IEc

MEMORANDUM | December 4, 2015

TO Elaine Shen, South Coast Air Quality Management District

FROM Henry Roman, Industrial Economics, Incorporated and Lisa Robinson, Independent Consultant

SUBJECT Review of Mortality Risk Reduction Valuation Estimates for 2016 Socioeconomic Assessment

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In its role as the air pollution control agency for the South Coast Air Basin, the South Coast Air Quality Management District (SCAQMD) develops air pollution control plans to help this portion of California achieve compliance with Federal and State air quality standards. As part of the development of the regional Air Quality Management Plan (AQMP), SCAQMD considers its socioeconomic impacts, including its expected benefits and costs. The resulting AQMP Socioeconomic Analysis includes a detailed assessment of the benefits of reducing air pollutant concentrations, which requires the use of several datasets covering a wide array of information including, but not limited to, baseline rates of disease, demographic data, concentration-response data, and valuation data.

A review of the Socioeconomic Analysis for the 2012 AQMP by Abt Associates (2014) identified the following ways in which the benefits analysis could be strengthened:[1]

- Instituting a more transparent and systematic process for conducting literature reviews relevant to the Socioeconomic Assessment;
- Clarifying the application of benefits transfer approaches that may be used to adjust concentration-response functions or benefit valuation inputs; and,
- Providing greater information about uncertainty in the benefits analysis, both qualitative and quantitative.

As it prepares for the 2016 AQMP Socioeconomic Analysis, SCAQMD needs to ensure that it is applying the most up-to-date, scientifically-defensible methods and inputs for calculating the benefits to society resulting from air pollution strategies. In this memorandum, we provide our recommendations for valuing mortality risk reductions associated with implementation of the 2016 AQMP, addressing the recommendations from the review of the 2012 analysis.

[1] South Coast Air Quality Management District. 2012. *Socioeconomic Report 2012: Air Quality Management Plan*; Abt Associates, Inc. 2014. *Review of the SCAQMD Socioeconomic Assessments.* Prepared for South Coast Air Quality Management District. Available at http://www.aqmd.gov/home/library/clean-air-plans/air-quality-mgt-plan/socioeconomic-analysis.

Based on our review, we recommend that SCAQMD apply a value of $9.0 million (2013 dollars) per statistical case of mortality risk averted, and test the sensitivity of the results to values ranging from $4.2 million to $13.7 million. We suggest that these values be adjusted to reflect the expected growth in population-average real income over time, as well as the cessation lag associated with decreases in air pollutant concentrations.

Below, we discuss these recommendations in more detail. We first define related concepts and then provide the results of our literature review, including the use of benefit transfer techniques and the assessment of related uncertainties.[2]

CONCEPTUAL FRAMEWORK

The approach for valuing mortality risk reductions, as well as other regulatory impacts, is grounded in standard welfare-economic theory. This framework assumes that each individual is the best judge of his or her own welfare, which means that benefit values should be based on the preferences of those affected by a regulation. As a corollary, economists conventionally assume that if an individual chooses to buy a good or service, then he or she values the good or service more than the other goods or services he or she could have used that money to buy. Money is not of interest *per se*; rather it is used to measure the trade-offs that individuals are willing to make between different types of consumption.

Given this framework, estimates of individual willingness to pay (WTP) provide the conceptually appropriate measure of value for benefits that represent an improvement from the status quo, such as the reductions in mortality risks associated with SCAQMD's 2016 AQMP. WTP is the maximum amount of money an individual would voluntarily exchange to obtain an improvement, given his or her budget constraint. It indicates the point at which the individual would be equally satisfied with having the good and less money, or with spending the money on other things. This framing mimics the actual trade-offs implicit in regulation. If we choose to spend more on regulations that reduce air pollution risks, we will have less to spend on other goods or services – including other risk-reducing measures.

For goods such as mortality and morbidity risk reductions, prices do not exist because they are not directly bought and sold in markets. Instead, economists typically use revealed or stated preference studies to estimate WTP. Revealed preference studies rely on observed market behavior to estimate the value of related nonmarket goods. For

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[2] This discussion is derived from substantial previous work conducted by Ms. Robinson in collaboration with Dr. James K. Hammitt of Harvard University. Examples include: Robinson, L.A. and J.K. Hammitt. 2013. "Skills of the Trade: Valuing Health Risk Reductions in Benefit-Cost Analysis." *Journal of Benefit-Cost Analysis.* 4(1): 107-130; and Robinson, L.A. and J.K. Hammitt. 2015a. "Valuing Reductions in Fatal Illness Risks: Implications of Recent Research." *Health Economics*. Early View. The former article can be freely download from: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=9456622&fulltextType=RA&fileId=S2194588800000518. The latter is included as an attachment to this memorandum for ease of reference. Note that circulation of the attachment is subject to copyright restrictions.

example, wage-risk (or hedonic-wage) studies examine the compensation associated with jobs that involve differing risks of death, using statistical methods to separate the effects of these risks from the effects of other job and personal characteristics. Stated preference methods typically employ survey techniques to ask respondents about their WTP for the outcome of concern. They may directly elicit WTP for a particular scenario, or may present respondents with two or more scenarios involving different attributes and prices. In the latter case, estimates of WTP are derived from the way in which respondents choose, rank, or rate alternatives.

Typically, regulatory analysts rely on existing valuation studies rather than incurring the substantial time and expense associated with conducting new primary research. This approach, referred to as "benefit transfer," generally involves careful review of the literature to identify high-quality studies that are suitable for use in a particular context. "Quality" can be evaluated by considering the likely accuracy and reliability of the data and methods used, referencing guidance on best practices. "Suitability" or "applicability" involves considering the similarity of the risks and the populations affected.

THE VALUE PER STATISTICAL LIFE

The approach for valuing mortality risk reductions is usually based on estimates of the value per statistical life (VSL), which is an individual's marginal rate of substitution between money and risk of dying in a defined time period. Conventionally, the VSL is calculated by first estimating individuals' WTP for a small change in their own mortality risk, then dividing by the risk change. For example, if an individual is willing to pay $900 for a 1 in 10,000 reduction in his risk of dying in the current year, his VSL is $9.0 million ($900 WTP ÷ 1/10,000 risk change). Presumably, in determining their WTP, individuals take into account both the pecuniary effects of the risk change (including out-of-pocket medical expenses and future earnings) and the non-pecuniary effects (including pain and suffering). The key parameter is the individual's WTP for the 1 in 10,000 risk reduction (i.e., the $900); it is expressed as the VSL (i.e., the $9.0 million) largely for convenience. The VSL is not the value of saving an individual's life with certainty.

This point is worth emphasizing, because the VSL concept is widely misunderstood. It is *not* the value "the government" is placing on an individual's "life." Rather, *it is based on the value that individuals indicate that they place on a small change in their own risk of dying each year*. We make decisions that reflect these values every day; for example, by choosing to spend money on bicycle helmets or other protective equipment. These values are generally taken from data on the change in wages that workers demand for more risky jobs, or from surveys that ask individuals how much they would be willing to pay for small changes in their own risks.

Because of this confusion, there is wide-spread interest in changing this terminology. In the United Kingdom, the term "value of a prevented fatality" (VPF) is often used instead of the VSL. In the U.S., the U.S. Environmental Protection Agency (EPA) proposed to instead refer to the "value of mortality risk" (VMR) in a 2010 White Paper.[3,4] In its 2011 response to this proposal, EPA's independent Science Advisory Board – Environmental Economics Advisory Committee (SAB-EEAC) strongly supported a change in terminology, but suggested that more work was needed.[5] It recommended that EPA consider other terms, such as the "value of risk reduction" (VRR), and conduct focus groups and sponsor other research into how to most effectively communicate this concept to the general public. This work is ongoing. Thus, for consistency with the terminology currently used in the research literature, we continue to use the term "VSL" in this memorandum while awaiting the results of EPA's research.

For reductions in air pollution-related mortality risks, the EPA currently relies on a literature review conducted in the early 1990s. EPA's 2010 *Guidelines for Preparing Economic Analysis* recommend a default central value of $7.9 million (in 2008 dollars, adjusted for inflation only).[6] If updated to 2013 dollars and income levels, this value is about $9.4 million, which is very similar to the $9.2 million value used by the U.S. Department of Transportation (DOT) for the same year.[7,8] In an appendix to its *Guidelines*, EPA notes that its value is based on distribution of 26 VSL estimates, typically described as a Weibull distribution. When analyzing the benefits of its air pollution regulations, EPA typically adjusts this value to reflect changes in population-wide real income over time as well as any lag between changes in exposure and changes in risk.

Over the past several years, EPA has developed a series of proposals to update its values for consideration by its expert advisory panels, and is now in the process of revising its

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[3] U.S. Environmental Protection Agency. 2010a. "Valuing Mortality Risk Reductions for Environmental Policy: A White Paper." SAB Review Draft. National Center for Environmental Economics, U.S. Environmental Protection Agency.

[4] One related issue is whether to report only the value individuals are willing to pay (e.g., the $900 in the preceding example) or to convert it into a value per statistical case (the $9 million in the example). Some have recommended using the term "micromort" or "microrisk" to reference willingness to pay for a 1 in 1,000,000 risk change. This value would be $9 based on the example, because individual WTP is expected to change roughly in proportion to the change in risk as long as the risk change is small. For more discussion of this terminology, see Howard, R.A. 1989. "Microrisks for Medical Decision Analysis." *International Journal of Technology Assessment in Health Care*. 5: 357-370; Cameron, T.A. 2010. "Euthanizing the Value of a Statistical Life." *Review of Environmental Economics and Policy.* 4(2):161-178.

[5] Kling, C.L. et al. 2011. "Review of 'Valuing Mortality Risk Reductions for Environmental Policy: A White Paper' (December 10, 2010)." Memorandum to Lisa P. Jackson, EPA Administrator, from the EPA Science Advisory Board and Environmental Economics Advisory Committee. EPA-SAB-11-011.

[6] U.S. Environmental Protection Agency. 2010b. *Guidelines for Preparing Economic Analysis*. EPA 240-R-10-001, with 2014 update.

[7] Values in EPA (2010b) adjusted to 2013 dollars and income levels by the authors using EPA's approach.

[8] U.S. Department of Transportation. 2014. *Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in Departmental Analyses – 2014 Adjustment*. Memorandum to Secretarial Officers and Modal Administrators from P. Rogoff, Acting Under Secretary for Policy, and K. Thomson, General Counsel.

VSL estimates. At the same time, the research literature has continued to evolve, and others have built on the advice EPA has received to propose values that may be appropriate for application to air pollution-related mortality risk reductions. Below, we discuss the results of these reviews as well as our supplemental literature search.

ANALYTIC APPROACH

To recommend VSL estimates to be used in SCAQMD's Socioeconomic Analysis of the 2016 AQMP, IEc first considered the results of relevant recent literature reviews, then conducted a supplemental review to identify newer research.

Recent literature reviews

In recent years, U.S. Federal agencies have completed several reviews of the VSL literature, focusing on the values appropriate for application in regulatory analysis. These include reviews completed by EPA and DOT, as well as a review conducted to support related work by the U.S. Department of Health and Human Services (HHS). We describe each of these efforts below.

In 2010, EPA assembled two databases summarizing the then-available VSL revealed-preference (wage-risk) studies and stated-preference studies.[9] EPA also outlined the selection criteria employed in creating these two databases, which were designed to exclude low-quality studies and ensure their applicability in the United States. These criteria built on the results of past EPA proposals for updating its VSL estimates and reviews of those proposals by its independent expert advisory panels, as well as the results of the evolving research literature. EPA's SAB-EEAC then reviewed these databases and selection criteria and suggested changes and additions in 2011.[10]

The 2011 SAB-EEAC report also provided guidance on the use of meta-analysis to combine VSL estimates from studies that meet these selection criteria. It indicated that the appropriate statistical approach varies and depends upon factors such as the total number of observations available and the number of VSL estimates to be drawn from each study. Thus the criteria for selecting individual revealed and stated preference studies also apply to meta-analyses that draw on these bodies of literature.

EPA is currently in the process of implementing the results of the SAB-EEAC's review. In the interim, DOT revised its approach for estimating the VSL based on a review completed in 2013.[11] DOT's approach incorporated those SAB-EEAC recommendations most relevant to the types of risks it regulates (which result primarily from injuries rather than illness). Subsequently, Robinson and Hammitt completed a review for HHS in 2014

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[9] U.S. Environmental Protection Agency (2010a).

[10] Kling, C.L. et al. (2011).

[11] U.S. Department of Transportation (2014).

that has now been published in the peer-reviewed literature.[12] That review, which is included as an attachment to this memorandum, includes some modifications of the SAB-EEAC criteria to reflect the evolution of the literature. The Robinson and Hammitt review is particularly relevant for SCAQMD because it explicitly considers the extent to which high quality studies are now available that address risks associated with illness rather than injury.

Supplemental review

IEc conducted a supplemental review of studies published since the Robinson and Hammitt review was completed. We applied the same criteria as Robinson and Hammitt, because these criteria were developed recently and take into account current best methodological practices.[13] In IEc's August 20, 2015 memorandum to the SCAQMD, we edited these criteria slightly to clarify the relationship to this project; the edited criteria are replicated in Exhibit 1. The August memorandum and the Robinson and Hammitt article describe these criteria in detail. In brief, they are designed to ensure the use of studies that are applicable to U.S. regulatory analysis, rely on high quality data, and meet standards for validity, consistent with the benefit transfer framework.[14]

EXHIBIT 1. CRITERIA FOR MORTALITY VALUATION STUDIES

GENERAL CRITERIA
1. Study is written in English. 2. Study is publicly available. 3. Study is based on a sample of the general U.S. population.
CRITERIA FOR REVEALED-PREFERENCE STUDIES
4. Study uses hedonic methods that address the trade-off between wages and job-related risks. 5. Study relies on high-quality risk data, equal or superior to the Census of Fatal and Occupational Injuries (limits studies to those published from 2003 – present). 6. Study controls for potentially confounding factors, such as nonfatal injury risk as well as both industry and occupation.
CRITERIA FOR STATED-PREFERENCE STUDIES
7. Study elicits values for private risk reductions that accrue to the respondent. 8. Study expresses the risk change as a probability, not as a life extension. 9. Study estimates willingness-to-pay, not willingness-to-accept compensation. 10. Study provides evidence of validity, including sensitivity of willingness to pay to changes in risk magnitude (more likely to be met by studies published from 1994 – present).

[12] Robinson, L.A. and J.K. Hammitt (2015a).

[13] These criteria were also applied in Robinson, L.A. and J.K. Hammitt. 2015b. "The Effect of Income on the Value of Mortality and Morbidity Risk Reductions. (Internal Review Draft)" Prepared for the U.S. Environmental Protection Agency under subcontract to Industrial Economics, Incorporated.

[14] See Robinson and Hammitt (2013) and (2015a) for more discussion of this framework.

IEc's supplemental search covered articles published from 2014 to the present. We conducted the search using the following search terms and databases:

Terms

- Value of a statistical life or VSL or value per statistical life in combination with one or more of the terms in the next bullet.
- Illness or health or disease or safety or pollutants/pollution or morbidity or mortality or smoking or smokers or children or infants or workers or California

Databases

- Scopus
- PubMed
- EBSCO EconLit, Business, and Environment databases
- Google Scholar

We compared the studies found in our search against those discussed in the Robinson and Hammitt review to identify any additional studies that estimate VSL based on primary research or meta-analysis. We then assessed whether the new studies we identified met our selection criteria and hence warranted additional consideration.

RESULTS FOR BASE VSL ESTIMATES

The results of the Robinson and Hammitt review are discussed in detail in the attached article and briefly summarized below. We then describe the results of our supplemental search and the implications for SCAQMD's analysis. In this section, we focus on base VSL estimates; the following section discusses adjustments to these values for growth in real income and for the lag between reduced exposure and reduced mortality risk. Note that all values are reported in 2013 dollars, and can be updated to 2015 dollars in early 2016, once economic data for the full year are available.

Robinson and Hammitt review

Robinson and Hammitt found that most of the studies that met the selection criteria were wage-risk studies that addressed injury-related risks among adult workers, rather than addressing illness-related risks. Only two of the three stated preference studies that met the criteria addressed illness-related risks, but they provided values that were similar to the other studies. The wage-risk studies generally suggest that the VSL ranges from roughly $5.3 million to $13.7 million with a mid-point of $9.5 million. The stated-preference studies yielded a slightly lower range, from $4.2 million to $11.2 million with a mid-point of $7.7 million. In combination, this results in a range from $4.2 million to $13.7 million with a mid-point of $9.0 million.

Robinson and Hammitt also discuss adjustments for health status and age, and conclude that the literature is not sufficiently robust to support such adjustments at this time.[15] The studies that meet the selection criteria also are not sufficient to address any variation in values across health conditions of different types.[16]

Supplemental literature review

Our supplemental literature search identified only two studies reporting VSL estimates that were not considered as part of the Robinson and Hammitt review. The first is a working paper by Long that reports preliminary findings from a stated preference study that explores adjustment of the VSL to reflect altruistic sentiments.[17] That study does not meet criterion 7, which requires that studies address individual WTP for reductions in one's own risks.[18] As discussed in more detail in the 2013 and 2015(a) Robinson and Hammitt articles cited earlier, the treatment of altruism raises difficult issues in the context of benefit-cost analysis, and we exclude such studies from consideration.

The second we identified is a revealed preference study by Rolfs et al. that focuses on averting behavior, considering the demand for air bags in the used vehicle market.[19] It does not meet criterion 4, which requires that revealed preference studies consider the trade-off between wages and job-related risks. As also discussed in the references cited previously, averting behavior studies (which consider defensive measures or consumer products used to protect against perceived health risks), are generally not recommended for use in regulatory analysis due to concerns about their limitations. For example, in this particular study, the extent to which respondents trust the air bag technology is unclear. We did not identify any studies that provide estimates specific to California or to the South Coast region.

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[15] For more discussion of the challenges inherent in developing these and other adjustments, see: Robinson, L.A. and J.K. Hammitt. 2015c. "Research Synthesis and the Value per Statistical Life." *Risk Analysis.* 35(6): 1086-1100. The EPA (2010a) White Paper and the Kling et al. (2011) SAB-EEAC review of that paper also discuss the difficulties inherent in adjusting values to reflect the differences between mortality risks associated with cancers and with other conditions.

[16] One stated preference study that met the criteria, by Cameron and DeShazo, provides estimates for multiple health conditions. However, the value used in the review is for sudden death; more work would be needed to confirm the results for other conditions. Cameron, T.A. and J.R. DeShazo. 2013. "Demand for Health Risk Reductions." *Journal of Environmental Economics and Management*. 65: 87-109.

[17] Long, M.C. 2014. "Estimating an Altruism Adjusted Measure of the Value of a Statistical Life: Preliminary Findings." Center for Studies in Demography and Ecology, University of Washington. Unpublished manuscript

[18] Because it only provides preliminary results, it also does not meet criterion 10 related to evidence of validity.

[19] Rohlfs, C., R. Sullivan, and T. Kniesner. 2015. "New Estimates of the Value of a Statistical Life Using Air Bag Regulations as a Quasi-experiment." *American Economic Journal: Economic Policy*. 7(1): 331-359.

Recommended base values and comparison to 2012 Socioeconomic Analysis

The VSL used by SCAQMD in its 2012 Socioeconomic Analysis was $6.1 million to $6.7 million (2005 dollars), based on a meta-analysis by Kochi et al., which equates to $7.1 million to $7.8 million if inflated to 2013 dollars.[20,21] While the central value from the Robinson and Hammitt review is somewhat higher, the range they recommend encompasses that value. Note, however, that the Kochi et al. estimate would be larger than $7.8 million if also adjusted for changes in real income.[22]

Kochi et al. and other previous VSL meta-analyses have been criticized by EPA expert panels, who recommended that they not be used in regulatory analysis.[23] In particular, these panels were concerned about the need to develop more stringent criteria for selecting studies for inclusion in the analysis, such as those discussed in the EPA (2010a) White Paper, the SAB-EEAC (2011) review of that paper, and the Robinson and Hammitt (2015a) review that is the basis for the recommendations in this memorandum.[24] A recent meta-analysis by Viscusi (2015) that applies such criteria but only addresses wage-risk studies results in values similar to those from the individual studies selected in the Robinson and Hammitt review.[25] Depending on the model specification, Viscusi's results range from $7.6 million to $13.7 million (2013 dollars).[26]

We recommend that SCAQMD use the range of values suggested by the Robinson and Hammitt review; i.e., a VSL ranging from $4.2 million to $13.7 million with a mid-point of $9.0 million (2013 dollars). This range reflects evaluation criteria derived from recent expert panel reviews as well as consideration of evolving best practices, and is based on the highest quality applicable research evidence now available. The use of this range also supports appropriate consideration of uncertainty.

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[20] According to SCAQMD (2012), this value also reflects adjustment to 2010 income levels. However, the details of how this income adjustment was implemented were not provided.

[21] Kochi I., B. Hubbell, and R. Kramer. 2006. "An Empirical Bayes Approach to Combining and Comparing Estimates of the Value of a Statistical Life for Environmental Policy Analysis." *Environmental and Resource Economics*. 34: 385-406.

[22] We are not able to easily implement this adjustment, because it requires first updating the results of each individual study based on the income level for the year in which it was conducted. Kochi et al. (2006) include 40 studies conducted between 1974 and 2002.

[23] Cropper, M. et al, 2007. "SAB Advisory on EPA's Issues in Valuing Mortality Risk Reduction," Memorandum from the Chair, Science Advisory Board, and the Chair, Environmental Economics Advisory Committee, to EPA Administrator Stephen L. Johnson. EPA-SAB-08-001; U.S. Environmental Protection Agency. 2006. Report of the EPA Work Group on VSL Meta-Analyses.

[24] Robinson and Hammitt (2015c) discuss issues related to the use of meta-analysis to estimate the VSL in more detail.

[25] Viscusi, W.K. 2015. "The Role of Publication Selection Bias in Estimates of the Value of a Statistical Life." *American Journal of Health Economics*. 1(1): 27-52.

[26] Unlike most of the previous meta-analyses, Viscusi (2015) corrects the estimates for publication bias, as discussed in more detail in the following section.

ADJUSTMENTS FOR REAL INCOME GROWTH AND CESSATION LAG

As discussed above, the research evidence is not yet sufficient to adjust the VSL to reflect some of the differences between the studies identified in these reviews and the air pollution risks addressed by SCAQMD's 2016 AQMP. Below, we turn our attention to two adjustments that are desirable given the currently available literature: the first is for real income growth over time, the second is for the lag between reduced pollutant concentrations and mortality risks.

Adjustment for real income growth

The estimates discussed above are U.S. population-averages. SCAQMD's 2016 AQMP is likely to consider risk reductions that accrue many years in the future, at which time real incomes are likely to have increased. Both theory and empirical evidence suggest that individual WTP is likely to increase as a result.

When conducting benefit-cost analyses, typically analysts inflate all values to a standard base year and then work in real dollars from that point forward. Federal agencies and others typically do not use different VSL estimates for individuals with different incomes within a particular time period; doing so has been misinterpreted as providing inequitable treatment of richer and poorer segments of the population rather than as reflecting differences in preferences. However, analysts generally adjust the VSL for population-average changes in income over time, using the same income-adjusted VSL for all members of the affected population.

This adjustment involves two inputs: an estimate of the change in the VSL associated with a change in real income (the income elasticity), and an estimate of the change in real income. Because it generally seems reasonable to assume that the income elasticity will be constant over time as well as across income levels in this context, these estimates are typically combined with the VSL using the following formula:

$$VSL_b = VSL_a * (income_b/income_a)^{elasticity}$$

where "a" and "b" represent different years, and income is expressed in real terms (excluding the effects of inflation).

Currently, EPA is using a distribution of VSL income elasticities centered at 0.40, with a low estimate of 0.08 and a high of 1.00.[27] These estimates are based on research conducted by IEc in 1999.[28] Since that time, several additional reviews have been completed by IEc and others, suggesting that differing elasticities may be appropriate.

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[27] U.S. Environmental Protection Agency. 2015. *BenMAP: Environmental Benefits Mapping and Analysis Program – Community Edition User's Manual*. Prepared for the Office of Air Quality Planning and Standards by RTI International.

[28] Kleckner, N. and J. Neumann. 1999. "Recommended Approach to Adjusting WTP Estimates to Reflect Changes in Real Income." Memorandum to J. Democker, Office of Air and Radiation, U.S. Environmental Protection Agency, from Industrial Economics, Incorporated.

However, EPA has not yet updated its estimates nor determined how to best incorporate the results of these reviews into its models.

In work conducted for EPA in 2015, Robinson and Hammitt reviewed the literature using selection criteria almost identical to those as described above, but focusing on studies that provide estimates of income elasticity. They identified one longitudinal wage-risk study (by Kniesner et al.) and one wage-risk meta-analysis (by Viscusi) that provided central income elasticities of 1.4 and 1.1 respectively.[29,30] In the stated preference literature, Robinson and Hammitt identified three studies that provided elasticities ranging from less than 0.1 to 0.7.[31] Taken as a whole, this review suggests that the appropriate elasticity is uncertain, but that the mid-point and high-end of the range may be above the estimates currently used by EPA.

One issue that has arisen in previous meta-analyses focused on estimating VSL income elasticities is concern about publication bias.[32] Such bias results when a researcher reports only a subset of his or her findings or when journals are unwilling to publish findings that depart significantly from previous results or appear inconsistent with theory. However, the Viscusi (2015) meta-analysis suggests that such bias at least in part reflects the failure to apply stringent selection criteria. He finds little evidence of bias when selecting only those wage-risk studies that use the higher-quality CFOI risk data reflected in our criteria.

Elasticities larger than 1.0 mean that individuals' WTP for small mortality risk reductions becomes a larger fraction of income as income increases, which appears consistent with the notion that wealthier individuals are able to invest more in risk-reducing measures

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[29] Kniesner, T. J., W.K. Viscusi, and J.P. Ziliak. 2010. "Policy Relevant Heterogeneity in the Value of Statistical Life: New Evidence from Panel Data Quantile Regressions," *Journal of Risk and Uncertainty*, 40: 15-31; Viscusi, W.K. 2015. "The Role of Publication Selection Bias in Estimates of the Value of a Statistical Life." *American Journal of Health Economics.* 1(1): 27-52.

[30] The Viscusi (2015) meta-analysis includes 17 U.S. wage-risk studies that rely on CFOI data and controls for whether they address potentially confounding variables such as workers' compensation and nonfatal injury, as well as other study characteristics. Thus, this study adheres to most of our criteria either by using the criteria in selecting individual studies for inclusion or by controlling for these characteristics in the modelling

[31] Corso, P.S., J.K. Hammitt, and J.D. Graham. 2001. "Valuing Mortality-Risk Reduction: Using Visual Aids to Improve the Validity of Contingent Valuation." *Journal of Risk and Uncertainty.* 23(2): 165-184; Hammitt, J.K. and K. Haninger. 2010. "Valuing Fatal Risks to Children and Adults: Effects of Disease, Latency, and Risk Aversion." *Journal of Risk and Uncertainty.* 40: 57-83; Cameron, T.A. and J.R. DeShazo. 2013. "Demand for Health Risk Reductions," *Journal of Environmental Economics and Management*, 65: 87-109.

[32] Doucouliagos, H., T. D. Stanley, and W. Kip Viscusi. 2014. "Publication Selection and the Income Elasticity of the Value of a Statistical Life." *Journal of Health Economics*. 33: 67–75.

once they satisfy basic needs.[33] Values greater than 1.0 are also more consistent with the literature on the coefficient of relative risk aversion for financial risks.[34]

Given these concerns, as well as the range of available estimates, we suggest that SCAQMD rely on the results from the Viscusi (2015) meta-analysis for its central estimate; i.e., an elasticity of 1.1.[35] The Viscusi analysis has the advantage of combining the results from several studies and also addressing concerns related to publication bias. If it appears that the results of the AQMP analysis may be significantly affected by uncertainty in the elasticity estimate, SCAQMD may wish to conduct sensitivity analysis using a low elasticity of 0.0 and a high of 1.4, based on the results of the studies cited earlier.

Adjusting for changes in real income also requires an estimate of real income growth. These data are needed for two periods: the time that has elapsed between when the data in the valuation studies were originally collected and the base year, and the time that will elapse between the analytic base year and each year for which impacts are estimated. In other words, both actuals and projections are required. For consistency with how income is measured in the underlying VSL studies, we recommend that SCAQMD rely on historical data on earnings from the Current Population Survey (CPS).[36] For future years, we recommend that SCAQMD rely on the Congressional Budget Office's (CBO's) most recent estimate of growth in real earnings per worker from their long-term budget outlook report.[37] In both cases, we suggest relying on U.S. income data rather than data for the South Coast area, because the VSL studies reflect the preferences of the broader U.S. population. However, SCAQMD may wish to test the sensitivity of the estimates to the use of South Coast income data.

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[33] For more discussion, see: Hammitt, J.K. and L.A. Robinson. 2011 "The Income Elasticity of the Value per Statistical Life: Transferring Estimates Between High and Low Income Populations." *Journal of Benefit-Cost Analysis.* 2: Art. 1. Available for free download at: http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=9455893&fulltextType=RA&fileId=S2152281200000024.

[34] See, for example, Kaplow, L. 2005. "The Value of a Statistical Life and the Coefficient of Relative Risk Aversion." *Journal of Risk and Uncertainty.* 31(1): 23-34.

[35] This elasticity is based on Viscusi's preferred estimates from the random-effects model with standard errors clustered by article. The random effects model has the most statistically significant income effects.

[36] More specifically, for income growth in prior years, analysts should use CPS data on the annual median usual weekly earnings of employed wage and salary workers, for fulltime workers (usual working hours over 35), reported on an average per capita basis in constant dollars, which are available at http://www.bls.gov/cps/earnings.htm. These estimates can then be multiplied by 52 weeks to estimate annual earnings.

[37] See, for example, U.S. Congressional Budget Office. 2014. *2014 Long-Term Budget Outlook.* Table A.1 indicates that CBO estimated an annual growth rate of 1.4 percent between 2014 and 2039, and 1.3 percent if averaged over 2014 through 2089. The 2014 report is available at http://www.cbo.gov/publication/45471.

Cessation lag

EPA regulatory analyses of particulate matter (PM) rules assume that there is a time lag between reductions in PM exposure in a population and the full realization of reductions in premature mortality, a concept termed the "cessation lag." The cessation lag occurs because of the complex nature of the relationship between exposure and disease or death. For example, disease processes related to PM exposure have latency periods between critical exposure and overt illness or death; this period can vary with the type of disease. A lag model accounts for the fact that a population takes time to move from its initial steady state risk level to its new, lower level, as latent cases of premature cardiovascular or respiratory mortality or cancer manifest themselves in previously exposed individuals, or as cumulative exposures even at new lower levels may produce irreversible frailty in some individuals.

Analysts typically account for cessation lag when valuing mortality risk reductions by discounting over the lag period. In theory, current WTP to reduce future risks should be equivalent to the present value of the individual's WTP at the time the risk would become manifest. However, this future WTP is affected by a number of factors other than timing, such as the change in the individual's age. Empirical studies generally support the use of lower VSLs for risks that occur farther in the future, with some exceptions, although the rate of discount varies across studies.[38] In regulatory analysis, analysts generally apply the same discount rate to the cessation lag period as applied to other regulatory impacts.

While there is limited empirical evidence to estimate the relative proportions of these short-term or longer-term risks in the PM mortality signal, EPA's Science Advisory Board (SAB) has indicated that "although there is substantial evidence that a portion of the mortality effect of PM is manifest within a short period of time, i.e., less than one year, it can be argued that, if no lag assumption is made, the entire mortality excess observed in the cohort studies will be analyzed as immediate effects, and this will result in an overestimate of the health benefits of improved air quality. Thus some time lag is appropriate for distributing the cumulative mortality effect of PM in the population".[39]

In more recent advice, the SAB suggested that appropriate lag structures may be developed based on the distribution of cause-specific deaths within the overall all-cause

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[38] See, for example, Hammitt, J. K. and J-T Liu. 2004. "Effects of Disease Type and Latency on the Value of Mortality Risk." *Journal of Risk and Uncertainty*. 28: 73–95; Alberini, A., M. Cropper, A. Krupnick, and N. Simon. 2006. "Willingness to Pay for Mortality Risk Reductions: Does Latency Matter?" *Journal of Risk and Uncertainty*. 32: 231-245; Van Houtven, G., M. B. Sullivan, and C. Dockins, C. 2008. "Cancer Premiums and Latency Effects: A Risk-Tradeoff Approach for Valuing Reductions in Fatal Cancer Risks." *Journal of Risk and Uncertainty*. 36: 179–199; Hammitt J.K. and K. Haninger . 2010. "Valuing Fatal Risks to Children and Adults: Effects of Disease, Latency, and Risk Aversion." *Journal of Risk and Uncertainty*. 40: 57–83

[39] U.S. Environmental Protection Agency—Science Advisory Board. 1999. The Clean Air Act Amendments (CAAA) Section 812 Prospective Study of Costs and Benefits (1999): Advisory by the Health and Ecological Effects Subcommittee on Initial Assessments of Health and Ecological Effects. Part 2. EPA-SAB-COUNCIL-ADV-00-001. http://yosemite.epa.gov/sab%5CSABPRODUCT.NSF/7D54675178C12703852571B90044B4F8/$File/coua0001.pdf.

estimate.[40] Considerable uncertainty remains, however, about the distribution of causes of death within the relatively broad categories analyzed in the long-term cohort studies and the cessation lag associated with each cause. As noted in the regulatory impact analysis for the most recent PM National Ambient Air Quality Standard (NAAQS), although it may be reasonable to assume the cessation lag for lung cancer deaths mirrors the long latency of that disease, there is more uncertainty about the lag structure for cardiopulmonary deaths, which include both respiratory and cardiovascular causes that vary in their duration.[41] For example, where air pollution contributes to cardiovascular disease, that would imply a relatively long lag prior to death; alternatively if air pollution is acting a trigger for premature death in individuals with preexisting cardiovascular disease, the lag would be very short.

In its follow-up advice provided in December 2004, the SAB recommended that until additional research has been completed, EPA should continue to assume a 20-year segmented lag structure with the following pattern: 30% of mortality reductions occur in the first year; 50% occur spread evenly over years 2 to 5 after the reduction in $PM_{2.5}$; and the remaining 20% occur spread evenly over years 6 to 20 after the reduction in $PM_{2.5}$.[42] The distribution of deaths over the latency period is intended to reflect the contribution of short-term exposures in the first year, cardiopulmonary deaths in the 2- to 5-year period, and long-term lung disease and lung cancer in the 6- to 20-year period. Furthermore, in their advisory letter, the SAB recommended that EPA include sensitivity analyses on other possible lag structures.

IEc conducted such a sensitivity analysis assessing the impacts of cessation lag model uncertainty on monetized estimates of avoided premature mortality as part of the most recent Section 812 benefit-cost analysis of the Clean Air Act.[43] The results of that analysis indicated that assumptions about the form of the cessation lag can substantively affect monetized benefit estimates because of the effect of discounting on the VSL. EPA performed a similar uncertainty analysis as part of its 2012 PM NAAQS regulatory impact analysis.

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[40] U.S. Environmental Protection Agency—Science Advisory Board. 2004a. Advisory on Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis—Benefits and Costs of the Clean Air Act, 1990-2020: Advisory by the Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis. EPA-SAB-COUNCIL-ADV-04-002. http://yosemite.epa.gov/sab/sabproduct.nsf/08E1155AD24F871C85256E5400433D5D/$File/council_adv_04002_resp.pdf.

[41] U.S. Environmental Protection Agency. 2012. *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*. http://www3.epa.gov/ttn/ecas/regdata/RIAs/finalria.pdf.

[42] U.S. Environmental Protection Agency—Science Advisory Board. 2004b. Advisory Council on Clean Air Compliance Analysis Response to Agency Request on Cessation Lag. EPA-COUNCIL-LTR-05-001. http://yosemite.epa.gov/sab/sabproduct.nsf/0/39F44B098DB49F3C85257170005293E0/$File/council_ltr_05_001.pdf.

[43] Industrial Economics, Incorporated. 2011. *Uncertainty Analyses to Support the Second Section 812 Benefit-Cost Analysis of the Clean Air Act, Final Report – March 2011*. http://www2.epa.gov/sites/production/files/2015-07/documents/iec_uncertainty.pdf.

We recommend that SCAQMD apply the EPA SAB's recommended 20-year lag function from 2004 to calculate its primary estimate of the value of avoided mortality in the 2016 Socioeconomic Analysis. We recommend this be supplemented by a sensitivity analysis with two alternative functional forms to illustrate how uncertainty in the lag may affect the potential range of monetized benefit values. Possible alternative lag structures that SCAQMD could consider including the following:

- A 0-year lag model, representative of an upper bound value that assumes exclusively short-term risk changes;
- An alternate lag structure from the 2012 PM NAAQS regulatory impact analysis that assumes that more of the mortality impact is associated with chronic lung diseases or lung cancer and less with acute cardiopulmonary causes (e.g., 20% of mortality reductions occurring in the first year, 50% occurring evenly over years 2 to 5, 30% occurring evenly over the years 6 to 20 after the reduction in $PM_{2.5}$.);
- A 5-year distributed lag structure used in previous analyses, which assumes 50% evenly spread across the first 2-year segment, 50% evenly spread across the second 3-year segment, and 0% in the 6- to 20-year segment; and
- A smooth negative exponential relationship between the reduction in exposure and the reduction in mortality risk, which is described in more detail in both the most recent 812 analysis and the most recent PM NAAQS regulatory impapct analysis.[44] We agree with the approach taken in that analysis to select a single time constant (k = 0.45) for the exponential function, based on an average across PM mortality cohort studies.

SUMMARY AND CONCLUSIONS

In sum, we recommend that the SCAQMD proceed as follows:

- Use, as a starting point, a base VSL with a range from $4.2 million to $13.7 million and a mid-point of $9.0 million (2013 dollars and income levels). This value should be updated for inflation and real income growth, to reflect the base year used in the analysis.
- Adjust these values for real income growth using an income elasticity of 1.1, and conduct sensitivity analyses using elasticities of 0.0 and 1.4 if it appears that real income growth is likely to significantly affect the analytic conclusions. Because the VSL estimates reflect the preferences of the general U.S. population rather than solely the preferences of those in the South Coast area, we suggest that data on U.S. real income be used in these calculations. However, sensitivity analysis could also be conducted to test the impacts of relying instead on South Coast income data.

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[44] IEc (2011) and U.S. Environmental Protection Agency (2012).

- Apply a cessation lag structure consistent with the SAB-recommended 20 year lag applied in the most recent EPA NAAQS regulatory impact analysis, supplemented by a sensitivity analysis using two alternative lag structures, one that assumes more accelerated risk reductions and the other that assumes more gradual reductions. The VSL should be discounted over the lag period at the same rate as used to discount other regulatory impacts.

The combined effect of these assumptions on the values used in SCAQMD's analysis is unclear. The recommendation for the base VSL and the income adjustment will increase the 2016 values (in real terms) in comparison to those used in 2012, but accounting for the cessation lag will have a somewhat counterbalancing impact.