one symptom-day. Third, because this is a value for incidence among children, it is not clear that values elicited from adults are applicable. Nonetheless, for purposes of sensitivity analysis we can use two approaches to valuing this health effect: as a complex of lower respiratory symptoms; and as a minor respiratory restricted activity day (MRRAD).

Using the symptom-based approach, a low estimate could be based on the combined incidence of coughing (with a mid-range value of \$6.29) and chest tightness (with a mid-range value of \$7.00). Using at least two symptoms seems plausible given the implied possibility that an infectious disease would take more than one day to resolve. The low symptom-based estimate is therefore \$13.29.

The available estimates for MRRADs are actually based on the incidence of multiple symptoms, although those symptoms are not well defined. Our mid-range value for avoiding an MMRAD (\$38.37) is based on Tolley's median bid to avoid a three-symptom complex of coughing, throat congestion, and sinusitis. To construct a high estimate, we could assume a four-day effect. Using these assumptions, and the mean adjustment for duration calculated in Appendix A, the high estimate of avoiding acute bronchitis would be \$38.37 times the square root of four, or \$76.74. We recommend use of these values for the purposes of sensitivity analysis only in the Section 812 study.

Summary of Recommendations

Exhibit 2 summarizes our quantitative recommendations for calculating benefits of avoided morbidity in the Section 812 study. In addition to these quantitative recommendations, our analysis indicates there are several important biases associated with the transfer of economic values. The most important of these biases appear to be related to the severity and duration of effects, attributes of respondents in the economic studies, and characteristics of the risk scenario presented to respondents. Unfortunately very little information is available to conclusively determine the effect of these factors on our estimates of the benefits of avoided morbidity. Although it may be possible to adjust the aggregate benefits estimate to account for the double-counting associated with emergency room visits and respiratory hospital admissions, for other effects we are unable to recommend a quantitative adjustment to correct these biases. Nonetheless, we recommend that EPA include qualitative discussion of these factors and their relative importance in the Section 812 study.

Exhibit 2			
SUMMARY OF RECOMMENDED VALUES			
<i>For use in primary benefits estimation:</i>			
Effect	Low Estimate	Mid-range	High Estimate
Cases of chronic bronchitis	\$190,000	\$1.5 million	\$4.3 million
Emergency room visits *	\$248.75	\$300	\$312.24
Respiratory hospital admissions *	\$3,890	\$6,842	\$7,763
Symptom days of cough	\$1.26	\$7.00	\$13.84
Symptom days of pain upon deep inspiration	\$1.26	\$4.41	\$28.04
Symptom days of shortness of breath	\$1.26	\$5.00	\$10.57
<i>For purposes of sensitivity analysis only:</i>			
Effect	Recommended Range of Estimates		
Cough with lower and upper respiratory symptoms	\$3.72 to \$54.94		
Symptoms among exercising asthmatics:	"at least noticeable"	\$7.56 to \$18.86	
	"at least moderate"	\$11.81 to \$53.80	
Acute bronchitis among children	\$13.29 to \$76.74		
* All values, with the exception of those for emergency room visits (ERV) and respiratory hospital admissions (RHA), are willingness-to-pay values (in 1990 dollars) reported from our earlier summary of the literature (IEc 1993). ERV and RHA values were derived from cost-of-illness measures reported in Abt Associates (1991).			

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Appendix A

ANALYSIS OF WILLINGNESS TO PAY AND DURATION OF SYMPTOMS

This appendix provides technical detail on two aspects of the willingness to pay (WTP)/duration issue discussed in the text. The first is estimating the rate of decline of daily WTP with increases in the duration of illness avoided. The second is technical detail on the question of aggregating WTP over individuals who experience different reductions in illness.

Empirical Analysis of Daily WTP and Duration

Hall (1989) empirically analyzed the relationship between average (i.e., daily) WTP to avoid an acute health effect and the duration of the effect avoided. An "adjustment factor" equal to the reciprocal of the square root of duration avoided was obtained. The adjustment factor would be used to convert marginal WTP to avoid one day of an acute health effect to average WTP to avoid t days. To apply the adjustment factor, divide the WTP to avoid one day by the square root of t . For example, if four days of a symptom were to be avoided, average daily WTP would be only 1/2 of WTP to avoid one day. If instead total WTP to avoid four days were estimated by multiplying the one-day value by 4, total WTP would be overstated by a factor of 2.

Hall's adjustment procedure is convenient and would be particularly useful for policy analysis if the WTP/duration-avoided relationship were constant over a range of acute health effects. We have examined this issue and conclude that the WTP/duration relationship does not appear to be constant over health effects. Moreover, it appears that the functional form adopted by Hall may not adequately represent the WTP/duration relationship. Consequently we recommend that Hall's adjustment procedure not be used to generate benefit estimates for health effects of greater than one day's duration. However, we believe the adjustment procedure is adequate for rough sensitivity analyses of the effect of duration on daily values. Finally, we recommend that symptom-specific estimates of the WTP/duration relationship be used for potentially more accurate sensitivity analyses for symptoms of substantial duration. We present details of our analysis below.

Hall's analysis is consistent with a model in which

$$w(t) = w(1)t^{\alpha + 1} \quad (1)$$

where $w(t)$ represents total WTP to avoid t days of a health effect, $w(1)$ represents WTP to avoid one day, and $\alpha + 1$ is the duration elasticity of WTP. If $a(t) = w(t)/t$ is average (daily) WTP to avoid t days, the relationship above is equivalent to

$$a(t) = w(1)t^{\alpha} \quad (2)$$

Clearly both these equations are linear-in-logarithms (or in percentage changes) and so are easily estimable. To illustrate, notice that

$$\log[a(t)] = \log[w(1)] + \log[t] \quad (3)$$

Hall estimated α by pooling data on median WTP and duration from the Loehman et al. (1978) study with data on mean WTP and duration from the Rowe and Chestnut (1986) study. It appears that in estimating α , Hall first averaged over health effects within each study, for each change in duration. Averaging over health effects has the effect of suppressing the variation in WTP over symptoms, making it difficult to assess whether the relationship is stable over symptoms or not. In addition, Hall does not report any tests of other functional forms. The functional form is of course a central issue here if adjustments for wide variations in duration are required.

We have re-examined the relationship between WTP and duration using data from Loehman et al., Tolley et al. (1986), and Rowe and Chestnut. There are six symptoms and three duration levels in the Loehman et al. study, seven symptoms and two durations in the Tolley et al. study, and four health effects and three duration levels in the Rowe and Chestnut study, for a total of 48 WTP/duration data points.

One way to estimate the logarithmic equation (3) above is to use all 48 observations to regress log daily WTP on log duration, allowing a symptom-specific intercept to pick up $\log[w(1)]$ by symptom. Thus

$$\log[a(t)] = \beta_j + \alpha \log[t] \quad (3a)$$

where β_j is an intercept term specific to the j th health effect. The resulting estimate of α is -0.479, with a standard error of 0.0167. Alternatively, one can condition more directly on $\log[w(1)]$ by defining the dependent variable as $\log[a(t)] - \log[w(1)]$, deleting all observations for one-day values, and regressing on log duration. According to the functional form adopted above, there is no constant term in the resulting equation, but generally it would be wiser to at least allow for a nonzero intercept. In this case

$$\log[a(t)] - \log[w(1)] = \beta + \alpha \log[t] \quad (3b)$$

and the estimate of α is -0.554, with a standard error of 0.0447. A variation on this approach would allow the intercept to vary over symptoms, to allow for potential omitted effects by symptom or study. Since results from this approach are similar to those from the other two methods, it is not discussed further.

These results then are roughly equivalent to Hall's estimate of α of -0.5. Because Hall's estimate amounts to adjusting by the reciprocal of the square root of duration, we recommend that Hall's estimate be used for rough sensitivity analyses, rather than our estimates which involve less convenient, but similar, values for α . However, it appears that these simple WTP/duration relationships are inadequate for analyses which demand greater accuracy.

We subjected our estimated relationships (equations 3a and 3b) to further testing, primarily to address the following questions: (1) does it appear that α is constant over symptoms? (2) Does it appear that the relationship is linear-in-logs? We address the first question by allowing α to vary over symptoms, and comparing results to the case in which α does not vary. We address the second in a simple way by including the squared log of duration as an additional regressor.

Testing for Variations Over Health Effects

When α is allowed to vary by symptom, we find substantial differences in estimated values across symptoms, whether equation (3a) or (3b) is estimated. As shown in Exhibit A-1, estimates of α range from about -0.27 (headache) to about -0.62 (nausea) regardless of whether (3a) or (3b) is applied. Thus, daily WTP appears to decline least rapidly for headaches and most rapidly for nausea. All of the estimated values of α reported in Exhibit A-1 exceed their associated standard errors by factors of at least six. The differences in α are therefore statistically significant at less than the five percent level. In other words, suppose one is willing to assume that the data represent a random sample from a population of WTP/duration pairs. If the WTP/duration relationship were stable over symptoms, differences in α this large would be expected in fewer than five percent of samples.

While there is some pattern to estimated values of α over studies (e.g., most of Lochman et al. symptoms have estimated values of around -0.55, while those of Rowe and Chestnut cluster around -0.45), further analysis suggests that the differences by symptom cannot be attributed solely to differences by study. As an additional check on the extent of variation in α over health effects, we re-estimated equations (3a) and (3b) after deleting data from the Rowe and Chestnut study, on the grounds that the health effect valued there (bad asthma days) is more complex than the single symptoms valued in the other two studies. Results do not alter the conclusions reached above.

Testing the Functional Form

When we enter the square of log duration as an additional regressor, we find a negative coefficient which is statistically distinguishable from zero at less than five percent significance in each of our three estimation procedures. In other word, it appears that the rate at which daily WTP declines increases with duration. Further, this more complex pattern of curvature does not appear to account for the variation over symptoms discussed above.

In conclusion, it appears that Hall's adjustment procedure is useful as a rough approximation, but not as an accurate representation of a stable relationship between WTP and duration across a range of acute health effects.

Exhibit A-1

ESTIMATES OF α BY SYMPTOM

Study and Symptom	Equation (3a)	Equation (3b)
Lochman et al. (1978)		
Mild shortness of breath	-.561	-.551
Severe shortness of breath	-.518	-.500
Mild cough	-.494	-.477
Severe cough	-.563	-.550
Mild head congestion	-.583	-.579
Severe head congestion	-.551	-.554
Tolley et al. (1986)		
Cough	-.445	-.452
Sinus	-.405	-.412
Throat congestion	-.423	-.430
Eye irritation	-.371	-.378
Headache	-.265	-.272
Nausea	-.615	-.622
Drowsiness	-.319	-.326
Rowe & Chestnut (1986)		
No symptoms	-.446	-.454
Very mild symptoms	-.446	-.452
Mild symptoms	-.450	-.458
Moderate symptoms	-.450	-.458

Variations in Duration of Illness Avoided and Aggregate WTP

As discussed in the text, one effect of declining daily WTP is that total benefits may be overestimated when WTP is aggregated over individuals who experience different reductions in symptom days. To illustrate the technical background underlying this conclusion, suppose the population consists of N individuals who differ in the number of symptom-days reduced, but who are otherwise identical. In other words, each individual's valuation is determined by the same function relating WTP to symptom-days avoided, but individual WTP differs because of variations in the number of symptom-days avoided. Suppose the i th person experiences a reduction of t_i days of symptoms for which he is willing to pay $w(t_i)$. Aggregate WTP (V) is the sum of individual values: $V = \sum w(t_i)$. The question at issue is, what error is made if aggregate WTP is estimated by assuming that all N individuals experience the same reduction in symptoms? The estimate of aggregate WTP is $\hat{V} = Nw(t)$, where $t = (1/N) \sum t_i$ is the average number of symptom-days avoided. Based on a second-order Taylor's series expansion of w around t , the error is approximately

$$V - \hat{V} = (N/2)w_{tt}\sigma^2$$

where w_{tt} denotes the curvature or second derivative of individual WTP with respect to the number of symptom days avoided, and σ^2 is the variance of reduced symptom days over the population. The symptom-day analysis cited above suggests that $w_{tt} < 0$, so that aggregate benefits (V) are overestimated.

For a given population size, the magnitude of error (from assigning average reductions in illness to individuals whose actual reductions vary) rises with the dispersion of symptom-day reductions over individuals (σ^2) and with the absolute curvature of the WTP-duration function (w_{tt}). For the reasons discussed above, we do not expect w_{tt} to be constant over health effects. For illustrative purposes, however, the value of w_{tt} implied by our estimates of equation (3b) above, evaluated at means of duration and daily WTP, is -0.171. This would imply that the error in estimating aggregate WTP equals one-half the population size times 17 percent of the variance in duration reductions over individuals.