



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

February 23, 2017

EPA-SAB-17-005

The Honorable E. Scott Pruitt
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: SAB Review of EPA's Proposed Methodology for Updating Mortality Risk
Valuation Estimates for Policy Analysis

Dear Administrator Pruitt:

The EPA's National Center for Environmental Economics (NCEE) requested advice from the Science Advisory Board (SAB) on proposed improvements in the agency's methodology for estimating the value of mortality risk reductions, also known as the value of statistical life (VSL). The EPA requested that the SAB review three documents: (1) a white paper titled *Valuing Mortality Risk for Policy: A Meta-Analytic Approach* ("White Paper"); (2) a report titled *The Effect of Income on the Value of Mortality and Morbidity Risk Reductions*; and (3) a technical memorandum titled *Recommended Income Elasticity and Income Growth Estimates: Technical Memorandum*. The White Paper was developed to describe the EPA's proposed approach for estimating values for reductions in mortality risk for use in benefit-cost analysis. The other documents discuss options for updating the agency's recommended estimate for the income elasticity of the VSL.

In response to the EPA's request, the SAB Environmental Economics Advisory Committee was convened to review the White Paper and other documents. The SAB was asked to respond to 17 charge questions organized into six topics focusing on: (1) whether the methods used to select data for the analysis were appropriate and scientifically sound; (2) whether relevant studies were adequately included in the analysis; (3) whether the methodology used to analyze the data was scientifically sound; (4) whether the EPA's VSL estimates represented scientifically sound conclusions; (5) the development of a protocol for future updates of the VSL; and (6) whether the EPA's approach for estimating the income elasticity of VSL was appropriate and scientifically sound. The enclosed report provides the SAB's consensus advice and recommendations.

The White Paper presents an innovative approach to developing a composite estimate of the VSL from diverse empirical studies. The EPA has confronted a diverse landscape of VSL estimates because existing studies use a variety of approaches to estimate risk trade-offs. Existing VSL estimates in the

peer-reviewed literature differ in their conceptual underpinnings, in the years in which they were estimated, and in the subpopulation groups they represent. The process of developing an empirically consistent summary of existing VSL estimates requires converting the published estimates (in this case estimates of a monetary trade-off to reduce the risk of death by a small amount) to a common metric of economic value. This process entails assumptions and the analyst must use discretion in deciding the concept of value to use and the assumptions to apply in developing a statistical summary measure of VSL. While the methods (i.e., the parametric and non-parametric estimators) used by the EPA to develop the statistical summary are consistent with conventional practice, the assumptions made to prepare the data for the parametric and non-parametric methods go beyond currently established practices. The assumptions made to combine the diverse VSL estimates to obtain a summary measure are not always transparent, conceptually consistent, or essential for developing a summary VSL estimate in constant dollar terms. Many of the assumptions would usually be made as part of the process of customizing the summary VSL estimate to conduct a benefit transfer for a specific policy. The enclosed report explains the SAB's conceptual and empirical concerns about the methods used in the White Paper. The SAB encourages the EPA to further develop the meta-analysis taking the SAB findings and recommendations into account. The EPA should aim to provide more transparent documentation of the underlying assumptions and methods and greater justification for the methodological choices made. The EPA should also consider whether use of a term such as value of risk reduction for mortality (VRRM) instead of VSL to describe the measure would lead to better understanding of the concept by the public. Other major comments and recommendations in response to the agency's charge questions are provided below.

- The evidence of study validity considered by the EPA in developing the data set for the analysis is incomplete. To strengthen the assessment, the EPA should consider applying additional tests of validity. The EPA should also clarify how evidence of validity was applied to all of the studies considered for use in the analysis.
- In the future, the EPA should broaden the scope of studies used to derive values for reducing both mortality and morbidity risks. There are a significant number of published studies that estimate willingness to pay for improved health and reduced health risks, and a literature on benefit-risk and risk-risk trade-off preferences in health and health care, as well as reduced risk for highway fatalities, which could enrich the evidence on risk preferences and provide support for benefits transfer applications.
- There has been little growth in the number of studies used by the EPA to estimate the VSL since the last consideration of this topic by the SAB in 2011. The SAB provides citations for additional studies that could be included in the White Paper. In addition, the SAB recommends that the agency consider commissioning more studies or creating other incentives for new studies to improve the prospect for a deeper literature to support future reviews of VSL. The EPA should consider whether estimation of VSL and its various attributes should be a high priority topic for grants and fellowships, sponsored conferences, and special issues of journals.
- The SAB finds that a five-year interval for updating VSL estimates is reasonable, but there is a need to increase the pool of high quality studies to support the VSL meta-analysis. All future updates of the VSL should simultaneously consider whether the conditions for investigating study validity and meta-analysis procedures should be updated, not just the VSL itself.

- Some VSL estimates in the White Paper were constructed by weighting subpopulation estimates to obtain an approximation for the general population. Given the limited VSL literature, the SAB recognizes the need to develop a weighting approach for subpopulation estimates. However, additional information is needed in the White Paper to better explain how the weighting was actually done and how the studies were brought together for the aggregate estimate. The White Paper mixes discussion of two kinds of procedures, population weighting and benefit transfer data weighting for estimation. EPA's analysis should be modified to ensure that population weighting is accomplished using standard procedures and subsequently that benefit transfer assumptions and procedures are appropriately described and applied.
- The White Paper classifies estimates into independent samples called groups. The SAB supports grouping the studies in the White Paper based on similar samples in order to account for the lack of independence in estimates constructed from the samples. However, additional detail should be provided to clarify how the grouping decisions were made and an analysis should be conducted to check the robustness of the results to alternative plausible group definitions.
- The EPA report and technical memorandum on the income elasticity of VSL provide reasonable summaries of the income elasticity literature. However, the SAB finds that this information is inadequate for deriving an overall estimate of the income elasticity of VSL. In addition, there has been relatively little growth in median income over the last two decades, particularly for groups represented in the samples used for hedonic wage studies. Therefore, it may not be appropriate to adjust VSL estimates by an income elasticity of VSL and index of income growth (based on Gross Domestic Product per capita) when preparing the estimates for use in the meta-analysis. However, conversion of VSL to inflation adjusted dollars is appropriate.

The SAB appreciates the opportunity to provide the EPA with advice on this important subject. We look forward to receiving the agency's response.

Sincerely,

/signed/

Dr. Peter S. Thorne, Chair
Science Advisory Board

/signed/

Dr. Madhu Khanna, Chair
SAB Environmental Economics Advisory
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Enclosure

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Acronyms and Abbreviations

BLS	U.S. Bureau of Labor Statistics
CFOI	Census of Fatal Occupational Injuries (U.S. Bureau of Labor Statistics)
CPS	Current Population Survey
CV	Contingent Valuation
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FES	Fixed Effect Size
GDP	Gross Domestic Product
IEVSL	Income Elasticity of Value of Statistical Life
NOAA	National Oceanic and Atmospheric Administration
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RES	Random Effect Size
STAR	Science to Achieve Results Program
VRRM	Value of Risk Reduction for Mortality
VSL	Value of Statistical Life
WTA	Willingness to Accept
WTP	Willingness to Pay

1. EXECUTIVE SUMMARY

The National Center for Environmental Economics in the EPA Office of Policy requested advice from the SAB on proposed improvements in the agency's methodology for estimating benefits associated with reduced risk of mortality. This methodology estimates the dollar amount that individuals are willing to pay for small reductions in mortality risk. The resulting values are combined into an estimate known as the value of statistical life (VSL) which is used in regulatory benefit-cost analysis. The EPA also requested that the SAB review options for accounting for changes in VSL over time as income grows, known as income elasticity of the VSL. The EPA submitted three documents to the SAB for review: (1) a white paper titled *Valuing Mortality Risk for Policy: A Meta-Analytic Approach* (hereafter referred to as the "White Paper"); (2) a report by Robinson and Hammitt (2015) prepared for the EPA Office of Air and Radiation titled *The Effect of Income on the Value of Mortality and Morbidity Risk Reductions*; and (3) an EPA memorandum titled *Recommended Income Elasticity and Income Growth Estimates: Technical Memorandum*. The White Paper was developed to describe the EPA's proposed approach for estimating values for reductions in mortality risk for use in benefit-cost analysis. This approach includes assembling a VSL data set from the published stated preference and hedonic wage study (studies that estimate the wage premium associated with greater risks of death on the job) literature and using non-parametric and parametric analytic methods to develop central estimates of the average VSL among the general U.S. adult population. The EPA report and technical memorandum discuss options for updating the agency's recommended estimate for the income elasticity of the VSL.

The EPA asked the SAB to review the White Paper and other documents and respond to 17 charge questions organized into six topics focusing on: (1) whether the methods used to select the data set for the analysis were appropriate and scientifically sound; (2) whether relevant empirical studies were adequately captured in the White Paper; (3) whether the methodology used in the White Paper to analyze the data represents an appropriate and scientifically sound application of meta-analytic methods to derive VSL estimates; (4) whether the EPA's proposed VSL estimates represent reasonable and scientifically sound conclusions; (5) development of a protocol for future updates of the VSL; and (6) whether EPA's approach to estimating the income elasticity of VSL was appropriate and scientifically sound. This executive summary highlights the findings and recommendations of the SAB in response to the charge questions provided in Appendix A.

Overarching Comments

The EPA's White Paper describes an innovative approach to developing a composite estimate of the VSL from diverse empirical studies. The EPA has confronted a diverse landscape of VSL estimates because existing studies use a variety of approaches to estimate risk trade-offs. While the methods (i.e., the parametric and non-parametric estimators) used by the EPA to develop the statistical summary are consistent with conventional practice, the assumptions made to prepare the data for the parametric and non-parametric methods go beyond currently established practices. The assumptions made to combine the diverse VSL estimates to obtain a summary measure are not always transparent, conceptually consistent, or essential for developing a summary VSL estimate in constant dollar terms. The SAB encourages the EPA to further develop the meta-analytic methods in the White Paper taking the SAB recommendations in this report into account. In future analyses, the EPA should aim to provide more transparent documentation of the underlying assumptions and methods and greater justification for the methodological choices made.

The SAB finds that a term such as “Value of Risk Reduction for Mortality” (VRRM) may be a better term than “Value of Statistical Life” (VSL) for communication with non-economists. The EPA should work with the research community, other agencies, and professional organizations to consider whether replacement of the term “VSL” would lead to better understanding of the concept and therefore be more appropriate terminology for public communication.

Question 1a - Evidence of Validity of the Stated Preference Studies

The SAB was asked to comment on whether the methods used in the White Paper to assess the validity of studies and value estimates were appropriate and scientifically sound. The SAB finds that the evidence of study validity considered by the EPA is incomplete. Therefore, the SAB cannot determine whether the value estimates summarized in the White Paper are appropriate and scientifically sound. To strengthen the assessment of study validity, the agency should clarify how the criteria of validity were applied to all of the studies considered for use in the analysis. To better inform a weight of evidence decision to include or exclude a study, the EPA should expand the consideration of evidence of validity to include answers to additional key questions. EPA should also fully document the validity evidence considered and how this evidence was used to include (or exclude) each study or value estimate. In addition, all future updates of the VSL should consider whether conditions for investigating study validity should also be updated. For example, when the last VSL estimate was developed and reviewed, consequentiality was not a predominant feature for evaluating study validity and it was not standard practice to investigate the sensitivity of meta-analysis estimates to study and value estimate inclusion/exclusion in the analysis. These are important, new features of the VSL update and there are likely to be other new innovations in the literature at the time of the next update of the VSL.

Question 1b - Construction of the Risk Variable in Hedonic Wage Studies

The SAB was asked to comment on whether the hedonic wage studies included in the White Paper constructed the risk variable in a manner appropriate for use in the meta-analysis. In the White Paper, the EPA used hedonic wage studies and estimates where the risk measure is differentiated by industry and at least one other characteristic (e.g., occupation, gender, age). The SAB supports excluding from the analysis those studies that employ fatality risk measures based on industry category alone. However, the current inclusion criterion that restricts the analysis to studies based on risk measures differentiated by industry and at least one other characteristic is inappropriate. Differentiating an industry level risk measure by some additional characteristics, for example age and gender, may lead to wage-risk trade-off estimates unequally influenced by wage discrimination.

In the short run, the SAB recommends that the EPA: (1) alter its inclusion criteria to restrict its analysis to hedonic wage studies that employ fatality risk measures differentiated by occupation; and (2) include in the white paper a summary of recent meta-analyses of hedonic wage studies. Such a summary could provide information on the likely sensitivity of the final VSL measure to variations in the set of studies included in the calculations without having to replicate the research efforts already completed. In the long run, the SAB recommends that the EPA compile, make publicly available (e.g., on an internet web page), and regularly update detailed fatality risk measures to encourage future revealed preference VSL research. These should be derived from the U.S. Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI) and merged with appropriate data from the Current Population Survey (CPS). The SAB also recommends that in the long run, the EPA apply a consistent hedonic wage model using data from the CPS and CFOI to generate comparable annual measures of VSL. Comparisons among these annual estimates could yield an estimate of the income elasticity of VSL. The SAB also

recommends that the EPA pursue research to examine the various biases associated with hedonic wage studies, including an assessment of the adjustment needed to convert the marginal willingness to accept VSL measure obtained from hedonic wage studies to a format that is consistent with the Hicksian willingness to pay VSL measure obtained from stated preference studies.

Question 1c - Estimates of Value of Immediate Risk Reduction

The SAB was asked to comment on whether appropriate estimates from the stated preference literature were used in the White Paper to estimate the marginal willingness to pay for reduced risk of immediate death. The SAB has provided citations for several additional studies that could be included in the White Paper. In addition, the SAB finds that the supplementary analysis in one of the studies the EPA selected for use, Viscusi, Huber, and Bell (2014), does not provide clear evidence of sensitivity of scope. Moreover, the SAB recommends that the EPA broaden the range of studies used to derive values for reducing both mortality and morbidity risks. There are a significant number of published studies that could enrich the evidence on risk preference and provide support for benefits transfer applications. These include studies that estimate willingness to pay for improved health and reduced health risks, literature on benefit-risk and risk-risk trade-off preferences in health and health care, and transportation literature on reduced risk for highway fatalities. The SAB also finds that simple discounting does not accurately account for morbidity values in converting future deaths to equivalent immediate death values. The EPA should account for morbidity values in converting future mortality risks to equivalent instantaneous risks.

Question 2 - Empirical Studies

The SAB was asked to comment on whether relevant empirical studies in the stated preference and hedonic wage literatures are adequately captured in the White Paper. There has been little growth in the number of studies used by the EPA to estimate the VSL since the last consideration of this topic by the SAB in 2011. The SAB recommends that EPA search more broadly for additional studies not restricted to hedonic or stated preference methods. This could include an evaluation of whether studies using experimental or quasi-experimental methods may offer insight to VSL. Citations for several studies are provided in Section 3.2.4 of this report. While these studies differ in methodology, data, or approach from studies already included in the White Paper, they offer potentially valid insight to the estimation of VSL. The EPA may need to commission more studies or create other incentives for new studies to improve the prospect for a deeper literature to support future reviews of VSL.

Question 3 - Population Weighting in EPA's Analysis

The SAB was asked to comment on whether the population-weighting approach used in the White Paper to provide a VSL estimate for the general population is appropriate and scientifically sound. Some estimates in the meta-analysis data set in the White Paper are constructed by weighting subpopulation-specific estimates within a study in order to approximate an estimate for the general population. Given the limited VSL literature, the SAB recognizes the need to develop an approach to use subpopulation estimates of VSL in the analysis. The SAB has three key concerns about the EPA's approach. First, the White Paper appears to describe a process in which the weights were selected for different years from those when the original sample was taken; this implies that the objective was to reflect estimates of statistics for a different population. Weights should be connected to the time periods of the original studies, otherwise the weighting would appear to be including assumptions that would be associated with benefits transfers. Second, the White Paper documents that the EPA has relied upon some studies

that are based on samples where an economic decision such as the decision to work (in hedonic wage studies) conditioned the eligibility for inclusion in the samples. The EPA should include in the White Paper an explanation of the implications of such selection bias as well as response bias in stated preference studies. Third, in addition to changing the years for the weights, some calculations used in constructing the population weights would be associated with a benefit transfer context; this practice implies that the explanation for the development and use of the weights is misleading. A clear and careful distinction is required to separately address weighting to make value estimates nationally representative, and weighting conducted in the estimation of the meta-equation to address issues of data gathered from an unbalanced panel.

Additional information is needed in the White Paper to explain in detail how the weighting was actually done and how the studies were brought together for the aggregate estimate. For example, the White Paper should contain a more detailed explanation of how weighting procedures would affect estimates of standard errors. The SAB recommends that EPA provide information sufficient to allow a third party to replicate the approach. The EPA should clearly distinguish between the use of population weights to derive a representative estimate of the VSL observation drawn from a particular study and the strategy of transferring benefit estimates from a source study as input to an estimate of VSL for some population (or timeframe) not directly addressed by the source study. In some cases, e.g., contingent valuation studies, the weighting procedure used by the EPA is comparable to using approximations for sampling weights. However, the procedure used for the hedonic wage studies is a benefit transfer. It is important that population weighting be accomplished using standard procedures and that benefit transfer assumptions and procedures for implementation be described and distinguished. Specific recommendations are provided in Section 3.2.5 of this report. The EPA should also investigate the possibility of developing a set of subpopulation weights and benefit transfer strategies that build upon what is known about the subpopulations covered in each of the available studies.

Question 4 - Estimation of Standard Errors

In the White Paper, the EPA attempts to estimate the standard errors of the VSL when the original studies do not report them. The SAB was asked to comment on whether the methods used to estimate these standard errors are appropriate and scientifically sound. There are two issues that should be addressed with regard to estimation of standard errors. The first issue involves calculation of the standard error of the VSL when the standard error is not reported in the original study. The SAB finds that the White Paper does not provide sufficiently detailed information describing this calculation. The EPA should document precisely how the standard error of the VSL is estimated when the original study does not report one so that an independent party could replicate the calculations. The second issue concerns the methods used to estimate standard errors for the parametric and non-parametric estimates of the VSL. The SAB finds that the White Paper does not provide sufficient information and justification for the methods used. As further discussed in this report, the SAB proposes an alternative approach that is grounded in theory to calculate standard errors for both the non-parametric and parametric VSL estimator.

Question 5 - Overall Methodology for Analyzing the Data

The SAB was asked to comment on whether the methodology used in the White Paper to analyze the data represents an appropriate and scientifically sound application of meta-analytic methods to derive generally applicable VSL estimates for environmental policy analysis. In general, the SAB finds that developing a statistical summary of VSL evidence from the literature is an appropriate approach to

deriving applicable VSL estimates. However, the SAB has concerns about the transformations used in developing the basic data for the statistical summary reported in the White Paper. The SAB recognizes that a summary necessarily confronts the task of developing consistent estimates of the response measure or “effect size” that is summarized when the source information is heterogeneous in the timing of the estimates, the methods used, and the concepts being measured.

The SAB agrees that certain adjustments to the VSL estimates from the source studies are needed and defensible to assure as much consistency as possible before applying the statistical methods used in developing the summaries. The SAB supports adjustments to address some of the heterogeneity arising from differences in the cost of living using price indices. In addition, because the underlying VSL studies use different methods to measure consumers’ responses to risk, they sometimes provide estimates of different economic concepts that characterize the trade-offs in distinct ways. For instance, the hedonic studies estimate Marshallian values (holding income constant) for marginal changes in risk and the stated preference studies estimate Hicksian values (holding utility constant) for discrete (non-marginal) risk changes. It is important for the EPA to evaluate the sensitivity of the statistical summaries to the decisions made in transforming the primary estimates to address these types of differences in the economic concepts being measured. This evaluation should be conducted before selecting specific transformations to be applied to estimates for computing a general summary measure of VSL for policy applications.

The SAB recommends that a distinction be made with respect to adjustments that more appropriately fit within the domain of benefits transfer and those adjustments that are made to prepare the data to develop the overall summary measure. In the first case, associated with benefit transfer tasks, adjustments are made using specific modeling assumptions to predict mortality risk values for populations with different characteristics than those in the source study. Such adjustments include adjusting individual VSL estimates to account for differences in income or, in some cases, to combine estimates for different demographic groups with specifically defined weighting approaches.

The SAB finds that some of the transformations of the empirical estimates used in the meta-analysis extend significantly beyond any meta-analytic practices in the literature. Because these practices are “new,” the SAB recommends more detailed evaluation and separate assessments of the practices in these new roles before judgments are made that could be interpreted as endorsements. In many cases these adjustments, if they are applied at all, should be conducted *ex post*, as part of a benefit transfer process, rather than as part of the development of data used in the meta-analysis. The SAB recommends that the White Paper: (1) provide more detail about each of the primary studies to reinforce the direct comparability of the objects/commodities being valued and allow an independent party to replicate the results; (2) discuss and, as appropriate, make adjustments for differences in value concepts being measured across studies; (3) conduct non-parametric and parametric analyses without a direct income adjustment to VSL estimates obtained from primary studies¹; and (4) justify the use of “sample size weighted mean” in the non-parametric analysis to account for heterogeneity in the variance of effect size estimates.

¹ There is insufficient evidence for deriving an overall estimate of the income elasticity of VSL from different studies. Furthermore, there has been relatively little growth in median income over the last two decades, particularly for groups represented in the samples used for hedonic wage studies. Therefore, it may not be appropriate to adjust VSL estimates by an income elasticity of VSL and index of income growth (based on Gross Domestic Product per capita) when preparing the estimates for use in the meta-analysis.

Question 6 - Grouping Samples for Analysis

The White Paper classifies estimates into independent samples, also called groups. Estimates from some hedonic wage studies that use the same or very similar worker samples are grouped together for the analysis. Similarly, some of the stated preference estimates using the same sample are grouped together. The SAB was asked to comment on whether this methodology represents an appropriate and scientifically sound approach to account for potential correlation of results that rely on the same underlying data. The SAB supports grouping the studies in the White Paper based on similar samples to account for the lack of independence in estimates constructed from the samples. The SAB endorses grouping studies that use the same data set. Additional detail should be provided to clarify how the EPA's grouping decisions were made. The SAB also recommends that the EPA conduct additional analysis to check the robustness of the results to different plausible group definitions. This robustness check should include: (1) exploring the sensitivity of results to alternative group assignments (e.g., grouping studies that used the same data set or the econometric approach); (2) using the influence analysis to examine the robustness of results to excluding each group; and (3) identifying the primary estimate from each study and re-estimating the meta-regression using only primary estimates.

Question 7 - Addressing Sampling and Non-Sampling Errors

The White Paper presents an expression characterizing optimal weights that account for sampling and non-sampling errors. The SAB was asked to comment on whether this is an appropriate and scientifically sound approach for addressing sampling and non-sampling errors. Additional information would be needed to fully address this question. The derivation of the expression characterizing optimal weights that account for sampling and non-sampling errors should be explained in a more transparent way in the White Paper. The SAB recommends including in the explanation the various steps required to derive equation 4 in Section 4.1 of the White Paper. The text should include the precise equation used by the EPA and citations that establish the validity of the basic approach. With regard to use of the weights, the SAB recommends that clarification of, and justifications for, the assumptions concerning the error components be included in the White Paper. In addition, the SAB recommends that transparency be considered when choosing among estimators that are otherwise equally appropriate.

Question 8 - Non-parametric and Parametric Approaches for Estimating Value of Statistical Life

The White Paper adopts both non-parametric and parametric approaches to estimate a VSL. The SAB was asked to comment on whether these approaches span a reasonable range of appropriate, scientifically sound, and defensible approaches to estimating a broadly applicable VSL for environmental policy and whether there are other methods that are more appropriate than those used in the White Paper. The SAB finds that additional information is needed in the White Paper to explain how these approaches were applied, particularly the non-parametric approach. Calculations should be documented with sufficient detail to allow a reader to know precisely how to replicate the calculations. Citations should be provided for the non-parametric approaches and better justification should be provided to explain why the methods used are relevant to finding the central tendency of VSL estimates from studies that, in most cases, report multiple estimates. Among the non-parametric estimators, the EPA prefers the mean of group means estimator because it has the smallest estimated standard error. The SAB cannot evaluate the EPA's choice of estimator without evaluating new results that address responses to other charge questions (e.g., issues raised regarding study/value selection, population weighting, and income growth adjustments). Changes made in response to SAB recommendations could affect the relative performance of the estimators. The need to examine new results notwithstanding, the

mean of group means estimator has the advantage that it avoids giving too much weight to studies that report multiple estimates. The SAB recommends that the EPA: (1) explore the use of an alternative non-parametric method that incorporates information on sampling error variance from each study; (2) provide a better explanation of, and justification for, the included control variables for the parametric estimator; and (3) not include a time trend variable in either the parametric or non-parametric models, but consider conducting a sensitivity analysis to determine whether older or newer studies have a strong influence on the average VSL.

Question 9 - Proposed Estimates of Value of Statistical Life

The White Paper presents VSL estimates that have been derived using parametric and non-parametric models, pooled across stated preference and hedonic wage studies as well as balanced (i.e., giving equal weight to each study type), and weighted using different approaches. The EPA has proposed using the non-parametric model balanced mean of study means VSL estimate and the parametric model balanced VSL estimate. The SAB was asked to comment on whether these proposed estimates represent reasonable and scientifically sound conclusions from the analyses in the White Paper and whether there is a different set (or sets) of results that are preferable based on the data and analysis in the White Paper. The SAB finds that it would be premature for the EPA to develop VSL estimates for the U.S. population using a meta-analytic approach. The EPA's transformations of the primary VSL estimates are an innovation that incorporates some features of previous SAB recommendations. The transformations could be described as partial preference calibration that implicitly makes assumptions about individuals' preferences. These assumptions are then embedded in the overall statistical summary that is part of the EPA's meta-analysis. This approach requires detailed evaluation and vetting in the published literature before it is used for either the analysis of rules or guidance concerning methods for evaluating rules. The SAB also recommends that the documentation of income adjustment to VSL be clarified in the White Paper. Adjustment of VSL estimates by an income elasticity of VSL and index of income growth (based on Gross Domestic Product, GDP, per capita) may not be appropriate. However, conversion of VSL to inflation adjusted dollars is appropriate.

Question 10 - Influence Analysis

The results section of the White Paper concludes with an influence analysis. The SAB was asked to comment on whether this analysis is a reasonable way to characterize the influence of individual studies on the estimated VSLs, whether the results of the influence analysis suggest any changes or modifications to the EPA's estimation approach, and whether it is important to include an influence analysis. The SAB agrees that some form of influence analysis is important for meta-analysis in cases where there are few studies to consider, and therefore one or two individual studies might have a substantial influence on the estimates. Influence analysis of the maximum likelihood stated preference estimates in the White Paper indicates that the Corso, Hammitt and Graham (2001) study is well over two times more influential than the second most influential study. Therefore, the SAB recommends that the EPA consider using a robust estimation technique that limits the influence of this observation. The SAB also recommends that the EPA consider the potential for using analysis of medians and regression diagnostic indexes for the parametric modeling of VSL.

Question 11 - Criteria for Inclusion and Exclusion of VSL Estimates in Future Analyses

The SAB was asked to comment on relevant statistical criteria for the inclusion of additional eligible VSL estimates and/or the exclusion of older VSL estimates that could help inform the development of a

standardized protocol for future updates. The SAB was also asked to comment on the timing or frequency of those updates. The SAB finds that a five-year interval for updating VSL estimates is reasonable, but there is a need to increase the pool of high quality studies to support the VSL meta-analysis. To accomplish this, the EPA should: (1) consider whether estimation of VSL and its various attributes should be a high priority topic for EPA grants and fellowships, sponsored conferences, special issues of journals, and awards; and (2) obtain more general information about protocols for updating estimates from the experience of other agencies that construct economic index numbers for policy.

The SAB also recommends that: (1) the EPA should consider whether it is feasible to include studies outside of the peer-reviewed journals in analyses to estimate VSL (following a transparent and rigorous peer review process); (2) the EPA should consider whether useful information can be extracted from other studies (not included in the VSL calculation) that could improve estimates of VSL and its characteristics (e.g., latency, morbidity); (3) the EPA should not exclude studies based on non-national samples from use in updating VSL as long as the samples are part of a group that is representative of the nation as a whole (or can be used to: develop a representative estimate for the nation as a whole or improve the representation of VSL values of subpopulations that are underrepresented or omitted from studies used to estimate a representative value for the nation as a whole); and (4) the EPA should consider a long-term strategy of requiring that a more inclusive set of research results, and even whole data sets, be made generally available for use by the research community and by government agencies.

Question 12 - Valuing Reductions in Risks of Cancer

The SAB was asked to comment on whether the selection criteria for identifying studies for valuing reductions in risks of cancer mortality should differ from those used in the White Paper. The SAB was also asked whether the literature supports a non-zero differential between valuation of cancer and other mortality risk. Based on available studies, the SAB concludes that there is not sufficient evidence at this time to justify a non-zero cancer differential. EPA should encourage and support ongoing research on whether willingness to pay to reduce the risk of an early death varies depending on the cause of death, with particular attention paid to mortality risks affected by EPA regulations. When evaluating such studies, the EPA should use the same selection criteria discussed in the SAB's response to Charge Question 1. Until new evidence becomes available to allow identification of a specific cancer differential, the SAB recommends that the EPA continue its current practice of using the same VSL to value cancer mortality and other mortality causes. This recommendation also applies to other environment-related mortality risks, including cardio-pulmonary disease.

Question 13 - Income Elasticity Literature

The SAB was asked to comment on whether the report by Robinson and Hammitt (2015) and the EPA Technical Memorandum provide an appropriate and scientifically sound summary of the literatures on income elasticity of VSL and income elasticity of non-fatal health effects. The SAB finds that the Robinson and Hammitt (2015) report and the EPA document *Technical Memorandum: Income Elasticity* provide reasonable summaries of the income elasticity literature. However, the SAB has provided citations for some additional studies that should be included in the summary of the literature. Very few studies have been conducted on the income elasticity of the VSL. Going forward, the SAB recommends that the EPA support research to provide methodological guidance that may enable use of estimates of the income elasticity for other related goods and services (such as consumer products that can be used to reduce health risks, and various forms of health insurance) to infer estimates of the income elasticity of the value of statistical life. While this may require more work on the microeconomic foundation of such

connections, the ability to use such estimates would greatly increase the empirical basis upon which to ground the income elasticity of the VSL. Moreover, giving greater attention to studies that have a clear identification strategy for linking environmental risks to behavior would also provide a more solid empirical basis for determining the income elasticity of the VSL.

Question 14 - Analysis of Very Low Income Elasticity Estimates

The “balanced” approach in the EPA Technical Memorandum on estimating income elasticity of VSL does not include reported mean estimates of zero, but does include very low reported mean estimates. The SAB was asked to comment on: (1) whether this was an appropriate and scientifically sound choice, and (2) how very low, non-zero, mean reported income elasticity results should be addressed in the EPA’s analysis. The SAB finds that, from a theoretical perspective, it is highly implausible for the income elasticity of VSL to be zero or negative. However, such estimates are statistically possible, so there is little statistical justification for dropping them. The SAB recommends that, instead of calculating an unweighted mean of the income elasticity of VSL estimates, the EPA should use standard errors of the individual income elasticity of VSL estimates to calculate a weighted mean of the income elasticity of VSL. This approach will be useful in addressing many of the very low elasticity estimates which may have large confidence intervals.

Questions 15 and 16 - Study Selection Criteria and Alternative Approaches for Estimating Central Income Elasticity of Value of Statistical Life

The SAB was asked to comment on whether the study selection criteria applied in the paper by Robinson and Hammitt (2015) are appropriate and scientifically sound, and whether the additional inclusion of Viscusi, Huber, and Bell (2014) in the EPA Technical Memorandum is appropriate based on results reported in the study’s on-line appendix. In addition, the SAB was asked to comment on two proposed alternatives for arriving at a central income elasticity of VSL. Robinson and Hammitt (2015) have done an admirable job summarizing the available literature. However, the SAB finds that this information is inadequate for deriving an overall estimate of the income elasticity of VSL. The inclusion of Viscusi, Huber and Bell (2014) in the analysis does not alter this finding. As discussed in Section 3.6.3 of this report, the SAB finds that neither of the two alternatives put forward in Robinson and Hammitt (2015) and described in EPA’s technical memorandum represent an adequate basis for providing an estimate of the income elasticity of VSL for policy purposes. Therefore, the SAB recommends that the EPA consider the alternative approach of using one or more of the preferred VSL model specifications to obtain and compare VSL estimates at different points in time and use that comparison to obtain the implied income elasticity of VSL.

Question 17 - Income Elasticity of the Value of Non-fatal Health Effects

The EPA’s Technical Memorandum recommends using the income elasticity of VSL to estimate income elasticity for the value of non-fatal health risks. The SAB was asked to comment on whether this represents an appropriate and scientifically sound approach given the available data. The SAB does not support using the income elasticity of VSL to estimate income elasticity for the value of non-fatal health risks because, without a theoretical or empirical justification, it is conceptually incorrect to apply income elasticity for one good to some other good, even though the two goods are related in some way. However, it may be possible to use a conceptual model of averting expenditures to show the conditions under which the income elasticities of private health care products could be used as a proxy for the income elasticity of the value of non-fatal health effects. The SAB recommends that the EPA support

research to develop such a model. The ability to use estimates of income elasticity of private health care products as a proxy would greatly increase the empirical basis upon which to ground income elasticity of the value of non-fatal health effects.

2. INTRODUCTION

The National Center for Environmental Economics in the EPA Office of Policy requested advice from the SAB on proposed improvements in the agency's methodology for estimating benefits associated with reduced risk of mortality. This methodology estimates the amounts that individuals are willing to pay for reductions in mortality risk. The resulting values are combined into an estimate known as the value of statistical life (VSL) which is used in regulatory benefit-cost analysis. The EPA also requested that the SAB review options for accounting for changes in VSL over time as income grows, known as income elasticity of the VSL. The EPA submitted three documents to the SAB for review: (1) a white paper titled *Valuing Mortality Risk for Policy: A Meta-Analytic Approach* (hereafter referred to as the "White Paper"); (2) a report by Robinson and Hammitt (2015) prepared for the EPA Office of Air and Radiation titled *The Effect of Income on the Value of Mortality and Morbidity Risk Reductions*; and (3) an EPA memorandum titled *Recommended Income Elasticity and Income Growth Estimates: Technical Memorandum*.

The White Paper was developed to describe the proposed approach for estimating values for reductions in mortality risk for use in benefit-cost analysis. This approach entailed: (1) assembling a database of stated preference and hedonic wage study (studies that estimate the wage premium associated with greater risks of death on the job) estimates of the value of statistical life (VSL) and, where possible, their standard errors; (2) assembling all of the VSL estimates from the primary literature that met selection criteria; and (3) using non-parametric and parametric approaches to develop central estimates of the average VSL among the general U.S. adult population. The non-parametric approach involved calculating weighted averages of the primary VSL estimates. The parametric approach involved estimating the central value of the VSL and the average sampling and non-sampling variation of the primary estimates within and between the studies using maximum likelihood. Based on the most efficient non-parametric estimator and the maximum likelihood estimation, the EPA proposed a VSL estimate for use in valuing mortality risk reductions for policy. The EPA report and technical memorandum on income elasticity of VSL discuss options for updating the agency's recommended estimate for the income elasticity of the VSL.

The White Paper provides context for the documents submitted to the SAB for review. A review in 2011 by the SAB provided the EPA with four options for combining mortality risk valuation estimates. These options were: (1) develop independent estimates for relevant cases using only studies that are closely matched on risk and individual characteristics; (2) develop a baseline distribution of estimates (perhaps for fatal injury) and a set of adjustment factors for risk and individual characteristics as warranted; (3) develop a meta-regression model to estimate the VSL as a function of risk and individual characteristics; and (4) develop and estimate a structural preference function (U.S. EPA Science Advisory Board 2011). The White Paper notes that these options were evaluated and a composite of two of the four was adopted in developing the analysis presented to the SAB in the White Paper and other documents. More specifically, the White Paper notes that:

“...in light of the number of studies and estimates that meet the selection criteria recommended by the SAB Environmental Economics Advisory Committee described above, the EPA chose an approach for updating the VSL that blends options 2 and 3. Specifically, we used meta-analysis to estimate the average value (among the U.S. general adult population) of the marginal willingness to pay to reduce the risk of immediate death, hereafter referred to as the VSL. In addition to the meta-analysis, we

also estimated a parsimonious meta-regression model that pools all of the observations in the meta-analysis data set and controls for study type (HW or SP¹), means versus medians, and year of data collection. We leave the task of estimating adjustment factors to account for the influence of risk and individual characteristics on the VSL, possibly through inclusion of additional control variables in the meta-regression model, for future work.”

The EPA’s composite strategy represents an innovation in benefits transfer practices. By embedding assumptions that adjust estimates of risk trade-offs for different members of the population based on what is available in the literature and then assigning these values to groups as part of constructing national averages (often for different years than when they were estimated), the EPA has developed a new strategy for introducing heterogeneity into the logic used to construct unit value transfers. This logic also identifies another issue to be considered in adjusting estimates from the literature. To the extent the analysis acknowledges heterogeneity in measures of risk trade-offs for different groups distinguished by observable characteristics, such as age or gender, then adjustments for increases in income or other sources of risk change that might affect the baseline risk need to be considered prior to constructing a national average measure for VSL. These groups may face different rates of growth in their incomes or have different income elasticities. They might experience other differences in factors that would affect the risk trade-off measure relevant for the group, and these would need to be applied before developing a composite nationwide average measure.

The White Paper describes approaches that were not envisioned in the earlier SAB recommendations. It is important to note that the final estimates for a national average cannot be evaluated without also evaluating all the assumptions applied in developing those estimates and evaluating whether specific assumptions are influential.

The EPA asked the SAB to review the White Paper and other documents and respond to 17 charge questions organized into six topics focusing on: (1) whether the methods used to select the data set for the analysis were appropriate and scientifically sound; (2) whether relevant empirical studies were adequately captured in the White Paper; (3) whether the methodology used in the White Paper to analyze the data represents an appropriate and scientifically sound application of meta-analytic methods to derive VSL estimates; (4) whether the EPA’s proposed VSL estimates represent reasonable and scientifically sound conclusions; (5) development of a protocol for future updates of the VSL; and (6) whether EPA’s approach to estimating the income elasticity of VSL was appropriate and scientifically sound. In response to the EPA’s request, the SAB convened its Environmental Economics Advisory Committee to conduct the review. The Committee held a public meeting on March 7-8, 2016 and teleconference meetings on June 16 and 17 and August 4 and 5, 2016 to deliberate on the charge questions and develop a consensus report of its findings and recommendations. The Committee’s draft report was reviewed and discussed by the chartered SAB at a meeting on November 30, 2016. This report provides the findings and recommendations of the SAB in response to the EPA charge questions (Appendix A). Key SAB recommendations are highlighted at the end of each section of this report.

¹ Hedonic wage or stated preference studies.

3. RESPONSES TO EPA'S CHARGE QUESTIONS

3.1. Overarching Comments

Transparency of Assumptions Underlying EPA's Approach

The EPA's White Paper describes an innovative approach to developing a composite estimate of the VSL from diverse empirical studies. By necessity, the EPA has confronted a landscape of VSL estimates that are heterogeneous in the methods and approaches used by existing studies in estimating risk trade-offs. Existing estimates in the peer-reviewed literature differ in their conceptual underpinnings, in the year in which they were estimated, and in the subpopulation groups they represent. The process of developing an empirically consistent summary of existing VSL estimates requires converting the published estimates (in this case estimates of a monetary trade-off to reduce the risk of death by a small amount) to a common metric of economic value. This process entails assumptions, and a formal model of rational choice can guide this process so that data manipulations are consistent across studies and estimates within studies. In the absence of such a model, the analyst must use discretion in deciding the concept of value to use and the assumptions to apply in developing the statistical summary, and then the further assumptions to support uses of the statistical summary for estimating the monetary value of human lives affected by policy.

In the White Paper, the EPA has made a series of assumptions to prepare published estimates of VSL for use in the meta-analysis. These assumptions extend the analysis beyond established practices. The assumptions embedded in this extension are not always transparent or essential to develop a summary VSL estimate in constant dollar terms. The assumptions applied, for the most part, would be made as part of the process of customizing the summary VSL estimate to conduct a benefit transfer for a specific policy. Due to the lack of transparency, it is not always possible to distinguish the effects of the added assumptions on the summary VSL estimate. The SAB's specific conceptual and empirical concerns about the methods used to develop the White Paper are explained in this report and recommendations are provided. The SAB encourages the EPA to further develop the meta-analytic methods taking the SAB recommendations into account. In future analyses, the EPA should aim to provide more transparent documentation of the underlying assumptions and methods and greater justification for the methodological choices made. The agency should clearly document the basis of the proposed methods in established approaches from the meta-analysis literature or clearly illustrate the formal econometric and empirical properties of the novel methods proposed.

Preference Calibration

The SAB appreciates the inherent heterogeneity in the set of empirical estimates of the risk trade-offs used to construct VSL measures. It also recognizes that an important dimension of the logic associated with constructing a meta-analytic summary of any set of empirical evidence is the definition of the concept to be summarized. A number of meta-analyses in the environmental economics literature have not been consistent in how measures of different concepts were pooled in their summaries. Some authors have criticized these oversights (Smith and Pattanayak 2002).

One approach for addressing these types of inconsistencies involves assuming a specific form for the representative individual's preference function and then using the assumptions that define the relationships between the parameters of this function and the risk trade-offs concepts measured in each empirical study. These relationships to the structural parameters of this preference function define a set

of moment conditions. This approach would then define the meta-analysis task as a method of moments estimator. The White Paper notes that this type of preference calibration approach is not ready for use in policy guidance. The SAB agrees with this judgment. Preference calibration has not been extensively used in the benefits transfer literature. The sensitivity of the results from such analyses to the set of assumptions maintained in constructing the calibrated models is not fully understood.

One interpretation of the EPA's proposed approach for adjusting the empirical estimates to define a consistent concept for the summary of existing empirical measures for risk trade-offs would maintain it is a form of preference calibration. That is, the transformations to measures of the risk trade-offs build in specific assumptions about the heterogeneity in these estimates. These maintained assumptions include linking a measure of the risk trade-offs to observable population characteristics and describing how risk trade-offs increase with increases in income. The SAB would describe this approach as *partial preference calibration*. The approach is a potentially important innovation to benefits transfer methods. However, the SAB has also concluded it is subject to the *same limitations* that the White Paper identified for *complete preference calibration*.

VSL Terminology

The term "Value of a Statistical Life" has proven to be widely misinterpreted by those outside the economics discipline to mean an intrinsic value of life (e.g., Cameron 2010; U.S. EPA Science Advisory Board 2011). This has led to unnecessary controversy (e.g., Borenstein, 2008; Fourcade, 2009), and has impeded consistent and rational policy on managing mortality risk (e.g., Viscusi, 2009).

The SAB concurs with prior SAB findings and recommendations that: (1) a term such as "Value of Risk Reduction for Mortality" (VRRM) is a more accurate description of the measure and is likely to be better understood by those outside of the economics profession; and (2) that EPA might use tools such as focus groups to determine whether VRRM is a better term for communicating the methodology to non-economists (U.S. EPA Science Advisory Board 2011). As a consequence, the SAB finds that it could be beneficial for the EPA to consider the adoption this new terminology following testing with tools such as focus groups. The proposed change in terminology derives from the fact that VSL can be misconstrued as a measure of the dollar value of avoiding certain death of a single individual and as violation of a tradeoff (money versus human life) perceived by many to be callous. At the same time, the SAB recognizes that the term "VSL" is an established term within the profession, and we do not wish to see a proliferation of such terms. Therefore, we recommend that the EPA work with the research community, other agencies, and professional organizations to consider whether modification of the term is appropriate.

Key Recommendations

- In the White Paper, the EPA has made a series of assumptions that extend the analysis beyond established practices. The assumptions embedded in this extension are not always transparent or essential to develop a summary VSL estimate in constant dollar terms. In future analyses, the EPA should aim to provide more transparent documentation of the underlying assumptions and methods and greater justification for the methodological choices made.
- The SAB finds that a term such as "Value of Risk Reduction for Mortality" (VRRM) may be a better term than "Value of Statistical Life" (VSL) for communication with non-economists. The EPA should work with the research community, other agencies and professional organizations to consider

whether modification of the term “VSL” would lead to better understanding of the concept and therefore be more appropriate terminology for public communication.

3.2. Meta-Analysis Data Set

3.2.1. Evidence of Validity of the Stated Preference Studies

Charge Question 1a. Evidence of validity for stated preference studies: The SAB noted in its earlier advisory report (U.S. EPA Science Advisory Board 2011) that each selected stated preference study “should provide evidence that it yields valid estimates” (page 16). The SAB did not, however, specify how validity should be assessed. In applying these criteria, EPA included studies and estimates that passed a weak scope test or provided other evidence of validity (e.g., a positive coefficient on the risk variable as in the appendix for Viscusi, Huber and Bell 2014) as explained in Appendix B of the White Paper. Please comment on whether the methods EPA used in the White Paper to assess the validity of studies and estimates are appropriate and scientifically sound.

The SAB previously recommended that specific criteria be used in identifying appropriate stated preference studies to estimate the Value of Statistical Life (EPA SAB 2011). In particular, the SAB recommended that the EPA use only estimates with evidence of validity, such as passing a scope test (i.e., showing that willingness to pay increases with the size of risk reduction within or between samples of respondents in a stated preference study). The EPA indicated that it applied the SAB’s recommended criteria in selecting the studies used in the White Paper, and has asked the SAB to comment on whether the methods used to assess the validity of the studies and estimates are appropriate and scientifically sound.

The SAB finds the evidence of validity considered by the EPA in selecting studies for use in the White Paper is incomplete. The following aspects of the methodology for assessing validity should be clarified:

1. Application of the methods to assess study validity should be clarified. It is not clear how the EPA applied the evidence of validity across all studies included in the analysis and whether the same criteria were applied to all studies (both the included and excluded studies).
2. The list of factors considered as evidence of validity is incomplete, especially with regard to study design and administration features. In order to strengthen the assessment of study validity and better inform a weight of evidence decision to include or exclude a study, the SAB recommends that the EPA expand the consideration of evidence of validity to include answers to the additional key questions discussed below.
3. The EPA should clearly document the evidence of validity used to exclude or include studies and value estimates in the analysis. It is not clear how, or if, evidence of validity was used to exclude or include studies and value estimates in the data set used by EPA. Excluded studies and value estimates are identified in the White Paper, but all of the exclusions may not be justified. The White Paper appendix that discusses assessment of validity (Appendix B) is silent on the investigations of validity for some studies. In addition, the threshold for inclusion of studies and value estimates is not clearly stated in the White Paper. This is not a bright line decision, but a consideration of the weight of evidence as discussed below. Thus, it is crucially important that

the EPA fully document the validity evidence considered and how this evidence was used to include each study or value estimate.

4. The characteristics of included studies should be documented. The EPA does not document characteristics of included studies to show that all VSL estimates are estimated using a common metric, nor are the data manipulations employed to transform value estimates to compute the updated VSL clearly documented. The White Paper should be transparent so the analyses are replicable, and clear justifications need to be presented for all data manipulations that are supported by economic theory, previous research, or the estimation procedures used.

Addressing many of the concerns raised above will require a series of carefully crafted appendix tables with the findings in the appendices clearly integrated into the main text of the White Paper.

Charge Question 1a addressed in this section refers to “stated preference studies,” but it is the strong opinion of the SAB that the general considerations discussed in the response to the charge question apply equally to the revealed preference studies used in the analysis to update the VSL, and the general recommendations should be applied to these studies/value estimates as well.

Concept of Study Validity

Validity is not based on a bright-line, valid/invalid criterion. In fact, as discussed below, there are three components of validity and multiple considerations associated with each. Thus, the validity of any study or value estimate for inclusion in the analysis must be based on a weight of evidence consideration of features that support a conclusion of validity or invalidity (Bishop and Boyle, 2016).

The three important concepts of stated preference study validity that should be considered are content, construct and criterion (Carmines and Zeller 1979). Content validity considers the extent to which a study uses established procedures to estimate values, e.g., U.S. EPA’s *Guidelines for Preparing Economic Analyses* (U.S. EPA 2010); construct validity involves the testing of responses to valuation questions to investigate whether they conform with hypothesized relationships (e.g., procedural invariance, convergent validity, tests of scope, etc.); and criterion validity investigates whether value estimates are statistically the same as an estimate of the presumed true value (e.g., comparisons with cash transactions). Each of these types of validity applies to all types of empirical estimates, including the hedonic and revealed preference estimates of VSL. The discussion in this SAB report focuses on applying these concepts to the estimation of nonmarket values.

All studies should consider the validity of the resulting value estimates, but no single validity investigation indicates a value estimate is valid or invalid. Further, there is no perfect study and all empirical estimates likely contain some bias; the presence of bias does not, by itself, indicate a value estimate is invalid. Validity assessment requires consideration of the weight of evidence regarding content, construct and criterion validity and is a matter of judgment based on the weight of evidence. This weight of evidence can include investigations conducted as part of the study that generated a value estimate and can rely on evidence published in the peer-reviewed literature. The SAB recommends clear documentation and application of the criteria used for such evidence of validity.

Evidence of Study Validity

The evidence of validity considered in the current draft of the White Paper includes sensitivity to scope and question ordering effects (i.e., the order of presentation of valuation questions in the stated preference survey should not affect responses and corresponding willingness to pay estimates). These two types of validity investigations are good examples of why any decision on validity requires a careful consideration of the weight of evidence. As explained below, failure to find a statistically significant scope effect and the presence of a question ordering effect are not, by themselves, evidence of invalidity.

It is not clear whether the EPA considered these validity tests for all studies used in the analysis or just for those studies where such evidence was made available by the authors. Therefore, the SAB recommends that in the White Paper, the EPA provide a table that lists the evidence of validity that was available (or not) for each of the studies excluded from and included in the agency's analysis. The EPA should document in this table whether such evidence of validity was used to support exclusion or inclusion of studies and value estimates within studies.

Scope and question ordering effects are examples of construct validity investigations. Evidence of scope and the lack of a question ordering effect (procedural invariance) are evidence of validity. It is logical to expect willingness to pay to increase for a larger reduction in risk and one would not expect value estimates to change within an arbitrary sequence of stated preference questions within a survey.

However, a scope failure or a question sequencing effect, while reason for concern, does not mean a value estimate is invalid. Tests of scope imply structure on respondent preferences that are imposed by the investigators and that may or may not be true (Van Houtven et al. 2011). As further discussed below, screening studies based on specific statistical outcomes can lead to selection bias. Instead, validity of studies should be determined based on the weight of evidence about the methods used and other features of a study. The basic axioms of choice only imply that marginal willingness to pay for a larger reduction in risk should be nonnegative, not that it should be positive and significantly different from zero, or further, proportional to the risk change. Thus, excluding studies with an insignificant scope effect may lead to an overestimation of value. Violation of procedural invariance, due to a question ordering effect, does not establish whether one or both value estimates are biased. In fact, both estimates could be valid within the sequence where subsequent questions were conditioned on previous questions and procedural invariance would not be expected to apply (Carson, Flores and Hanemann 1998). Thus, failure of a test of construct validity typically requires additional investigation to understand if the failure is evidence of invalidity or validity.

Not every study conducts or reports validity investigations. This makes it difficult, if not impossible, to consistently evaluate every stated preference study for evidence of every type of validity based on the available documentation. In order to inform weight of evidence decisions for study/estimate inclusion/exclusion, the SAB recommends that the EPA expand the consideration of evidence of validity to include answers to the following key questions:

1. Was the survey pretested using focus groups, one-on-one interviews, or field pretest?
2. Was the survey applied to a random sample of a clearly specified population?
3. Did the survey clearly define the baseline risk?
4. Did the survey clearly explain the change in risk to be valued?
5. Was the valuation scenario consequential (payment mandatory and valuation response has a non-zero probability of influencing provision of the item being valued)?

6. Was the stated preference question a binary choice framed as a referendum or product purchase?
7. Were robustness checks of the statistical analyses that led to the value estimate conducted?
8. Were construct validity tests conducted?
9. Was the sample of respondents investigated for comparability to the population sampled?
10. Has the study been subject to peer review?

The first six items relate to content validity. Construct validity tests (items 7, 8 and 9) provide evidence of validity in one or more dimensions of the study design and implementation. Construct validity could involve any tests of respondents' understanding of the risk scenario and choice they are being asked to value, as well as modeling assumptions imposed by the analyst. Peer review is evidence of the scientific validity of a study². This broader consideration of validity can inform the weight of evidence supporting the exclusion or inclusion of studies and individual value estimates in the meta-analysis (Bishop and Boyle 2016). Consistent with arguments presented earlier, a study or value estimates need not satisfy every item in the above list to be deemed valid and worthy of inclusion in the EPA's analyses. In fact, it may not be possible to determine that a study or estimate is valid, but it may be possible to decide that there is insufficient evidence to support a conclusion of invalidity and the data are therefore worthy of inclusion in the analyses. In such cases the burden of proof should be on rejecting studies. If the weight of evidence points toward validity the study should be included. The SAB notes that the EPA should develop and use a similar set of criteria for evaluation of hedonic estimates of VSL for inclusion/exclusion in the analyses.

Publication and Selection Bias

The SAB notes that the potential for publication and selection bias is a key challenge to any meta-analysis of economic phenomena. One of the primary areas of emphasis in the meta-analysis literature is the identification and amelioration of such biases (Rosenberger and Johnston 2009; Stanley and Doucouliagos 2012). Screening studies for validity based on empirical scope tests risks can exacerbate the problem of selection bias, potentially leading to mean effect size estimates different from the true underlying values. Studies should not be screened simply on the basis of a specific statistical outcome. As previously noted, a range of study features should be considered in determining validity, and a specific outcome such as scope effect should not be used by itself to invalidate a study. Another concern is that, although publication of a study in the peer reviewed literature may be used as a signal of scientific validity, the EPA's systematic exclusion of unpublished studies could lead to publication bias. One way to partially ameliorate publication bias is to include unpublished studies in the metadata after conducting a transparent and rigorous peer review process (unless there is clear justification for excluding such studies beyond generic and often unverified concerns of study quality). The SAB suggests that the EPA develop a process for peer reviewing studies that have not been published in journals. Other standard bias diagnosis and correction methods can also be used (Rosenberger and Johnston 2009; Stanley and Doucouliagos 2012). Given the availability of measures of standard errors for the studies included in the EPA analysis, the agency has the capacity to diagnose and make corrections for publication bias. Such diagnostics should be performed and used to inform the analysis, particularly with regard to appropriate methods that are applied for the meta-analysis. More generally, the EPA should revisit the study search, reporting, and screening criteria to ensure they meet standards of the meta-analysis literature.

² Publication of studies in the peer reviewed literature is not unquestionable evidence of study validity. Stanley and Doucouliagos (2012) found no detectable difference in quality between published and unpublished studies as measured by the objective statistical criterion of precision.

Judging the Weight of Evidence

Validity decisions need to proceed with caution. For example, the elements of content validity may or may not be reported in a journal article. As noted above, tests of construct validity are not a prerequisite of any individual study and failure of construct validity does not necessarily imply invalidity. While journal articles typically include a theoretical or methodological twist that will provide evidence of construct validity, what is reported in journal articles may be constrained by space limitations and the specific focus of the article. A broader consideration of peer-reviewed and auxiliary supporting documents may provide more evidence of validity or invalidity and lead to the inclusion of studies with more policy relevant value estimates. Thus, decisions on validity need to consider the weight of evidence from the elements in the list above that are documented and available.

There is no precedent in the stated preference literature to establish a standard for what is a valid or invalid stated preference study. The closest analog is the National Oceanic and Atmospheric Administration (NOAA) Blue Ribbon Panel report (Arrow et al. 1993), which lists a large number of validity considerations for contingent valuation (CV) surveys, but does not clearly state that all validity considerations must be met for a study to provide useful information. In fact, the NOAA Panel stated:

“... we try to lay down a fairly complete set of guidelines compliance with which would define an ideal CV survey. A CV survey does not have to meet each of these guidelines fully in order to qualify as a source of reliable information to a damage assessment process. Many departures from the guidelines or even a single serious deviation would, however, suggest unreliability *prima facie*.”

These guidelines were established for studies conducted for estimating nonuse (or passive use) values to support natural resource damage cases filed in court and where the government can recover the cost of conducting the studies from the responsible party, whereas most valuation studies are conducted for academic purposes (or to inform policy decisions where the cost of the studies is a major consideration with hard budget constraints that limit the possible design features). The lack of clear guidance on assessing validity suggests that the EPA needs to make a judgment based on weight of evidence, depending on the objectives of the study, when making validity assessments. Therefore, the SAB recommends careful documentation of studies that meet or do not meet validity criteria as evidenced in the answers to the key questions listed above.

Other Validity Assessments

The discussion above has focused on whether a specific stated preference study or value estimate from a study is valid. There are also broader validity assessments that can be conducted to determine whether a body of literature is valid and whether a method is valid. With regard to method validity, there can be evidence in the literature that establishes whether stated preference design and implementation procedures lead to valid value estimates. These general insights from the literature can provide evidence of validity or invalidity. For example, with regard to consideration of a consequential valuation scenario, a study that contained the key elements of consequentiality might be deemed valid based on the understood wisdom in the peer-reviewed literature even if the individual study did not conduct a statistical investigation of consequentiality. The SAB recommends that weight of evidence assessments of study validity be informed by consideration of the broad stated preference literature and pre-existing meta-analyses of VSL (e.g., Mrozek and Taylor 2002; Lindhjem et al. 2011).

Updating the VSL Estimate

It is important that the knowledge and assessment of study validity evolve through time as research progresses. Future updates of the VSL should consider advancements in the literature pertaining to study design, conduct, and testing relating to validity. For example, a consequential survey design (Carson, Groves and List 2015) was not a central point of discussion in the last update of the VSL, but is a study-design component that should be considered in any contemporary evaluation of a stated preference study.

Such updating does not necessarily exclude older studies. For example, while consequentiality has only entered the stated preference literature in recent years, many, if not most, earlier studies following good practices were consequential. One way to consider consequentiality is to contact investigators and request their survey instruments to evaluate if a binding payment was used and if subjects were informed that their responses would influence provision of the item being valued. The SAB notes that information on the effect of decision making may also be available in cover letters or other front matter that accompanies a survey. Many earlier studies may not have included questions to inquire if subjects considered the valuation exercise consequential so this would be much harder to assess after the studies have been completed.

All future updates of the VSL should simultaneously consider whether the conditions for investigating study validity should also be updated. For example, when VSL was previously reviewed, consequentiality was not a predominant feature for evaluating study validity and it was not standard practice to investigate the sensitivity of meta-analysis estimates to study and value estimate inclusion/exclusion in the estimation. These are important, new features of the VSL updating today and there are likely to be other new innovations in the literature at the time of the next updating of the VSL. The recommendations here are for processes to follow and not hard and fast rules that are invariant over time. The EPA should review the study search, reporting, and screening criteria to ensure they meet standards of the meta-analysis literature.

Key Recommendations

- All criteria for inclusion/exclusion of studies/value estimates should be documented systematically for each study considered, and characteristics of included studies should also be documented along with all data manipulations used to adjust the data for the update analysis of the VSL. In the White Paper, the EPA should provide a table that lists the evidence of validity that was, or was not, available for each of the studies considered for inclusion in the agency's analysis. The EPA should also document in this table how the evidence of validity was used to support exclusion or inclusion of studies and value estimates within studies. The White Paper should also clearly indicate the types of studies other than hedonic wage or stated preferences that were available for use but eliminated by screening criteria. EPA should provide a rationale for excluding these types of studies.
- Consideration of evidence of study validity should be expanded to include answers to the following questions:
 - Was the survey pretested using focus groups, one-on-one interviews, or field pretest?
 - Was the survey applied to a random sample of a clearly specified population?
 - Did the survey clearly define the baseline risk?

- Did the survey clearly explain the change in risk to be valued?
 - Was the valuation scenario consequential (payment mandatory and valuation response have a non-zero probability of influencing provision of the item being valued)?
 - Was the stated preference question a binary choice framed as a referendum or product purchase?
 - Were robustness checks conducted of the statistical analyses that led to the value estimate?
 - Were construct validity tests conducted?
 - Was the sample of respondents investigated for comparability to the population sampled?
 - Has the study been subject to peer review?
- Evidence in the literature can be used to establish whether stated preference study design and implementation procedures lead to valid value estimates. That is, validity need not be solely based on statistical investigations conducted within studies, but also on considerations of the consistency of design, implementation, and analysis features with established practices in the peer-reviewed literature. Therefore, weight of evidence assessments of study validity should be informed by consideration of the broad stated preference literature and pre-existing meta-analyses of VSL.

3.2.2. Construct of the Risk Variable in Hedonic Wage Studies

Charge Question 1b. Construct of the risk variable in hedonic wage studies: The SAB noted in its earlier advisory that the EPA should “Eliminate any study that relies on risk measures constructed at the industry level only (not by occupation within an industry)” (U.S. EPA Science Advisory Board 2011, page 18). It is not clear whether the SAB’s parenthetical addition was meant as an example or as a directive. Only four studies constructed the risk variable by occupation and industry and met other selection criteria. In applying this criteria EPA included studies and estimates where the risk measure is differentiated by industry and at least one other characteristic (e.g., occupation, gender, age). Please comment on whether the hedonic wage studies included in the White Paper constructed the risk variable in a manner appropriate for use in the meta-analysis.

The SAB supports excluding from the analysis those studies that employ fatality risk measures based on industry category alone but finds the current inclusion criterion that restricts the analysis to studies based on risk measures differentiated by industry and “at least one other characteristic” inappropriate. Further differentiating an industry-level risk measure by some additional characteristics, for example age and gender, is unlikely to sufficiently resolve the measurement error problem and may lead to wage-risk trade-off estimates biased by wage discrimination.

The SAB makes the following two short run recommendations to the EPA. First, the SAB recommends that the EPA alter its selection criterion to restrict its analysis to hedonic wage studies that employ fatality risk measures differentiated by occupation. This change would lead to the inclusion of studies that use risk measures based on occupation alone (e.g., Deleire, Khan, and Timmins 2013) as well as those studies based on risk measures differentiated by occupation and another characteristic, such as industry (e.g., Viscusi 2004). Second, the SAB recommends that the EPA include in the White Paper a summary of recent meta-analyses of hedonic wage studies. The summary should provide information about how the results of those studies vary according to study design and data sources (e.g., alternative risk measures, studies without a morbidity risk measure, sub-national geography within the U.S., and possibly studies from other countries). This summary will enable the White Paper to convey the likely

sensitivity of the final VSL summary measure to variations in the set of studies included in the calculations without having to replicate the research efforts completed in those meta-analyses. Recent VSL meta-analyses include: Miller (2000); Bowland and Beghin (2001); Mrozek and Taylor (2002); De Blaeij et al. (2003); Viscusi and Aldy (2003); Kochi et al (2006); Robinson (2008); Bellavance et al. (2009); and OECD (2012).

Enhancing the Quality of VSL Estimates Generated by Hedonic Wage Studies

The SAB finds that research is needed to enhance the quality of VSL estimates generated by hedonic wage studies. The SAB makes two long run recommendations toward this end. First, the SAB suggests that the EPA consider compiling, regularly updating, and making publicly available (e.g., on an internet web page) detailed fatality risk measures by industry and occupation. These should be derived from the U.S. Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI) and merged with appropriate data from the Current Population Survey (CPS). Doing so would sharply reduce barriers to new hedonic wage studies as access to the CFOI data is currently limited to researchers who have completed a cumbersome process with the BLS. By hosting the fatality risk measures on an EPA platform, the agency could resolve one of the largest challenges in conducting hedonic wage studies (e.g., accessing the occupation and industry differentiated risk measures), signal the importance of new research, offer a resource for innovative benefit transfer studies using these data (independent of new estimates of hedonic wage models), establish estimates of baseline risks for policy evaluation, and enhance the quality of future updates of the VSL.

Second, the EPA should use the above-mentioned data to apply a consistent hedonic wage model to all of the available years of data to generate comparable annual measures of VSL. Since publication in primary economics journals favors innovation in methods rather than replication, such research is unlikely to be carried out solely to generate comparable measures of VSL. Comparisons among these annual VSL estimates could yield an estimate of the income elasticity of the VSL (IEVSL), recognizing that worker income, not per-capita Gross Domestic Product (GDP), would be the relevant income measure and that additional assumptions are needed for the annual changes in the equilibrium wage-risk trade-off to reflect the income elasticity of the VSL. The SAB recommends that this analysis be regularly updated as new data become available. This analysis would be relatively inexpensive to conduct, could be done by EPA staff or by other researchers, and would assist EPA in systematically updating its estimates of the VSL and IEVSL over time.

Additionally, the SAB identifies the following two areas of research that would improve the quality of future updates of the VSL.

1. The first broad category includes research that examines the potential biases associated with hedonic wage studies. The SAB notes that the VSL obtained from hedonic wage studies may differ systematically from the VSL obtained from stated preference studies; it is also based on a sample of workers, not the whole population. The following four potential issues are noted.
 - Limited worker awareness of risks or limited worker mobility across jobs could lead the hedonic VSL to understate workers' true preferences. Worker misperception of risk could also lead to underestimation of the VSL.
 - Sorting of risk-averse workers into safer jobs could lead the hedonic VSL to understate the average preferences of the whole population.

- The hedonic sample includes only employed individuals, who may have systematically different risk preferences than the rest of the population due to, for example, higher incomes. These selection effects could lead the hedonic wage model to overstate or understate the average preferences toward risk reductions for the whole population.
 - The VSL estimate from hedonic wage studies relates to an estimate of the marginal rate of substitution that, under ideal conditions, holds non-wage income constant. As such it can be interpreted as a measure of Marshallian willingness to accept (WTA) a marginal increase in fatality risk. In contrast, the VSL estimate from stated preference studies can be interpreted as the Hicksian willingness to pay (WTP) for a marginal reduction in fatality risk. In general, it is expected that WTA measures will be larger than WTP measures. In the near term, the EPA should acknowledge the differences between these measures. In the future, the EPA should determine how to develop a framework that recognizes the underlying differences in the way these estimates are obtained and how they should be combined. With regard to the VSL estimate, it is difficult to state *a priori* the direction of the relationship between these different measures. The SAB notes that the approach described in Smith et al. (2006) could be used to assess the magnitude of the difference between these two measures in order to determine the importance of this issue.
2. The second research category includes studies that examine the underlying factors that help to explain differences in VSL estimates across hedonic wage studies employing different risk measures. Viscusi (2004) examines both an industry-only risk measure and an industry and occupation risk measure using the same sample and the same model. The results run counter to the classical measurement error model, which predicts lower impacts for the industry-only risk measure because everyone in the same industry is mistakenly assigned the same risk. Instead, the industry-only VSL results are twice as large as the industry and occupation results. Understanding why these differences occur could provide guidance on the appropriate risk measures to consider including in future updates of the VSL.

Key Recommendations

- In the short run, the SAB recommends that the EPA alter its inclusion criterion to restrict its analysis to hedonic wage studies that employ fatality risk measures differentiated by occupation. This change would result in the inclusion of studies that use risk measures based on occupation alone (e.g., Deleire, Khan, and Timmins 2013) as well as those studies based on risk measures differentiated by occupation and another characteristic, such as industry (e.g., Viscusi 2004).
- In the long run, the SAB recommends that the EPA apply a consistent hedonic wage model using data from the CPS and CFS to generate comparable annual measures of VSL. Comparisons among these annual VSL estimates could yield an estimate of the income elasticity of the VSL (IEVSL). The SAB recommends that this analysis be regularly updated as new data become available.

3.2.3. Estimates of Value of Immediate Risk Reduction

Charge Question 1c. Estimates for immediate risk reductions: To estimate the average value of the marginal willingness to pay for reduced risk of immediate death, the EPA selected estimates from the stated preference literature that are most closely comparable to the accidental deaths

from the hedonic wage literature. The EPA made several judgment calls in determining the appropriate estimates to use from the stated preference literature. Specifically, Viscusi, Huber and Bell (2014) estimate reductions in risk of bladder cancer that will occur in 10 years. The authors discount the estimates to derive a comparable estimate for an immediate risk reduction. Alberini, et al. (2004) estimate a willingness to pay for an annual reduction in risk over 10 years. We include estimates from both of these studies in the meta-analysis. Please comment on whether appropriate estimates from the stated preference literature were used in the White Paper to estimate the marginal willingness to pay for reduced risk of immediate death.

The SAB was asked to comment on whether the agency selected appropriate estimates from the stated preference literature for its analysis of willingness to pay for reduced risk of immediate death. As discussed in Section 3.2.4 of this report, the SAB has provided citations for several additional VSL studies that could be included in the White Paper. In addition, the SAB finds that the supplementary analysis in one of the studies selected by the EPA for use, Viscusi, Huber, and Bell (2014), does not provide clear evidence of study validity (i.e., sensitivity of scope).

Use of a Benefits Transfer Approach

The SAB finds that, as in other areas of environmental valuation, the limited available VSL literature points to use of a benefits transfer approach. EPA should consider using best practice benefits transfer methods that employ principled adjustments in existing estimates to fit the particular policy problem of interest. In contrast, meta-analysis relies heavily on a statistical weighting of evidence to produce a single value.

The SAB recommends broadening the scope of studies the EPA uses to derive values for reducing both mortality and morbidity risks. There are a significant number of published studies that estimate willingness to pay for improved health and reduced health risks (see studies listed in Appendix B of this report). There also is a burgeoning literature on benefit-risk and risk-risk trade-off preferences in health and health care that could provide a basis for enriching the evidence base on risk preferences and providing support for benefits transfer applications (see studies listed in Appendix C of this report). Unlike the expected small increments in the VSL literature over the foreseeable future, there is a strong demand and growing funding for stated preference benefit-risk studies in health and health care as the result of recent U.S. Food and Drug Administration (FDA) regulatory guidance on conducting such studies (U.S. Department of Health and Human Services 2015).

Other Concerns about the Estimation of Willingness to Pay for Reduced Risk of Immediate Death

The SAB also notes the following additional concerns about EPA's general approach to estimation of willingness to pay for reduced risk of immediate death.

1. The risk of immediate death is not a policy-relevant outcome. Virtually all deaths of policy interest occur with latency and are preceded by a period of morbidity and disability, including potential pain and discomfort associated with treatment as well as the ultimately fatal condition itself. It is desirable to distinguish values based on short-term versus long-term effects.
2. Simple discounting does not account for confounded morbidity values in converting future deaths to equivalent immediate-death values. Cameron and DeShazo (2013) estimate the stated preference willingness to pay to reduce risks of different illness profiles. With a discount rate of

3%, willingness to reduce the risk of sudden death corresponds to a willingness to pay of \$8.33 million per microrisk (in 2003 U.S. dollars). Illness preceding death adds a morbidity premium, as willingness to pay to prevent one year of sickness before death is valued at \$9.22 per microrisk. Gentry and Viscusi (2016) derive a morbidity-component value of up to 25% of total VSL from the CFOI data for non-instantaneous deaths.

3. Survey respondents may not be able to precisely evaluate long-latency risks, particularly when there is considerable uncertainty regarding timing of conditions, so value estimates of future risks may be imprecise.
4. EPA used estimates of willingness to pay for reduced risk of future death (Viscusi, Huber, and Bell 2014). In this study the authors estimate reductions in risk of bladder cancer that will occur in 10 years. A discount rate of three percent was applied to derive a comparable estimate for an immediate risk reduction. The SAB finds that the selection of a three percent discount rate is arbitrary.

Key Recommendations

- The SAB recommends that the EPA broaden the scope of studies used to derive values for reducing both mortality and morbidity risks. There are a significant number of published studies that estimate willingness to pay for improved health and reduced health risks, a burgeoning literature on benefit-risk and risk-risk trade-off preferences in health and health care, and transportation literature on reduced risk for highway fatalities that could provide a basis for enriching the evidence base on risk preferences and providing support for benefits transfer applications.
- The SAB recommends that EPA account for morbidity values in converting future mortality risks to equivalent instantaneous risks.

3.2.4. Empirical Studies

Charge Question 2. Please comment on whether relevant empirical studies in the stated preference and hedonic wage literatures are adequately captured in the White Paper. If additional studies should be included in the White Paper, please provide citations.

The SAB finds that there has been little growth in the number of studies used by EPA to estimate the VSL since the last consideration of this topic by the SAB in 2011. The SAB recommends that EPA search more broadly for additional studies not restricted to hedonic or stated preference methods. This could include an evaluation of whether studies using experimental or quasi-experimental methods may offer insight to VSL. The SAB suggests that the EPA consider the following additional VSL studies: Ashenfelter and Greenstone (2004); Davis (2004); Deleire, Khan, and Timmins (2013); Viscusi and Gentry (2015); and Gentry and Viscusi (2016). While these studies differ in methodology, data, or approach from studies already included, the SAB finds that they offer potentially valid insight to estimation of VSL. If any of these studies are excluded the EPA should provide a justification for their exclusion. The SAB also suggests that the EPA consider hedonic studies other than those related to hedonic wage rates. The EPA may need to commission more studies or create other incentives for new studies in order to improve the prospect for a deeper literature to support future reviews of VSL. The SAB also notes that the pool of stated preference questions could be expanded, perhaps by adding

relevant questions to national panel studies like the National Longitudinal Surveys (U.S. Bureau of Labor Statistics 2016), although there may be consequentiality concerns associated with this approach.

In considering whether relevant studies are adequately captured in the White Paper, it is important to recognize a number of limitations related to the scope of hedonic wage studies, particularly with regard to forms of sampling bias and the ability of these studies to provide a nationally representative estimate in the absence of assumptions needed to extrapolate from subpopulations included in published studies to a broad national population. As previously discussed, hedonic wage studies exclude non-workers, so the EPA should address the implications of using studies that fail to address individuals' choices of whether to work, rather than a near-exclusive focus on valuation derived from choice among different jobs with different risk levels. The SAB suggests that the EPA consider using hedonic wage studies that apply data other than the CFOI data and acknowledge concerns that studies based on survey data may be subject to non-response biases. The SAB finds that the CFOI data represent the minimum quality of data that should be considered. Therefore, the EPA should identify other data sources of similar or higher quality that may provide a valid foundation for estimation of VSL.

The SAB also provides specific recommendations concerning clarification of the study selection process and potential limitations of studies used in the White Paper. The White Paper should contain more detail or information, likely in appendices, that would allow readers to assess how the reliance on published studies, particularly other meta-analyses (including studies that drew from international data), might lead to results that differ due to publication bias, lags in publication, data sources included, methodology relied upon, or other concerns. Additional information is needed in the White Paper to more clearly indicate the types of studies, other than hedonic wage or stated preferences, which were available for use but eliminated by screening criteria. The SAB notes that existing meta-analysis studies might provide insight into the foundation for maintaining or altering study screening criteria.

Key Recommendations

- In the White Paper the EPA should address limitations of hedonic wage studies, particularly with regard to forms of sampling bias and the ability of these studies to provide a nationally representative estimate in the absence of assumptions needed to extrapolate from subpopulations included in published studies to a broad national population.
- The EPA should consider commissioning more studies or creating other incentives for new studies in order to improve the prospect for a deeper literature to support future reviews of VSL.

3.2.5. Population Weighting in EPA's Analysis

Charge Question 3. Some estimates in the meta-analysis data set in the White Paper are constructed by weighting subpopulation-specific estimates within a study in order to approximate an estimate for the general population. The specific weights used are described in Appendix B of the White Paper. Please comment on whether the population-weighting approach used in the White Paper is appropriate and scientifically sound.

Key Concerns about the EPA's Weighting Approach

The SAB recognizes that it is well-established practice to use subpopulation weights to account for sampling weights (or sampling effects) in well-designed valuation studies when researchers have used

(for example) stratified random sampling to assure that with reweighting, data underlying an original study provide a representative sample of a target population. This conventional use of sample weights is intended to recover a representative estimate of the value for a parameter describing some feature of the population, such as the population mean income or age. The SAB identifies the following three key concerns with the EPA's approach in the White Paper. These concerns lead to the recommendation (further discussed below) that the EPA distinguish weighting implemented to adjust for any potential sampling bias in original studies from calculations implemented to leverage sample estimates through benefit transfer. In the case of benefit transfer, the primary purpose is application of value estimates drawn from one population to provide estimates of the same value concept for a different population or subpopulation.

1. As further discussed below, the EPA should be sure that the population or subpopulation weights used to serve as estimates of sampling weights are drawn from Census or similar sources that are contemporaneous with the time that data in an original study were generated. The White Paper appears to describe a process where the weights were selected for different years from those when the original sample was taken, implying the objective was to reflect estimates of statistics for a different population.
2. The White Paper documents that the EPA has relied upon some studies that are based on samples where an economic decision conditioned the eligibility for inclusion in the sample. For example, a sample of those working at a particular time implies the decision to work affected inclusion in the sample. These samples may be subject to selection bias. In the case of samples involving employed people, the estimates for compensation to accept risks omits non-working individuals (unemployed, underemployed, retired, etc.). The purpose of using sampling weights should be clarified in the White Paper and, as previously indicated, such weights should be drawn from population data that are contemporaneous to the samples underlying the original studies.
3. The SAB is concerned that some calculations in the White Paper used population weights in the context of a benefit transfer; this appears to be a misleading characterization of the motivation for the use of population weights. The EPA should explicitly point out any manipulations motivated by a benefit transfer purpose. For example, in using hedonic wage studies, the EPA transfers estimates based on worker populations for applications to non-worker subpopulations. The White Paper should be clear regarding the source of a valuation estimate being transferred from one population or subpopulation to another in order to establish a foundation for deriving an estimate that is representative of the value for the target population. After transfer, if weighting is used, the weighting should be consistent with the recommendations discussed in this section. The EPA should not confound calculations of benefit transfer with calculations to recover a representative value by controlling for sampling bias or sampling weights.

General Comments on the EPA's Weighting Approach

The SAB previously recommended that the EPA select studies that are representative of populations affected by EPA regulations (EPA SAB 2011). Given the limited VSL literature, the SAB recognizes the need to develop an approach to use subpopulation estimates of VSL in the EPA's analysis. The SAB recommends that EPA provide detail sufficient to: (1) allow a third party to replicate the approach; and (2) distinguish between the use of population weights to derive a representative estimate of the VSL observation drawn from the sample used in a particular study and the strategy (not necessarily using population weights) used to transfer benefit estimates from a source study to estimate the VSL for some population (or timeframe) not directly addressed by the source study. That is, the White Paper should

provide additional explanation of how population weighting was actually done and the strategy used by the EPA to bring together observations (or estimates) drawn from several studies to create the aggregate estimate. Adequate information should be provided to enable a reader to replicate the results. In particular, the following issues should be addressed.

1. In many cases, the EPA's approach to weighting focused on deriving an estimated mean. The White Paper should provide a more detailed explanation of how population weighting procedures would affect estimates of standard errors (distinguishing between procedures to derive a nationally representative estimate from a study and procedures to transfer information from a subpopulation considered by a particular study for application in another context) and assess the effects of these procedures on estimates of VSL and standard errors.
2. Subpopulation weighting may not account for all of the potential sources of selection bias that could result in exclusion of some members of the intended population (by choice of authors of original studies, by response bias, or other known factors contributing to selection bias). The White Paper should more explicitly address the implications of selection bias that may be present in studies used or excluded. Furthermore, EPA should distinguish the use of weights to adjust for sampling or response bias associated with observable characteristics from how (or whether) the EPA has been able to account for selection bias due to unobservable characteristics, such as individuals' risk attitudes.
3. Weighting approaches should give much greater consideration to details of the specific studies being weighted. Appendix B in the White Paper mixes discussion of two kinds of procedures, population weighting and benefit transfer. In some cases (e.g., contingent valuation studies) the weighting procedure used by the EPA is comparable to using approximations for sampling weights. However, the procedure used for the hedonic wage studies is a benefit transfer. It is important that population weighting be accomplished using standard procedures and that benefit transfer assumptions and procedures for implementation be described and distinguished.
4. Several of the studies do not provide representation across all possible groups (age, income, employment, ethnicity, agricultural workers, etc.) that necessarily compose a truly representative sample. The White Paper should discuss the implications of the resulting limitations of source studies and clearly describe any procedures or calculations that EPA implemented to mitigate these limitations or implications.
5. As previously mentioned, weights should be tied to the time period of the original study, at least for the development of a representative estimate supported by that study, while aggregating available estimates across studies to obtain an overall estimate for 2013. This raises questions, which will be discussed further below, of whether weights should correspond to the sample the study is intended to represent or to the full U.S. population.

Specific Comments on the Weighting of Subpopulation Estimates

The SAB provides specific comments on the manner in which the weighting of particular estimates was conducted by the EPA to accomplish the benefit transfer purpose and adjust for sampling procedures to create the VSL estimate for a representative population.

There are two sets of weights that affect the estimates in the White Paper. The set of weights described in the body of the White Paper concerns the weights applied to the various summary statistics describing VSL estimates from each study. The second set of weights is discussed primarily in Appendix B of the White Paper. It appears that the process discussed in Appendix B was not used in all studies. The first mention of these weights is on page 50 of the White Paper and relates to the Cameron, DeShazo, and Johnson (2010) study where the 28 estimates reported in Tables 4 and 5 of that study were summarized. These estimates are distinguished based on number of children, respondents' gender, age, and marital status. The discussion in the White Paper suggests that the 2010 U.S. Population Census was used to develop a weighted average of the 28 estimates. However, the SAB notes that the Cameron–DeShazo survey was conducted in December 2002. The SAB questions why the EPA did not use the 2000 Census to develop the weighted average. The SAB also notes that the discussion in the background material of the Cameron–DeShazo research indicates that the Knowledge Networks Panel used for the research was representative of the 2000 census. Therefore, Knowledge Network weights could also have been used. As previously indicated, when population weighting is necessary to develop an observation of a representative VSL from a source study, the SAB recommends that the EPA use population weights that are drawn from data (for example the U.S. Population Census) available for a time that is, to the extent practicable, contemporaneous to the data used in a source study.

In addition, the SAB finds that clarification of the weighting process is needed with regard to the following specific issues.

1. Some stated preference surveys used in the White Paper are based on samples but do not report averages for subpopulations. It is not clear whether this is the reason why no weights were applied in these cases.
2. Estimates from the Cameron, DeShazo, and Stiffler (2013) study used in the White Paper were also based on the 2002 samples. Again, 2010 weights were used but the demographic allocation was different. It is not clear whether the weights reconciled. Moreover, the EPA should state what sampling weights were used by the authors of the original studies.
3. The Cameron and DeShazo (2013) study is again based on the same 2002 sample. The weighting approach described on page 55 of the White Paper should be clarified. It notes that “The first four estimates were weighted with each of the last five estimates such that six estimates were used to calculate each weighted average.” As previously recommended, EPA should provide information to enable readers to distinguish population weighting used to develop a representative estimate from a source study (using available estimates pertaining to particular subpopulations) from procedures and calculations (adjustments) the EPA used as part of a benefit transfer strategy.
4. The weighting process is more complex for the hedonic wage studies. For the Viscusi and Aldy (2007) study, VSL measures were constructed for each of 5 age groups. Although separate hedonic wage models were estimated for 1998, the weights appear to be for 2013 for the entire population. No adjustment was made to account for the difference between those who are working and those who are not (for a variety of reasons). As a result, in this case the weights appear not only to be for the wrong year but the wrong population. This approach mixes a benefit transfer issue (assuming non-workers have the same VSL as workers) with the construction of a population mean based on a sample. The SAB has similar concerns about the EPA's weighting of the Aldy and Viscusi (2008) estimates and the weighting of any of the other hedonic wage

estimates based on subpopulations. These observations provide examples illustrating the need to distinguish the use of population weighting for the standard purpose of sample weighting to derive a representative value from a particular study from explicit (or implicit) assumptions applied to implement a benefit transfer strategy or calculation.

Improving the Population Weighting Approach

In order to decide how much effort should be devoted to weighting subpopulations, the EPA could first determine whether there are large variations in VSL across subpopulations relative to variation across individuals. To improve the population weighting approach, future work could then be undertaken to investigate the possibility of developing a set of subpopulation weights and benefit transfer strategies that build upon what is known about the subpopulations covered in each of the available studies (whether currently included in analysis or not) in order to derive additional input to (or observations for) the estimation of VSL. An approach based on such studies could eliminate the need for the screening criterion that studies necessarily provide a foundation, on their own, of a representative, population-weighted estimate of VSL. This approach could broaden the foundation for estimation of VSL by enabling the use of a wider spectrum of available studies to derive VSL estimates for subpopulations. Meta-regressions over VSL estimates drawn from a larger set of studies, each of which might focus on subpopulations, could be conducted to develop a function that would allow adjustment for representativeness of the whole population. This approach could also be used to identify studies that appear to offer outliers in estimation, and then further consider whether there is reason to believe those studies may nonetheless offer valid insight to a portion of the distribution of values that may not be available from other studies. Such a meta-analysis would include statistical controls for methodological choices of the authors of studies.

An investigation of the feasibility of developing such an approach would involve consideration of the following questions:

1. Is it feasible to develop a weighting approach that builds upon multiple studies to improve estimation of VSL specific to many subpopulations of the U.S. and then aggregate such subpopulation estimates to reach an improved, broadly representative estimate?
2. Would such a process be aided by including information from scientifically sound studies that focused on narrower groups (e.g., specific subpopulations), rather than setting the criteria for the included studies to arise from a broadly representative sample?

The SAB finds that such an approach could offer the advantage of including more information from more studies that may meet appropriate screening criteria while relaxing the requirement for a national focus at the level of the original studies used to support a nationally representative population estimate. If the EPA develops a strategy for drawing from studies targeting specific subpopulations in order to develop additional observations of the VSL for the national population, the agency should indicate how its calculations identify and manage any variation in VSL across subgroups. This approach would improve the resulting estimate which would be based on a wider foundation of the literature. This could raise confidence in benefit-cost analysis sufficiently to justify the loss of transparency involved. The SAB notes, however, that if there are systematic variations in VSL across subgroups, computing and applying a nationally representative VSL may not be appropriate for some regulations. If some groups are more exposed to risk than others, the national VSL may be biased.

Key Recommendations

- The White Paper should provide further explanation of how the weighting of subpopulation-specific estimates was actually done and how the studies were brought together for the aggregate estimate. The EPA should provide sufficient documentation to allow an independent party to replicate the analysis. This might be done in an appendix, perhaps with supporting information (e.g., a spreadsheet) that offers specific mathematical formulae used. In particular, the White Paper should:
 - Provide a more detailed explanation of how weighting procedures would affect estimates of standard errors.
 - More explicitly address the implications of selection bias as related, for example, to an individual's decision to work (in hedonic wage studies) or to any potential response bias (in stated preference studies).
 - Give much greater consideration to details of the specific studies being weighted. Appendix B mixes discussion of two kinds of procedures, population weighting and benefit transfer. It is important that population weighting be accomplished using standard procedures and that benefit transfer assumptions be described and distinguished from weighting used to develop a representative estimate of VSL.
 - Tie weights to the time period of the original study (at least for the development of a representative estimate supported by the original study) while aggregating available estimates across studies to obtain an overall estimate for 2013.
 - If income was used to form sampling weights, then population weights to obtain a representative sample may involve using income as a demographic variable to develop a representative estimate for a study population. This recommendation is not intended to suggest that the derivation of representative estimates necessarily apply an income elasticity adjustment; rather, this recommendation concerns the statistical use of income as a demographic variable.

3.2.6. Estimation of Standard Errors

Charge Question 4. In some cases, EPA estimated standard errors in the White Paper using information within studies or provided by the study authors, as described in Appendix B. Please comment on whether the methods used in the White Paper to estimate standard errors when such information was not readily available are appropriate and scientifically sound.

There are two major aspects of Charge Question 4 that must be addressed. One is related to how the standard error of the VSL is calculated in situations when the standard error is not reported in the original study. The second, perhaps more important, aspect of the charge question is related to the methods the EPA used to estimate standard errors for the VSL estimates in the White Paper.

Calculation of the Standard Error of the VSL when it is Not Reported in the Original Study

The White Paper does not provide sufficiently detailed information about how the standard error of the VSL is calculated in situations where one is not reported in the original study. The SAB suggests that the White Paper provide a detailed description of the method, including the formula. In particular, the SAB suggests that the EPA provide the following additional information in the White Paper.

1. For several stated preference studies, including Corso, Hammitt, and Graham (2001) and Viscusi, Huber, and Bell (2014), the White Paper states that standard errors for the reported VSL estimates were calculated using the confidence intervals reported by the authors. However, the White Paper does not provide details about how this was done. For example, under some assumptions, one can calculate the standard error (se) of a VSL estimate (\widehat{VSL}) based on its 95% confidence interval using the following formula:

$$se(\widehat{VSL}) = \frac{\overline{VSL} - \widehat{VSL}}{t_{0.025}(n)} \quad (1)$$

where \overline{VSL} is the upper bound of the 95% confidence intervals, and $t_{0.025}(n)$ is read off as the 2.5 percent point of the t -distribution with n degree of freedom. The White Paper should describe the method it uses to translate confidence interval to standard error estimates.

2. For the Cameron, DeShazo, and Stiffler (2013) study, the White Paper states that “[w]e approximated the standard errors of the weighted VSL estimates using the graphical information provided in an on-line appendix referenced in Figure 3 of the original study. We enlarged each graphic to visually identify an approximate point estimate for the 5th and 95th percentiles associated with each WTP estimate. We then used this information to calculate a standard error for each estimate.” The SAB recommends that the EPA contact the authors to obtain the data instead of visually identifying an approximate point estimate for the 5th and 95th percentiles.
3. In several cases, the White Paper calculated standard errors for mean willingness to pay when the original study reported variance for median willingness to pay. The SAB recommends that in the White Paper the EPA provide a detailed explanation of how this was done.
4. For hedonic wage studies, the White Paper notes that the standard error of the VSL is calculated “based on the standard error of the risk coefficient alone.” However, the exact formula used is not provided. The SAB recommends that EPA include this information in the White Paper. If the study provides the average wage information, then there is sufficient information available to accurately calculate the standard error of the VSL. Specifically, assuming a log linear specification and that each worker works 50 weeks per year (i.e., treating this as a constant) for average wage \bar{w} , let $\hat{\beta}$ represent the estimated coefficient on the occupational fatality risk variable (i.e., the estimate of the true parameter β) and $se(\hat{\beta})$ its standard error. Assume risk is measured as the number of fatalities each year per 1,000 workers in the occupation-industry category. The estimated VSL is then given by (Aldy and Viscusi 2008):

$$\widehat{VSL} = 1,000(50)(\hat{\beta})(\bar{w}) = 50,000\hat{\beta}\bar{w}. \quad (2)$$

This equation normalizes the VSL estimate to an annual basis by assumption of a 50-week work-year and by accounting for the units of the mortality risk variable. If the sample mean of wage provides an accurate estimate of the average wage \bar{w} , the standard error of the VSL is given by:

$$se(\widehat{VSL}) = 50,000 \bar{w} se(\hat{\beta}).$$

On the other hand, if the sample mean of wage does not provide an accurate estimate of the average wage \bar{w} , and the original study treats the average wage estimate \bar{w} as a random variable and provides a standard error estimate for \bar{w} ,³ the standard error of the VSL is given by:⁴

$$se(\widehat{VSL}) = 50,000 \sqrt{\{[se(\hat{\beta})^2 se(\bar{w})^2 + E(\hat{\beta})^2 se(\bar{w})^2 + E(\bar{w})^2 se(\hat{\beta})^2]\}}.$$

Methods for Estimating the Standard Error for the VSL

It is extremely important to provide accurate standard error estimates for the VSLs because standard errors are used to select the “preferred” model and the non-parametric estimate of the VSL. The SAB has reviewed the methods used in the White Paper to estimate the standard errors for the VSL estimates and finds that the analysis could be clarified and improved by addressing the following issues.

1. Given the important role that standard errors play, the SAB finds that the White Paper does not provide detailed enough information about how standard errors of VSLs are estimated. There are only two short paragraphs that discuss the methods used to estimate the standard errors for the non-parametric VSL estimates (Section 4.1.1 of the White Paper). The methods used to estimate the standard errors for the parametric VSL are not discussed at all.
2. The SAB finds that there are alternative, theoretically better, approaches (discussed below) to estimate standard errors for the VSL estimates.
3. For the non-parametric approaches, the White Paper suggests five approaches/weighting methods for estimating the VSL. For each approach, the white paper uses a bootstrap method to estimate the standard errors of VSLs. The SAB finds that, because the discussion of the bootstrap methods is so brief, it is unclear how this is implemented. For example, the paper states that “[t]o maintain the within-group correlation structure among the observations, we randomly drew I sets of groups with replacement from the primary sample of grouped observations. We did not re-sample observations below the top (group) level (Davison and Hinkley 1997 p 100-101, Ren *et al.* 2010).” (p. 25). It is not clear how each I set of groups was drawn and why observations below the top level were not re-sampled. The meaning of “group/data sample” is unclear. In footnote 11 on page 20, the White Paper states that “Hammit and Graham (1999) and Corso, Hammit, and Graham (2001) each examined four samples.” However, when looking at the last column of Table 6 on page 17, it appears that Hammit and Graham (1999) examined only one sample and Corso, Hammit, and Graham (2001) examined three samples. It is important to provide a clear definition of groups.
4. The SAB has conceptual concerns about bootstrap approach used in the White Paper to estimate standard errors for non-parametric VSL estimates. When the bootstrap approach is used, it seems that the estimated standard error reflects the variance of VSL estimates among the sample; it does not reflect the deviation of the VSL estimate from the true VSL. Conceptually, the accuracy of VSL estimates from individual studies used in the White Paper should affect the accuracy of

³ It should be noted that the sample standard deviation of wage might not provide a good estimate of how the mean wage estimate \bar{w} deviates from the real average wage.

⁴ The calculation assumes β and w are independent random variables and makes use of the following formulas. The variance of the product of a constant a and a random variable X is given by $a^2 var(X)$. The variance of the product of two independent random variables X and Y is given by $var(X)var(Y) + var(X)[E(Y)]^2 + var(Y)[E(X)]^2$.

the VSL estimates. This means that standard errors of individual VSL estimates should affect the standard error of the overall VSL estimate. However, the bootstrap estimates of the standard error do not use the standard error estimates from the individual studies at all.

5. The SAB finds that there is an alternative, perhaps theoretically better, way to calculate standard errors for each non-parametric VSL estimator. Specifically, by definition, the standard error of a non-parametric VSL estimate equals

$$\begin{aligned}
 se(\widehat{VSL}) &= [E(\hat{y}) - E\hat{y}]^2]^{1/2} = \left[E \left(\sum_{i=1}^I \sum_{j=1}^{m_i} w_{ij} (y_{ij} - E y_{ij}) \right)^2 \right]^{1/2} \\
 &= \left[\sum_{i=1}^I \sum_{j=1}^{m_i} w_{ij}^2 (\sigma_{\eta}^2 + \sigma_{\mu}^2 + se_{ij}^2) \right]^{1/2} \tag{3}
 \end{aligned}$$

Thus, once the variance of the group-level non-sampling errors (σ_{η}^2), the variance of the observation-level sampling errors (σ_{μ}^2), and the sampling error variance for observation j from group i (se_{ij}^2) are estimated, one can use the above formula to estimate the standard error of the VSL estimate directly. The SAB recognizes the challenges in estimating σ_{η}^2 and σ_{μ}^2 , but the proposed approach has three main advantages: (1) it is based on theory, (2) it is consistent with the weighting strategy used, and (3) it uses the standard error estimates from individual studies.

6. The SAB finds that the White Paper does not currently provide any discussion about the approach used to estimate the standard error of VSL estimates for the hedonic wage approach. It is assumed that the standard error of β_0 from the hedonic wage equation regression is used as the standard error of the VSL estimate. Again, it seems that the standard error of β_0 reflects the variance of VSL estimates among the sample; it does not reflect the deviation of the VSL estimate from the true VSL. Alternatively, because the hedonic wage regression provides estimates of σ_{η}^2 and σ_{μ}^2 , one can calculate the standard error of the VSL estimate by using equation (3) above.

3.3. White Paper Analysis

3.3.1. Overall Methodology for Analyzing the Data

Charge Question 5. Please comment on whether the methodology used in the White Paper to analyze the data represents an appropriate and scientifically sound application of meta-analytic methods to derive generally applicable VSL estimates for environmental policy analysis.

In general, the SAB finds that developing a statistical summary of VSL evidence from the literature is an appropriate approach to deriving applicable VSL estimates. However, the SAB has concerns about the transformations used in developing the basic data for the statistical summary reported in the White Paper. The SAB recognizes that a summary necessarily confronts the task of developing consistent estimates of the response measure or “effect size” that is summarized when the source information is heterogeneous in the timing of the estimates, the methods used, and the concepts being measured.

The SAB agrees that certain adjustments to the VSL estimates from the source studies are useful and defensible to assure as much consistency as possible before applying the statistical methods used in developing the summaries. The SAB supports adjustments to address some of the heterogeneity arising from differences in the cost of living using price indices. In addition, because the underlying VSL studies use different methods to measure consumers' responses to risk, they sometimes provide estimates of different economic concepts that characterize the trade-offs in distinctive ways. For instance, the hedonic studies estimate Marshallian values (holding income constant) for marginal changes in risk and the stated preference studies estimate Hicksian values (holding utility constant) for discrete (non-marginal) risk changes. The SAB finds that it is important for the EPA to evaluate the sensitivity of the statistical summaries to the decisions made in transforming the primary estimates to address these types of differences in the economic concepts being measured. This evaluation necessarily precedes any selection of a specific transformation that would be applied to estimates before computing a general summary measure for VSL that would be used in a wide range of policy applications.

Some of the adjustments made by the EPA to VSL estimates from the source studies appear to be benefit transfers and thus are not unambiguously appropriate as part of constructing the input data for the meta-analysis. As discussed in the response to Charge Question 9, some adjustments proposed in the White Paper are a form of partial calibration that has not been evaluated in the literature. More analysis and evaluation will be needed to determine whether these practices are appropriate. In the interim, benefit transfer calculations should be identified more clearly and justified explicitly. The SAB recommends that a distinction be made between the adjustments that more appropriately fit within the domain of benefits transfer, as part of sensitivity analyses of results for analysis of a specific rule, and adjustments that are built into the overall summary measure that is used as the starting point for the evaluation of risk trade-offs in all subsequent policy analyses. In the first case, associated with benefit transfer tasks, adjustments are made using specific modeling assumptions to predict mortality risk values for populations with different characteristics than those in the source study. They include adjusting individual VSL estimates to account for differences in income or, in some cases, to combine estimates for different demographic groups with specifically defined weighting approaches. All of these details should be enumerated as part of describing the scenarios being considered. As a result, the assumptions are identified and the alternative outcomes displayed. This approach encourages a transparent description of what is derived from the empirical record and what is assumed as part of the required adjustments.

Many of the transformations to the empirical estimates in the White Paper are transformations of the primary VSL and related measures prior to including each of the individual records in the summary statistics developed by the meta-analysis methods. These types of transformations appear to fall within the group that would be associated with the scenario analyses generally considered as part of benefits transfer practices. The SAB finds that they extend significantly beyond any meta-analytic practices found in the literature. Because these practices are "new," the SAB recommends more detailed evaluation and separate assessments of the practices in these new roles before judgments are made that could be interpreted as endorsements. In many cases these adjustments, if they are applied at all, should be conducted *ex post*, as part of a benefit transfer process, rather than as part of the development of data used in the meta-analysis.

In some respects, the White Paper offers advances beyond current common meta-analytic practices, for example in its decomposition of statistical error into three distinct components (group-level and observation-level non-sampling error and observation-level sampling error). It would be helpful for the

White Paper to be more explicit about what accepted meta-analytic practices are and how they are applied. This could be accomplished in several ways.

1. Several papers have proposed general steps, guidelines, and/or recommendations for conducting meta-analysis. The most relevant paper is Nelson and Kennedy (2009). This paper is referenced in the White Paper, but on a narrow issue. The White Paper would be strengthened by organizing the discussion around (or least referencing) these types of best practice guidelines. The White Paper does this to a limited extent with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Moher et al. 2009), but this really only applies to the study selection step.
2. The non-parametric statistical methods used in the EPA's analysis include approaches ("sampling error" and "total error" variance weighted mean) that are fundamentally similar to methods typically referred to in the meta-analysis literature as "fixed effect size (FES)" and "random effect size (RES)" methods.⁵ Using, or least referring to, these labels, and describing how the methods used in the White Paper depart from these more standard practices, would help strengthen the presentation in the paper by tying it to the broader literature on meta-analysis. Also, when applying and comparing these non-parametric meta-analytic approaches, standard tests of homogeneity across groups (Q-tests) are generally recommended. These types of tests should be discussed and reported in the White Paper.

One of the principal best practice guidelines suggested by Nelson and Kennedy (2009) and supported by the SAB is to "ensure that the effect-size measures from the primary studies are all measuring the same thing." The White Paper could better address this recommended practice in several ways.

1. The White Paper should provide detailed documentation about each of the primary studies and the selected value estimates in a way that would allow an independent party to replicate the results and that reinforces the direct comparability of the objects/commodities being valued. For example, it is important that the temporal dimensions of the willingness to pay estimates be directly comparable (i.e., that they all measure or are converted to annual willingness to pay estimates for annual risk reductions). In the White Paper more attention should be given to describing the temporal features used in each study.
2. Where there are differences in the effect size measures across studies or value estimates, the White Paper should consider, discuss, and as appropriate include, adjustments to make the measures more comparable. For example, as previously discussed, the stated preference studies provide Hicksian value measures and the hedonic studies provide Marshallian measures. Also, whereas the stated preferences studies provide value estimates for non-marginal changes in risk, hedonic studies provide estimates of the marginal rate of substitution. The SAB recommends that EPA consider and describe the types of assumptions (e.g., preference structure) that would be needed to convert the Marshallian to Hicksian measures and the non-marginal to marginal values and evaluate the advantages or limitations of making these types of adjustments.
3. Although it is important to ensure that all included effect size estimates are measuring the same thing, the SAB finds that there is insufficient evidence in the income elasticity of VSL literature to adjust the VSL values from different studies to account for differences in income. Furthermore, gross domestic product per capita, which was used as the measure of income, has

⁵ The RES method is mentioned in the White Paper, but only in reference to the parametric/meta-regression approach.

not increased for some income groups. Therefore, the SAB recommends that both the non-parametric and parametric analyses be conducted without this direct adjustment to VSL.

Another best practice guideline is to explicitly address and account for heterogeneity in the variance of the effect size estimates. The White Paper does this in several ways, including the use of “sample size weighted mean” in the non-parametric analysis. Sample size weighting has often been used in meta-analyses of willingness to pay estimates. Typically it is used as a proxy for variance when variance estimates are not available. However, in this application variance estimates are available; therefore, it is not clear what is gained by including a sample size weighted approach. Its inclusion should be better justified.

Key Recommendations

- Where there are differences in the effect size measures across studies or value estimates, the White Paper should consider, discuss, and as appropriate make adjustments for differences in value concepts being measured across studies (e.g., hedonic studies provide Marshallian measures and stated preference studies provide Hicksian measures) to make the measures more comparable. The White Paper should provide detailed documentation of any adjustments that are made so that an independent party could replicate the calculations.
- Both the non-parametric and parametric analyses should be conducted without adjusting the VSL values from the different studies to account for differences in income. There is insufficient evidence in the income elasticity of VSL literature to adjust VSL values from different studies to account for differences in income. Furthermore, gross domestic product per capita, which was used as the measure of income, has not increased for some income groups.

3.3.2. Grouping Samples for Analysis

Charge Question 6. The White Paper classifies estimates into independent samples, also called groups, as described in Section 4. Estimates from some hedonic wage studies that use the same or very similar worker samples are grouped together for the analysis. Similarly, some of the stated preference estimates using the same sample are grouped together. Please comment on whether this methodology represents an appropriate and scientifically sound approach for accounting for potential correlation of results that rely on the same underlying data.

The SAB agrees that it makes sense to group studies in the White Paper based on similar data sets to account for the lack of independence in estimates constructed from the samples. The SAB endorses grouping studies that use the same data set. Additional detail should be included in the White Paper to clarify how the grouping decisions were made. A column should be added to Table 6 of the White Paper to provide information more clearly identifying the composition of the various study groups.

The SAB also recommends that the EPA conduct additional analysis to check the robustness of the results to different plausible group definitions. Specifically, the SAB recommends that the EPA: (1) explore the sensitivity of results to alternative group assignments (e.g., grouping studies that used the same data set or the econometric approach together); (2) use the influence analysis to examine the robustness of the results to individually excluding each group; and (3) identify the primary estimate from each study and re-estimate the meta-regression using only primary estimates.

Key Recommendations

- EPA should check the robustness of the results to different plausible study group definitions. This robustness check should include:
 - Exploring the sensitivity of results to alternative group assignments;
 - Using the influence analysis to examine the robustness of results to excluding each group;
 - Identifying the primary estimate from each study and re-estimating the meta-regression using only primary estimates.

3.3.3. Addressing Sampling and Non-Sampling Errors

Charge Question 7. Section 4.1 of the White Paper presents an expression that characterizes optimal weights that account for sampling and non-sampling errors, a framework that guides EPA's approach. Please comment on whether this is an appropriate and scientifically sound approach for addressing sampling and non-sampling errors.

Additional information would be needed to fully address this charge question. The derivation of the expression characterizing optimal weights that account for sampling and non-sampling errors should be more transparent in the White Paper. Therefore, the SAB recommends including in the text of the White Paper (or in an appendix) the various steps required to derive equation (4) in Section 4.1. Citations establishing the validity of the basic approach, and the specific equation, should also be included. With regard to the use of the weights, the SAB recommends that clarification of and justifications for the assumptions concerning the error components be included. Finally, the white paper emphasizes the efficiency of the various estimators presented. The SAB also recommends that transparency be considered when choosing among estimators that are otherwise equally appropriate.

3.3.4. Non-parametric and Parametric Approaches for Estimating Value of Statistical Life

Charge Question 8. The analysis in the White Paper adopts both non-parametric and parametric approaches (sections 4.1 and 4.2, respectively). Please comment on whether these approaches span a reasonable range of appropriate, scientifically sound, and defensible approaches to estimating a broadly applicable VSL for environmental policy and whether there are other methods that are more appropriate than those used in the White Paper.

The SAB finds that some additional information is needed to explain the approaches adopted in the White Paper, especially to explain the use of the non-parametric approach. The SAB recommends that the EPA provide citations for the non-parametric approaches (estimators 1-5 on pages 22-23 of the White Paper) and better justification for the methods used in the specific application. Specifically, the justification should explain why these methods are relevant to finding the central tendency of VSL estimates from studies that in most cases report multiple estimates. Some discussion of the conceptual merits and data requirements of each method is needed. Calculations should be documented with sufficient detail to allow a reader to know precisely how to replicate the calculations. The SAB notes that estimator 3 is described in the text on meta-analysis by Hunter and Schmidt (2004) and estimator 4 is described in the text on meta-analysis by Hedges and Olkin (1985) and implemented in a recent meta-analysis by Hsiang et al. (2013).

The EPA concludes that the mean of group means estimator is the preferred non-parametric method. The EPA's argument is that it has the smallest estimated standard error (p. 32 of the White Paper). The SAB cannot evaluate the EPA's choice of estimator until it sees new results that address responses to other charge questions (e.g., issues raised regarding population weighting and income growth adjustments). Changes made in response to other charge questions could affect the relative performance of the estimators. The need to examine new results notwithstanding, the SAB notes that the mean of group means estimator avoids giving too much weight to studies that report multiple estimates, a point that could be emphasized by the EPA as a rationale for choosing this estimator. It is not clear why there is so much variation across papers in the number of reported estimates. This may be a result of idiosyncratic factors (e.g., stylistic choices by authors, requests by referees for robustness checks) and, as such, it is better to give equal weight to groups of estimates.

The SAB recommends that the agency explore the use of an alternative non-parametric method that incorporates information on sampling error variance from each study. This estimator is a blend of two estimates calculated in the White Paper (estimator #2, the mean of group means, and estimator #4, the sampling error variance weighted mean) and would be calculated as follows:

$$\hat{y} = \frac{1}{I} \sum_{i=1}^I \frac{1}{\sum_{j=1}^{m_i} se_{ij}^{-2}} \sum_{j=1}^{m_i} se_{ij}^{-2} y_{ij} \quad (4)$$

The estimator computes the mean of sampling error variance weighted group means.

For the parametric estimator, the SAB recommends that the EPA provide better explanation of and justification for the included control variables. Some of this discussion is found in section 6.1 of the White Paper, but is better placed in section 4.2. The SAB recommends that, if feasible, the EPA should include additional controls in the parametric model. One suggestion is to include indicator variables for a study having specific major contributors to the VSL literature as co-authors. The parametric model that the EPA used to estimate the VSL included a time trend variable for the year the data were collected in the study from which the primary estimate was drawn (see equation 16 in the White Paper). The SAB recommends that time trend variables not be included in either the parametric or the non-parametric models. The SAB concludes there is not a rationale for giving different weights to estimates from different years and, thus, recommends the use of equal weights in forming the average VSL. However, to explore whether older or newer studies have a strong influence on the VSL estimate, the EPA should consider conducting a sensitivity analysis similar to the influence analysis in Table 10 of the White Paper.

Key Recommendations

- Additional information is needed to explain the approaches adopted in the White Paper, especially to explain the use of the non-parametric approach. Better justification should be provided for the methods used for the specific application. Specifically the justification should explain why these methods are relevant to finding the central tendency of VSL estimates from studies that in most cases report multiple estimates.
- EPA should not include a time trend variable in either the parametric or non-parametric models, but should consider a sensitivity analysis to determine whether older or newer studies have a strong influence on the average VSL.

3.4. White Paper Results

3.4.1. Proposed Estimates of Value of Statistical Life

Charge Question 9. The White Paper presents estimates using parametric and non-parametric models, pooled across stated preference and hedonic wage studies as well as balanced (i.e., equal weight to each study type), and weighted using different approaches. Of the range of estimates presented (see Section 4) the White Paper proposes the use of estimates from the following models:

- *Non-parametric model, balanced, mean of study mean*
- *Parametric, balanced*

Please comment on whether these proposed estimates represent reasonable and scientifically sound conclusions from the analyses in the White Paper and whether there is a different set (or sets) of results that are preferable based on the data and analysis in the White Paper.

Summary VSL Estimates

Answering this charge question requires that the sample used in deriving the summary VSL estimates be placed in context. The EPA's White Paper uses non-parametric and parametric methods to summarize estimates for the fatality risk trade-offs (VSL estimates) that are derived from nine stated preference and eight hedonic wage papers. The data underlying these studies were collected at different times. The year of the earliest sample was 1993 for a hedonic wage study. The sample year for the most recent study was to 2007 for a stated preference analysis. The grand mean, derived as a summary of all of these results, varies depending on a number of factors. The White Paper reports results using different samples, different summary statistics, and different weighting procedures. The overall mean VSL estimate that results varies from \$9.36 million to \$11 million in 2013 dollars. There is approximately a 17.5% difference from the lowest value derived to the highest. This difference seems small when evaluated in comparison to the primary data reported in Table 6 of the White Paper. The estimates reported in this table are the data that were used in the development of the summary statistics. They range from \$1.06 million to \$23.8 million (in 2013 dollars). These estimates have been adjusted with an income elasticity of 0.7 and rely on the increase in per capita gross domestic product rather than the increase in income to develop this adjustment.

Each of the research papers providing the basic data for the meta-summary has distinguishing features. These characteristics reflect the objectives of the sampling process and procedures used to recover risk trade-off information, including the associated theoretical concept that is measured and a variety of distinctions associated with the estimator and model specifications for each study. The EPA's meta-analysis procedures focus on two adjustments to account for the heterogeneity. The first of these is an overall selection criterion for including a study's results in the sample. The second involves adjustment to the primary estimates reported in each research paper. The adjustments are intended to develop a consistent risk trade-offs measure from the heterogeneous set of estimates. The strategies used in developing these adjusted VSL measures are potentially important innovations in the practice of benefits transfer. They are a departure from the methods conventionally used in most meta-analyses.

A number of meta-summaries of existing literature seek to evaluate how modeling assumptions, sample features, the timing of the data collection for the sample, and other details of the modeling decisions

made for each study influence the estimates for a consistently defined outcome measure such as the VSL (e.g., Mrozek and Taylor 2002). The EPA's approach adopts a series of maintained assumptions to adjust the heterogeneous estimates before they are used in the meta-summary. For example, it is assumed that the risk trade-offs measure would increase with progressive increases in household income. Equally important, when estimates are available for separate demographic groups, the White Paper uses approximate population weights to develop an overall population mean. In some cases, the decisions associated with selecting weights appear to be an attempt to approximate what might be interpreted as survey sample weights. In others, the analysis appears to be assigning the VSL estimate as a risk trade-offs measure for a specific subgroup in the population at a different time than the estimate associated with the primary study. This strategy amounts to selecting a measure for the VSL based on one demographic group and assuming it applies to a closely related demographic group in a different year.

To investigate the potential importance of these adjustments, the SAB reviewed the most recent of the hedonic wage studies (Scotton 2013) used for the EPA's VSL meta-analysis. Review of this study reveals a number of issues that might have been raised concerning the selection of 12 of the 24 estimates included in the meta-summary. For example, Scotton does not seem to regard those 12 as the preferred estimates due to the heterogeneity of the full sample used in estimating the models. She suggests that they were included for comparison purposes. For these 12 estimates, 31% of the sample required the use of imputed wages for the dependent variable used in the hedonic wage model. In the restricted sample, which is associated with the other 12 estimates from her study, none of the estimates relied on imputed wages. In addition, comparing the difference in the VSL estimates between linear and semi-log specifications for models based on the full sample, when all other features of the models held constant, yields as much as a 38% difference in the estimated VSL. These are large differences. They are the types of differences that would be reflected in a conventional meta-model's summary of diverse estimates. They would not be captured by the weighting adjustments in the White Paper. Because of this limitation, these types of issues call into question the EPA's logic for selecting estimates for meta-analyses. The EPA approach focuses on the risk measure used in each study and whether the study has been published in a peer-reviewed outlet. It appears that most, if not all, estimates from each study are then included in the analysis without considering qualifications a study author may have included as part of discussing the estimates. Many meta-analyses devote considerable effort to coding variables that reflect the original study author's decisions and insights about models that are reported. This could be considered as additional information to be included in a meta-data set. The strategy is certainly consistent with what the EPA does in other contexts where a criteria document is prepared as a literature review and detailed summaries and written evaluations are prepared for each study included in the document.

The SAB previously proposed several strategies for developing summary measures of the VSL estimates based on new research (U.S. EPA Science Advisory Board 2011). These strategies are summarized on pages 7-8 in the White Paper. One of the strategies involves the use of preference calibration. The White Paper notes that this approach is not feasible at the present time. More specifically, on page 8 it notes that:

“Developing a structural preference function (option four above) could in principle provide a strong theoretical foundation for benefit transfers, as noted by the SAB. However, this option would require longer-term research and is not yet ripe for implementation in guidance.”

As previously indicated, the SAB finds that the current adjustments proposed in the White Paper are a form of preference calibration. Indeed, these adjustments might be labeled as *partial preference calibration*. They implicitly make assumptions about individual preferences. That is, these assumptions relate to either the way in which the VSL responds to income or how heterogeneity in these risks trade-offs arises among different subgroups in the population. These assumptions are then embedded in the overall statistical summaries that are part of the EPA's meta-analysis. This arises because the transformations are applied to the basic estimates from each study before the set of VSL measures are combined into the statistical summary.

This charge question asks the SAB to comment on the *estimates* derived from parametric and nonparametric statistical methods. Its focus is on the *estimates* and not the methodologies used to develop the summary statistics. If the SAB were asked to evaluate the methods (i.e., the parametric and non-parametric estimators) we would have concluded that the methods are consistent with conventional practice. However, in preparing the data for the application of parametric and non-parametric methods, the data were transformed using *partial preference* calibration. These partial calibration methods have not been evaluated in the literature and thus are not ready for implementation in regulatory guidance.

Weights Used Across Studies

As indicated in the response to Charge Question 8, the SAB recommends that the EPA consider using the non-parametric sampling error variance weighted group mean in place of the non-parametric mean of group means estimator. However, it is important to distinguish these estimates from those that have used weights to construct "general population" measures for the U.S. population. There are inconsistencies in the weights used across studies. For the estimates derived from the 2002 stated preference study designed by Cameron and DeShazo for a representative sample of U.S. households, the weights should be based on the Knowledge Network Survey sampling weights for the 2000 census not the 2010 census. For the hedonic wage studies, the weights appear to be based on 2013 information for the general population when the samples are for earlier years and are designed to represent populations of individuals who choose to work full time. As previously noted in the introduction of this report, this weighting to derive a mean for the general population mixes a *benefit transfer* assumption with a *sample weighting* decision. The benefit transfer assumption involves assuming non-workers whether unemployed, retired or not participating for another reason have the same risk trade-offs (VSL) as those working.

Income Adjustments

Adjustment of VSL estimates by an income elasticity of VSL and index of income growth (based on GDP per capita) does not appear to be appropriate. However, conversion of VSL to inflation adjusted dollars would be appropriate. Income adjustment could involve: (1) adjustment for differences in the income across different samples that could hypothetically alter the risk trade-off; and (2) adjustment for changes in real income over the time period covered by the effects of a rule where assumptions about the growth of the income might be expected to raise all households income for the future date when the policy was implemented. This type of "income adjustment" would be a part of the benefits transfer associated with modifying a unit value so it is consistent with the economic conditions at the time the policy is assumed to affect mortality risks. At present, the documentation of income adjustment in the White Paper is not clear. Table 6 of the White Paper refers to the use of an income elasticity of 0.7 but does not clearly discuss the income used in the two adjustments. In addition, the SAB notes that

adjustment for income with the stated preference measures would need to be different because these are derived from Hicksian welfare measures (Smith et al. 2002, 2003).

Key Recommendations

- The documentation of income adjustment to VSL should be clarified in the White Paper. Adjustment of VSL estimates by both an income elasticity of VSL and index of income growth (based on GDP per capita) does not appear to be appropriate. However, conversion of VSL to inflation adjusted dollars is appropriate.
- Income adjustments of the VSL estimates derived from hedonic wage and contingent valuation studies must be consistent with the income concept relevant to each model. For hedonic wage models income is endogenous. However, for stated preference studies this is not the case and expected utility is being held constant. The analysis of proper treatment of income should reconcile the modeling assumptions (including the role of income in Hicksian or Marshallian-based analyses) used by source studies with the use of any approach to deriving an estimate of VSL based on a study, before applying any adjustment.

3.4.2. Influence Analysis

Charge Question 10. The results section of the White Paper concludes with an influence analysis. Please comment on whether this analysis is a reasonable way to characterize the influence of individual studies on the estimated VSLs, whether the results of the influence analysis suggest any changes or modifications to the estimation approach, and whether it is important to include an influence analysis.

An influence analysis is important, especially given the implicit assumptions underlying the structure of the non-sampling error related to groups and given the relatively small number of VSL estimates. Some form of influence analysis is important for meta-analysis in cases where there are few studies to consider, and therefore one or two individual studies might have a substantial influence on the estimates. Influence analysis is most important to evaluate the potential for the influence of a few observations to skew the results in a single direction. For example, if there are two studies with +10% and -10% influence the two studies are more or less balanced. With regard to the mean of group means in the White Paper, the two most influential studies are Corso Hammitt and Graham (2001) at -13.8% and Chestnut, Rowe, and Breffle (2012) at +11.1%. Taken together, these studies nearly balance each other. In contrast, for the maximum likelihood stated preference estimates, the Corso, Hammitt and Graham (2001) at -22.8 % is well over two times more influential than the second most influential study, which fortunately is of the opposite sign. Rather than dropping Corso, Hammitt and Graham (2001) altogether, one might use a robust estimation technique that limits the influence of this observation. One possibility is to use a median based analysis and another would call for adjusting the weight on this study downward until it just balances the Alberini et al. (2004) study, or to down-weight all studies that are identified as relatively influential (perhaps studies that fall above the +/- 10% influence range). These types of approaches down-weight highly influential observations. There has been extensive experience with these approaches and further review of this research would assist in selecting a set of methods for application to the meta-analysis.

It would also be useful to consider the potential for using regression diagnostic indexes (Belsley et al. 1980; Cook and Weisberg 1982; Belsley 1991) for the parametric modeling of VSL. These statistics

allow analysts to consider whether specific observations were influential to individual coefficients in the meta-regression function. They allow an assessment of whether the magnitude and significance of individual coefficients was influenced by particular observations.⁶ Since these correspond to the specific studies and models within a study, they could be useful in understanding how the group definition discussed earlier influences the specific mean statistics proposed to construct a population level measure for the mean VSL.

Key Recommendations

- Influence analysis of the maximum likelihood stated preference estimates indicates that Corso, Hammitt and Graham (2001) at -22.8% is well over two times more influential than the second most influential study. The EPA should consider using a robust estimation technique that limits the influence of this observation, such as one based on the analysis of medians.
- The EPA should consider the potential for using regression diagnostic indexes (Belsley et al. 1980; Cook and Weisberg 1982; Belsley 1991) for the parametric modeling of VSL.

3.5. Protocol for Future Revisions of Value of Statistical Life

3.5.1. Criteria for Inclusion and Exclusion of VSL Estimates in Future Analyses

Charge Question 11. In the previous SAB advisory report (U.S. EPA Science Advisory Board 2011), the SAB endorsed the idea of establishing a standardized protocol and regular schedule for future updates to the Agency's mortality risk valuation estimates. Please comment on relevant statistical criteria for the inclusion of additional eligible estimates and/or the exclusion of older estimates that could help inform the development of a standardized protocol for future updates and the timing or frequency of those updates.

The SAB provides general and specific recommendations concerning the development of a standardized protocol for future updates and the timing or frequency of those updates.

General Recommendations

The SAB notes that the value of VSL is very likely the most important “benefit measure” used in EPA’s benefit-cost analyses for policies related to mortality risk. The level of staff effort and other research resources devoted to regularly updating and refining VSL estimates should be commensurate with their importance for policy evaluation.

Given the importance of VSL, high priority should be assigned to increasing the pool of high quality studies to support the VSL meta-analysis. This is particularly important due to the small number of data sets supporting hedonic price estimates, and the relatively small number of stated preference studies currently included in the meta-analysis. In addition to improving the precision of VSL estimates, additional high quality studies could improve the ability to estimate other important characteristics of

⁶ These are “old” references but they can provide useful indexes of how specific observations influence results. The discussion of “short data” in chapter 7 in Belsley (1991) may be especially relevant to parametric models and developing meta-summaries with limited variation in the risk and/or income measures that are used to estimate income elasticities or scope effects.

VSL, such as possible time trends, income elasticities, variability over subpopulations, cancer premiums, and other factors that are central to policy analysis.

In the near term, the EPA can expand the number of studies by considering whether useful information can be extracted from a variety of studies previously excluded from VSL calculations. Subject to caveats and recommendations detailed below, such studies might include those with samples that are not representative of the national population, and results from other economic studies of risk preferences (e.g., transportation safety, risk-risk trade-offs, etc.).

Consideration of research outside of studies published in traditional peer-reviewed journals represents another potential opportunity for expanding the base of studies for estimating VSL. For example, VSL estimates from government-funded research reports might be included in the analysis following a transparent and rigorous peer review process. However, the SAB recognizes that practical challenges may preclude the EPA from establishing a credible “arms-length” peer review process in the near term, particularly given budgetary realities.

In the long term, new high quality studies could be elicited by EPA using existing and new mechanisms. For example, EPA should consider whether estimation of VSL and its various attributes (e.g., time trends, income elasticity, etc.) should be a high priority topic for Science to Achieve Results (STAR) grants and fellowships, EPA sponsored conferences, special issues of journals, and young researcher awards.

The EPA might also obtain more general information about protocols for updating estimates from the experience of other agencies that construct economic index numbers for policy. For example, the U.S. Food and Drug Administration periodically develops dietary guidelines that are based on the preponderance of current scientific and medical knowledge. The EPA could learn from protocols used by the FDA and other agencies for periodic updates.

Statistical Criteria for the Inclusion of Additional Eligible Estimates and/or the Exclusion of Older Estimates

The validity criteria for inclusion and exclusion of studies have been discussed in detail in the response to Charge Question 1a. As previously discussed, the SAB recommends that all future updates of the VSL also consider whether the conditions for investigating study validity should be updated. The SAB recommends that the exclusion of older estimates be evaluated on a case-by-case basis using the same validity criteria, rather than dropping studies simply based on their being dated, *per se*. If there is strong evidence that risk preferences change over time, the SAB recommends developing procedures to adjust older estimates that are otherwise judged to be valid, rather than dropping estimates simply because they are older. This is especially pertinent given the small number of studies upon which current VSL estimates are based.

Timing or Frequency of Updates

The SAB finds that a five-year interval of updating estimates is reasonable. More frequent updating might be desirable, but based on experience in the past several years, there appear to be too few new estimates each year to justify the time and expense involved in more frequent updating.

Potential Sources of Information Outside of Peer-Reviewed Journals

As previously indicated, increasing the number of high quality studies included in the meta-analysis is a high priority. For this reason, the SAB has considered whether studies should be restricted to those that are published in peer-reviewed journals. While recognizing the challenges, the SAB recommends that the EPA consider whether it is feasible to include studies outside of the peer-reviewed journals following a transparent and rigorous peer review process. The SAB emphasizes that it is inadequate to simply assert that a study was subject to peer review. Rather, a quality controlled peer review process should be established. For example, EPA might organize a process to review research results outside of traditional peer-reviewed journals, both to identify appropriate reviewers and to determine whether or not studies that undergo peer review are judged to “pass” the review process, and therefore qualify for inclusion.

Extending sources of information to research outside of peer-reviewed journals has the potential to substantially increase the number of studies available to estimate VSL. As previously noted, there has been little growth in the number of studies used by the EPA to estimate the VSL since the topic was considered by the SAB in 2011. There is an acute need to increase the number of available studies for estimation of the VSL. Research papers outside of peer-reviewed journals are likely to include high quality empirical analyses even if they are not submitted for publication in journals. A major challenge to relying only on publications in peer-reviewed journals is that economics journals rarely publish articles that contain routine empirical analyses without some sort of innovation or other improvement in the state-of-the-art in economic theory or empirical methodology. In contrast to some other disciplines, the field of economics places a low priority on improvements in the state-of-the-art in empirical knowledge. This severely discourages production of studies serving a primary function of recording value estimates useful for policy analysis. As a consequence, many analyses could provide satisfactory estimates of VSL, but may not be submitted to peer-reviewed journals, or may be rejected for publication because they do not improve upon the state-of-the-art in economic theory or empirical methodology. This may be particularly relevant for analyses carried out by consulting companies for government agencies, for whom publication of research results in peer-reviewed journals may or may not be of high priority. At the same time, the SAB recognizes the importance of assessing studies for inclusion on the basis of an arms-length peer review process, and the challenges in doing so, particularly given budgetary realities.

Information from Other Economic Studies of Risks

The SAB recommends that the EPA consider whether useful information can be extracted from other studies excluded from the VSL calculation to improve estimates of VSL and its characteristics (e.g., latency, morbidity). This might include studies of risk-risk trade-offs, hedonic analyses in addition to hedonic wage studies, risk studies in the transportation safety literature, and possibly others. For example, EPA might consider using results of risk-risk studies that employ a stated preference approach, wherein respondents were asked to choose whether to undergo treatment (e.g., a risky surgery) that has a stated risk of immediate mortality versus a given risk of cancer, which involves stated risks of both long-term morbidity and subsequent mortality. EPA might also use the results of a study that asked respondents to choose whether to undergo treatment that has a stated risk of morbidity (e.g., paralysis, chronic pain, etc.) versus foregoing treatment, in which case they faced a stated mortality risk (Hauber et al. 2013). These studies could potentially be useful for calibrating differences in VSL across risks with differing degrees of latency, morbidity, etc. (e.g., a possible cancer premium). These issues are

particularly relevant given EPA's focus on environmental risks, which often involve long latency periods, and where mortality is often preceded by a significant period of morbidity.

The EPA should also consider whether useful information can be extracted from other categories of studies, such as hedonic literature outside of hedonic wage studies, the literature on health care cost effectiveness analysis, and possibly transportation safety studies. For example, it may be possible to extract useful VSL information from hedonic studies of the effects of air pollution on housing prices, although challenges may exist in isolating mortality and morbidity effects from other effects, such as visibility. Studies that have derived transport-specific VSLs are cited in Viscusi and Gentry (2015). Studies on health care cost effectiveness analysis use measures of health-related quality of life that often fall short of utility-theoretic standards but could nevertheless be useful. There is a comprehensive searchable database of such studies that is managed by Tufts University (Tufts University Medical Center, 2016).

Information from Studies with Non-National Samples

Similarly, the SAB recommends that EPA not necessarily exclude studies simply because they are based on non-national samples, as long as there is a broad set of studies that as a group is generally representative of the nation as a whole (or can be used to develop a representative estimate for the nation as a whole, or to improve the representation of VSL values of subpopulations that are underrepresented or omitted from studies used to estimate a representative value for the nation as a whole). For example, the EPA should consider studies based on representative samples at the state and regional levels as long as there is an adequate number of studies using representative samples for a diverse set of states and/or regions. This is particularly relevant since even samples using national data are not representative of the U.S. population. For example, hedonic wage studies are limited to members of the workforce. The SAB suggests that it probably would not be appropriate to adopt estimates from studies based on narrow demographics or a very small geographic area (e.g., a single community) since they may not be representative. The SAB notes that there have been recent advances in how to use Bayesian methods to "correct" estimates collected from non-representative samples, known as multilevel regression and post-stratification (MRP) methods. These originated as corrections to political polling results, but have far broader applicability (e.g., Park et al. 2004).

If a reasonable number of studies at the state and regional levels are available, one could carry out consistency checks to ensure that similar estimates result from national level studies and a set of state and/or regional level studies. As previously indicated, in addition to improving the precision of VSL estimates, increasing the number of high quality studies has the advantage of allowing improvements of estimates of related measures, such as time trends, income elasticities, and variability over subpopulations.

Open Data Initiatives

Another challenge in depending only on existing studies published in peer-reviewed journals for VSL estimates is it that makes EPA dependent upon those results that are reported in the publications (and possibly additional information that can be obtained by contacting the authors). For example, some studies report VSL estimates, but do not report associated standard errors or confidence intervals on VSL, income elasticities, and estimates by subpopulation. In addition, different studies use different statistical methods, control for different influences, and otherwise use different procedures that are difficult to control for after the fact.

The SAB recommends that the EPA consider a long-term strategy of requiring that a more inclusive set of research results, and even whole data sets, be made generally available for use by the research community and by government agencies. Project Open Data (U.S. Office of Management and Budget and U.S. Office of Science and Technology Policy 2016) provides an excellent framework for making data available in order to improve the information obtained from available studies.

It is becoming increasingly common practice for agencies and professional associations to develop open data policies which require or strongly encourage that data be made widely available to the research community. For example, in May 2013 President Barack Obama issued an Executive Order and an associated Open Data Policy for all federal agencies. The Office of Management and Budget's Open Government Directive creates a "presumption in favor of openness to the extent permitted by law and subject to privacy, confidentiality, security, or other valid restrictions," and requires that agencies publish high value data sets in an open format through Data.gov (The White House 2016). The EPA could also require that data collected under grants and contracts awarded by the agency be published to Data.gov in standard format (U.S. General Services Administration 2016), unless there is a compelling reason that the data not be published. Such a policy might allow exceptions and be subject to possible censoring of individual variables and observations as necessary to ensure protection of confidentiality. This is consistent with U.S. Office of Management and Budget (OMB) policy, which established the principle that, where feasible, data be public, accessible, fully described, reusable, complete, timely, and managed post-release. Similar open data policies have been adopted by peer-reviewed journals like *Science*, *Nature*, *PLOS*, and the *American Economic Review*.

An open data policy would have the advantage of providing opportunities to: (1) replicate research results; (2) improve quality control on reported estimates; and (3) carry out "after the fact" estimates of parameters of importance that are not reported in the original publication (e.g., VSL standard errors). Additionally, data from multiple studies could be used to: apply more refined estimation techniques, apply more comparable standards (e.g., explanatory variables) across studies, and correct possible biases in studies. For example, data collected in the immediate aftermath of a major event (e.g., the Great Recession of 2007-2009) might not be representative of the long term. A single parameter estimate from a study using pooled data from 2005-2010 might not be refined enough to adjust for differences during the recession years. Access to the original data set could provide researchers with the opportunity to adequately take such influences into account.

More broadly, collecting primary data is expensive, and it is inefficient to expend large amounts of funding to collect data for a single analysis and then exclude those data from use for other productive purposes. Indeed, a recent report has estimated that open data could add \$3 trillion to \$5 trillion in economic value to the global economy each year (Manyika et al. 2013). While the SAB has not had an opportunity to review this particular study, it is clearly suggestive of the substantial social value in making data more widely available to the research community.

At the same time, the SAB recognizes there are important challenges to making data sets publicly available. For example, issues may arise with respect to confidentiality of survey respondents in some data sets. Also, all data sets have important limitations that are often best known to those who originally collected that data. In addition, many researchers will want to publish results from data sets prior to making them public. However, the SAB finds that challenges associated with these issues can be minimized by carefully considering data sharing policies and the important efficiencies in making data publicly available. The SAB also notes that making data publicly available after a reasonable amount of

time would fit into the process of updating the VSL estimate. The SAB recommends that the EPA work in collaboration with other agencies and professional associations to pursue reasonable and prudent actions to make data publicly available. For example, the EPA could learn from the policies established by the National Science Foundation program for Long-Term Ecological Research.

Routine Compilation of Existing Data Sets

The EPA might also make an effort to routinely compile data from various key sources for regular use. For example, as previously indicated, the EPA might simplify periodic updating of hedonic wage estimates of VSL by creating an archive of wage data, and perhaps other data, from the U.S. Census Bureau's demographic supplement to the CPS, matched with data from the U.S. Bureau of Labor Statistics CFOI in standardized form, and perhaps other data sets. Once in place, such a data archive would allow for consistent periodic updates of VSL at low cost, rather than waiting for updated publications in the peer-reviewed literature. This approach also has the advantage of providing a consistent methodology underlying hedonic wage estimates over time. EPA might create its own data archive or the compiled data might be published in existing data archives, such as Data.gov.

Key Recommendations

- A five-year interval for updating VSL estimates is reasonable but the pool of high quality studies to support the VSL meta-analysis should be increased. To accomplish this the EPA should:
 - Consider whether estimation of VSL and its various attributes (e.g., time trends, etc.) should be a high priority topic for Science to Achieve Results (STAR) grants and fellowships, EPA sponsored conferences, special issues of journals, and young researcher awards
 - Obtain more general information about protocols for updating estimates from the experience of other agencies that construct economic index numbers for policy.
- The EPA should not exclude studies based on non-national samples from use in updating VSL as long as there is a set of studies that as a group is broadly representative of the nation as a whole.
- EPA should consider whether it is feasible to use studies outside of peer-reviewed journals for updating VSL following a transparent and rigorous peer review process.
- The EPA should consider whether useful information can be extracted from other studies that could improve understanding of VSL estimates and how they relate to underlying characteristics (e.g., latency, morbidity). This might include studies of risk-risk trade-offs, hedonic analyses in addition to hedonic wage studies, and risk studies in the transportation safety literature.
- EPA should consider a long-term strategy of requiring that a more inclusive set of research results, and even whole data sets, be made generally available for use by the research community and by government agencies.

3.5.2. Valuing Reductions in Risks of Cancer

Charge Question 12. In its 2011 report the SAB-EEAC recommended "...EPA work toward developing a set of estimates...for policy-relevant cases characterized by risk..." (U.S. EPA Science Advisory Board 2011, pp. 10). Among the studies that meet the selection criteria in the

current White Paper, three stated preference studies provide values for reductions in risks of cancer (i.e., Hammitt and Haninger 2010, Chestnut, Rowe, and Breffle 2012, and Viscusi, Huber and Bell 2014). Only two of those studies (Hammitt and Haninger 2010 and Chestnut, Rowe, and Breffle 2012) allow for a within study comparison of values for cancer and non-cancer risk reductions. However, EPA could augment the literature by modifying the selection criteria to include studies from other countries or from the grey literature, and/or using other methods (e.g., risk-risk studies). Please comment on whether, and if so how, selection criteria for identifying studies for estimating a cancer differential should differ from those used in the current White Paper. Does the literature support a non-zero cancer differential?

The SAB has previously concluded that “research suggests that people are willing to pay more for mortality risk reductions that involve cancer than for risk reductions from accidental injury and proposes a placeholder value that could be used for this cancer differential while the Agency pursues long-term research to differentially value other types of risks” (U.S. EPA Science Advisory Board 2011). The motivation behind a potential cancer differential is that a death from cancer is preceded by a significant period of morbidity⁷. Cancer treatment typically is accompanied by surgery, chemotherapy, and radiation that can have serious debilitating side effects. The experience of death is also traumatic for family and friends as well as the affected individual in ways that sudden death is not. According to this motivation, a cancer death can be thought of as two events, a period of morbidity followed by an early death. Logically, a death preceded by a significant period of morbidity would be viewed as worse than a sudden accidental death (though there may be some benefit to being given a period of time to put one’s affairs in order). Indeed, Gentry and Viscusi (2016), using revealed preference wage data, find that wage premiums for occupational mortality risks that tend to be preceded by longer periods of morbidity are higher than premiums for occupational mortality risks that tend to be preceded by shorter periods of morbidity, and that the value of a statistical life can be decomposed into a value of the fatality risk plus a value of the associated morbidity risk. These studies show that people value both mortality risks and associated morbidity risks, suggesting that a cancer premium could exist.

Given that a cancer premium is possible, is there enough evidence in the literature to establish its size? Few studies have done “clean” comparisons of an estimated VSL for cancer-related deaths to a VSL for sudden death. Hammitt and Haninger (2010) found that willingness to pay to reduce risk of death from disease caused by consumption of pesticides was larger than, but not statistically different from, willingness to pay to reduce risk of death from an automobile accident. Chestnut, Rowe, and Breffle (2012) found that willingness to pay to reduce risk of death from cancer was larger than, but was not statistically different from, willingness to pay to reduce risk of death from heart attack. Cameron and Deshazo (2009) compared VSL for sudden death to VSL for an illness profile that involved one or five years of illness followed by death. They found that willingness to pay for a risk reduction was not significantly different across these three treatments, though this comparison confounds morbidity and latency.

One study that did claim to find a cancer differential was Viscusi, Huber and Bell (2014). They estimate a VSL of \$10.85 million for a cancer death. They compare this VSL to the median value of the VSL for an accidental death estimated from several studies, which they find to be \$9 million. From this they conclude that there is a positive cancer differential of twenty-one percent. Several points should be made about their findings. First, the \$10.85 million VSL estimate is based on a VSL of \$8.1 million for a cancer death with a ten-year latency. The \$10.85 million value was determined by discounting over ten

⁷ It should be noted that a second motivation for a positive cancer differential has been proposed, namely that people associate a higher level of dread with cancer risks than with other health risks (Sunstein 1997, for example).

years at a discount rate of three percent. People may use a method other than financial discounting to trade-off current and future health risks. Second, while Viscusi, Huber and Bell (2014) present confidence intervals for their VSL estimates, their own robustness checks show that the estimated VSL for cancer risks is sensitive to their analytical approach. Viscusi, Huber and Bell (2014) elicited willingness to pay values using a multiple-bounded dichotomous choice method. They found, as is often the case, that the estimated VSL differs depending on whether only the first response is used in the analysis or all responses are used. Specifically, they found that using all three responses per respondent resulted in a VSL estimate that was thirty-one percent higher than the VSL estimate based on only the first response. Had they used only the first response in their analysis, they would have concluded that the value of a cancer VSL was actually less than the median VSL value for accidental deaths.

In considering whether to apply a cancer premium, several points should be considered. First, it is unlikely that there would be a single cancer differential suitable for all types of cancer. The type and duration of morbidity prior to death from different types of cancer can be very different. Second, cancer is not the only mortality risk where death is typically preceded by significant morbidity. Chronic obstructive pulmonary disease and heart disease are two other relevant mortality risks where a premium might exist. Third, most existing VSL estimates are not really “pure” in the sense that they measure willingness to pay to reduce mortality risks absent any associated morbidity. Therefore, the following question is relevant: “is the value of avoiding a cancer death with a long debilitating period of morbidity larger than the value of avoiding the kinds of deaths valued in studies that have estimated VSLs?”

Based on the few available studies that provide “clean” comparisons of VSL for cancer mortality and VSL for other sources of mortality, the SAB concludes that there is not yet sufficient evidence to justify a specific non-zero cancer differential. The EPA should encourage more studies that examine how VSL may differ for different mortality risks, with particular attention paid to differences in VSL between mortality risks affected by EPA regulations and the accidental workplace mortality risks typically valued in hedonic wage studies. Gray literature studies, studies conducted outside the United States, and studies that do not directly estimate VSL, such as risk-risk trade-off studies and risk-benefit studies (see studies cited in Appendix C), could be examined to help determine whether there is evidence that the VSL for different mortality risks with different morbidity profiles differs. However, if and when it is determined that a cancer differential (or a differential for other diseases) is justified, the same selection criteria should be used to identify studies to measure the differential(s) and studies to establish the baseline VSL.

The EPA’s current practice is to use the same VSL to value cancer mortality risks and other mortality risks, and not to value morbidity that occurs prior to a cancer death. The EPA does value morbidity from non-fatal cancer cases, and includes cost of treatment for both fatal and non-fatal cases. This approach implicitly values the morbidity associated with fatal cancer and morbidity associated with the average types of death used to generate VSL estimates in the same way. While the SAB notes that there may well be a premium associated with cancer (or other relevant) mortality, until there is sufficient evidence to establish its size, the EPA’s current approach is reasonable and justified.

Key Recommendations

- Until sufficient new research is available to allow identification of premiums for different relevant mortality risks, the SAB recommends that the EPA continue its current practice of valuing cancer mortality using the same VSL used for other mortality risks, and not include a value for morbidity in cancer cases that result in death. The EPA should also continue its practice of including cost of

treatment for both fatal and nonfatal cancer cases, with appropriate attention to avoid double counting.

3.6. Income Elasticity of the Value of Statistical Life

3.6.1. Income Elasticity Literature

Charge Question 13. The EPA document Technical Memorandum: Income Elasticity presents a summary of the recent income elasticity literature based on a review presented in Robinson and Hammitt (2015). Please comment on whether Robinson and Hammitt (2015) and the EPA Technical Memorandum provide an appropriate and scientifically sound summary of the income elasticity of VSL (IEVSL) and income elasticity of non-fatal health effects literatures. If there are additional relevant empirical studies that should also be included in the summary, please provide citations.

The SAB finds that Robinson and Hammitt (2015) and the EPA document *Technical Memorandum: Income Elasticity* provide reasonable summaries of the income elasticity literature. The SAB does, however, recommend that the EPA consider including the study by Murphy and Topel (2006) and the meta-analysis by Mrozek and Taylor (2002) in the summary. If these studies are not included in the EPA analysis, the agency should provide justification for not including them because the studies provide information that should be relevant. The SAB generally finds that very little research has been conducted in this important area. The EPA should support more research to provide methodological guidance and empirical estimates of the income elasticity of VSL. One area to explore further, in the absence of explicit studies, is the possibility of using estimates of the income elasticity for other related goods and services to infer estimates of the income elasticity of VSL (e.g., Chetty 2006; Hall and Jones 2007). Examples of related goods and services to consider for this purpose could include consumer products that can be used to reduce health risks, such as bottled water and suntan lotion and various forms of health insurance. While this may require more research on the microeconomic foundation of such connections, the ability to use such estimates would greatly increase the empirical basis upon which to ground the income elasticity of the VSL. Moreover, giving greater attention to studies that have a clear identification strategy for linking environmental risks to behavior would also provide a more solid empirical basis for the income elasticity of the VSL.

Key Recommendations

- Very little research has been conducted on the income elasticity of the value of statistical life. The EPA should support more research to provide methodological guidance and empirical estimates in this important area. The EPA should also support research that may enable the use of estimates of the income elasticity for other related goods and services (such as consumer products that can be used to reduce health risks and various forms of health insurance) to infer estimates of the income elasticity of the value of statistical life, looking also to micro-econometric studies with clear and credible strategies for identifying causal effects.

3.6.2. Analysis of Very Low Income Elasticity Estimates

Charge Question 14. Several reported mean income elasticity estimates from stated preference studies are quite low, sometimes even zero. The “balanced” approach in the EPA Technical Memorandum does not include reported mean estimates of zero, but does include very low

reported mean estimates (e.g., 0.1). Please comment on whether this an appropriate and scientifically sound choice. How should very low, non-zero, mean reported income elasticity results be addressed in the analysis?

The SAB finds that, from a theoretical perspective, it is highly implausible for the income elasticity of VSL to be zero or negative. However, such estimates are statistically possible so there is little statistical justification for dropping them from the analysis, and the SAB recommends including them. Perhaps some of these estimates will not pass the stricter validity tests that will be imposed as discussed in the response to Charge Question 1a, and that may render this point moot. The SAB also recommends that, instead of calculating an unweighted mean of income elasticity of VSL estimates, the EPA should use standard errors of individual income elasticity of VSL estimates to calculate a weighted mean of the income elasticity of VSL. This approach will also be useful in addressing many of the very low elasticity estimates, which may have large confidence intervals.

Key Recommendations

- The EPA should include in the analysis the estimates from the papers with low/zero estimates of the income elasticity of VSL.

3.6.3. Study Selection Criteria and Alternative Approaches for Estimating Central Income Elasticity of Value of Statistical Life

Charge Question 15. Please comment on whether the selection criteria applied by Robinson and Hammitt (2015) are clearly enumerated, appropriate, and scientifically sound and whether the additional inclusion of Viscusi, Huber, and Bell (2014) in the Technical Memorandum is appropriate based on results reported in the study's on-line appendix (attached).

Charge Question 16. Given the relatively limited number of studies upon which to draw for estimating the income elasticity of VSL, the EPA Technical Memorandum describes two alternatives for arriving at a central income elasticity of VSL estimate and range for use in environmental policy analysis. Of these alternatives which is the most appropriate and scientifically sound? Please provide the rationale for your choice. Would it be appropriate to consider using the alternative as a sensitivity or uncertainty characterization?

Charge questions 15 and 16 pertain to the same general topic, how to best arrive at an estimate of the income elasticity of the VSL. These charge questions are therefore discussed together.

EPA's Selection Criteria and Alternatives for Estimating Income Elasticity of VSL

The SAB finds that neither of the two alternatives put forward in Robinson and Hammitt (2015) and described in EPA's technical memorandum represent an adequate basis for providing an estimate(s) of the income elasticity of VSL for policy purposes. With regard to the first option, using the central estimates and range from a meta-analysis, Robinson and Hammitt (2015) do an admirable job summarizing the available literature. Their analysis, however, drives home the point that there is not an adequate informational basis for deriving a consensus estimate of the income elasticity of VSL. The inclusion or non-inclusion of the Viscusi, Huber and Bell (2014) does not alter this conclusion. Robinson and Hammitt's (2015) inclusion of studies that are publically available, but not in the peer-reviewed literature clashes with the EPA study selection criteria used for determining a central estimate

for the VSL, but is best seen as an indication of the lack of an adequate information basis for estimating a central value for the income elasticity of VSL. The second option that Robinson and Hammitt (2015) put forward is to use estimates from the Viscusi (2015) meta-analysis of hedonic pricing results that rely on the CFOI data. This meta-analysis is recent and was performed competently but the set of studies used is somewhat narrow. The preferred estimates from this study are substantially larger than those found in other recent meta-analyses that draw on broader set of studies, including those by Lindhjem, et al. (2011) and Doucouliagos, Stanley and Viscusi (2014) which suggest much lower central values for the income elasticity of VSL.

Nature of the Problem Faced in Estimating Income Elasticity of VSL

It is useful to understand several aspects of the nature of the problem faced in arriving at an estimate of the income elasticity of VSL for policy purposes.

1. To estimate the income elasticity of VSL, variation in income is needed. However, there has been relatively little change in median income over the last two decades particularly for groups represented in the samples used for hedonic wage studies. Changes in per capita income have been more pronounced, but much of the change has been in the two tails of the income distribution. This calls into question what the appropriate income variable is if a causal relationship is needed.
2. Some studies estimate the income elasticity of VSL from a cross section of individuals while others estimate the income elasticity of VSL from time series data. It is well known that estimates based on cross sectional data measure what would be expected to happen to an individual's VSL if that individual swapped income with someone else in the current income distribution. In contrast, income elasticity of VSL estimates based on a time series measure provide an estimate of how VSL statistics would shift if the entire income distribution rises or falls. The EPA's use of income elasticity of VSL estimates to adjust VSL estimates over time generally calls for a time series-based measure⁸.
3. The hedonic wage approach does not, by design, provide an estimate of the income elasticity of VSL.⁹ Indeed, income is inherently endogenous in the standard hedonic wage equation due to the nature of the risk-wage trade-off. This raises important theoretical issues concerning the definition of income that have not been well explored in the literature given the EPA's intention to use the income elasticity of a VSL to account for income growth.
4. While stated preference studies are carefully designed to produce reliable VSL estimates, this is not the case for income elasticity of VSL estimates. The single income question asked in the typical stated preference survey is most often taken from standard government surveys and its initial use is to help make a determination as to whether the data collected are adequately representative of the population of interest with respect to income. This is done by comparing the distribution in income to that of U.S. Census Bureau statistics. This type of income question is

⁸ The income elasticity of a VSL is also related to the coefficient of relative risk aversion, a preference parameter that plays an important role in many other economic analyses. Evans and Smith (2010) provide exploration of this issue that should be useful to EPA in examining this issue further.

⁹ The use of quantile regression, e.g., Kniesner et al. (2010) and Evans and Schaur (2010), to estimate a hedonic wage equation can potentially provide a cross-sectional estimate of the income elasticity of VSL at different points in the wage distribution if there is wage-related heterogeneity in the wage-risk trade-offs being made by individuals in the sample.

known to be fraught with measurement error due to substantial respondent heterogeneity with respect to what constitutes income, and to suffer from having a high rate of missing values.¹⁰ It has long been known that in order to adequately measure income, a very large set of questions about specific types of income and monetary transfers is required.¹¹ Furthermore, from a theoretical perspective, income is not the correct variable that should help determine the risk-wage trade-off but rather the correct variable in the absence of borrowing constraints and committed expenditures is permanent income. The best that can be hoped for is that a simple regression of this variable on income, as typically measured in surveys, has independent and identically distributed normal error terms. In this case, the presence of classical measurement error is known to bias the estimate of the income elasticity of VSL downward, a result that has considerable support in the broader literature on income elasticities. The situation is more complex in the case of non-classical measurement error, and an assessment of the implications of measurement error would require examination of the specific income measure and VSL model being used.

Methodologies for Estimating Income Elasticity of VSL

Evans and Smith (2010) identify four methodologies to estimate the income elasticity of VSL: (1) stated preference studies; (2) meta-analyses of hedonic wage studies; (3) cross-country comparisons of VSL estimates; and (4) comparisons of VSL estimates at different points in time for a single country. Robinson and Hammitt (2015) concentrate on the first two. The two main problems with the stated preference estimates of the income elasticity of VSL were noted previously: they are cross-sectional estimates rather than time series estimates and they suffer from substantial measurement error problems with respect to income. A meta-analysis of hedonic wage studies might serve as a basis on which to estimate the income elasticity of VSL. However, to make this work one needs a large number of studies across time periods with both income variation and a relatively constant mix of estimation techniques used to estimate the VSL in those different time periods. Unfortunately, there are not a large number of available studies and the desire of journals to publish papers using new methodologies means that particular methodologies for estimating the VSL are always confounded with time/income variation.¹² Using cross-country comparisons of VSL estimates is an attempt to increase the range of income levels observed and hence to be able to statistically estimate the income elasticity of VSL with reasonable precision. There are several difficulties with this approach. The preferences of people in other countries may be systematically different from people living in the United States. Indeed, this is the rationale advanced by the EPA for not relying on VSL estimates in other countries. A variant of the cross sectional data problem is seen when considering the situation where the different VSL estimates used in estimating the income elasticity of VSL come from different countries in the same year.

The fourth approach of comparing VSL estimates at different points in time from a single country provides a coherent way to obtain an income elasticity of VSL estimate for policy purposes. An example of this approach is found in Costa and Kahn (2004) who look at the evolution of the VSL from 1940 to 1980. Their work is not relevant to the EPA's current need because their analysis stops in 1980 and the

¹⁰ A common example here is that some retired people view drawing money from a retirement savings account like an IRA to be income while others don't.

¹¹ For the two exemplars of purpose built that do this, see the Survey of Consumer Finances sponsored by the U.S. Federal Reserve Board and the U.S. Census Bureau's Survey of Income and Program Participation.

¹² It would also be desirable to have a number of distinct data sources among the studies used in the meta-analysis that were evenly distributed over time periods with different income. Unfortunately, the available studies often share some common data sources but are idiosyncratic enough with respect how key variables are constructed that these differences too are confounded with the specific time period when the study was conducted.

CFOI risk data being used in current hedonic wage studies does not exist for the time period Costa and Kahn examine. It would be possible, however, to examine one of the currently preferred VSL hedonic wage model specifications that can be estimated by combining the U.S. Census Bureau's Annual Social and Economic Supplement to the CPS with CFOI data.¹³ By holding the methodology and data sources used to estimate the VSL constant, it should be possible to use the income variation over the last two decades to obtain a defensible income elasticity of VSL estimate.¹⁴ Each annual cross section of the CPS can be used to produce a VSL estimate. To each of these VSL estimates, the desired measure of income for that year can be attached. Calculation of the income elasticity of VSL is then a straightforward econometric exercise.

The sensitivity of the income elasticity of VSL estimate to the different model specifications for estimating the VSL can be examined if there are two or more models that the EPA deems to represent best theoretical and econometric practice. In this situation, the resulting income elasticity of VSL estimates can be averaged if there is not a clear reason for favoring one model specification over another. The sensitivity of the income elasticity of VSL estimate to the particular definition of income can also be examined and may be of greater empirical relevance. For example, income elasticity of VSL estimates could be estimated using median per capita income and GDP per capita. The income elasticity of VSL estimate(s) to be used in assessing regulations could be updated at regular intervals simply by adding VSL estimates based on more recent years of the CPS, with earlier time period perhaps given less weight in determining the income elasticity of VSL estimate following the literature on time series forecasting. This fourth approach could be implemented in a relatively timely manner and should be capable of providing the EPA with a reliable estimate of the magnitude of the income elasticity of VSL that could be used for policy purposes.

Key Recommendations

- Neither of the two alternatives put forward in Robinson and Hammitt (2015) and described in EPA's technical memorandum represent an adequate basis for providing an estimate(s) of the income elasticity of VSL for policy purposes. Comparing VSL estimates at different points in time from the same U.S. data source provides a coherent way to obtain an income elasticity of VSL estimate for policy purposes. The SAB recommends selecting one or more of the currently preferred VSL model specifications that can be estimated by combining the U.S. Census Bureau's Annual Social and Economic Supplement to the CPS with CFOI data and using the income variation over the last two decades to obtain a defensible income elasticity of VSL estimate.
- The SAB recommends examining the sensitivity of the income elasticity of VSL estimate to different model specifications and averaging the resulting income elasticity of VSL estimates if there is not a clear reason for favoring one model specification over another. Sensitivity of VSL estimates to different definitions of income should also be examined.

¹³ In principle, it would be possible to use the same general approach with stated preference data if the same survey instrument was administered annually to a large sample of respondents from the general population and if the same sampling and interviewing protocol was used.

¹⁴ Much of the effort would be in the form of preparing the CPS and CFOI data for the first cross-sectional hedonic wage regression. Because subsequent cross sections would use the same variable definitions and industry-occupation fatality rates, the data preparation and program effort involved should be substantially reduced. Some of hedonic wage regressions use the CFOI rates averaged over multiple years. Doing this is similar to including a lagged regressor in the sense of reducing the effective number of observations in the regression model by the length of the lag period.

3.6.4. Income Elasticity of the Value of Non-fatal Health Effects

Charge Question 17. As described in Robinson and Hammitt (2015), there are limited data on income elasticity of non-fatal health effects. As a result, the Technical Memorandum recommends using the income elasticity of VSL to estimate income elasticity for the value of these non-fatal health risks. Please comment on whether this represents an appropriate and scientifically sound approach given the available data.

The SAB recognizes that there are limited data available on income elasticity of non-fatal health effects but does not support using the income elasticity of VSL to estimate income elasticity for the value of these non-fatal health risks as an interim solution. The SAB finds that, without a theoretical or empirical justification, it is conceptually incorrect to apply income elasticity for one good to some other good, even though the two goods are related in some way. However, it may be possible to use a conceptual model of averting expenditures to show the conditions under which the income elasticities of private health care products could be used as a proxy for the income elasticity of the value of non-fatal health effects. The SAB recommends that the EPA support research to develop such a model. The ability to use estimates of income elasticity of private health care products as a proxy would greatly increase the empirical basis upon which to ground income elasticity of the value of non-fatal health effects.

Key Recommendation

- The SAB does not support using the income elasticity of VSL to estimate income elasticity for the value of non-fatal health risks because, without a theoretical or empirical justification, it is conceptually incorrect to apply income elasticity for one good to some other good, even though the two goods may be related in some way. The SAB recommends that the EPA support research to develop a conceptual model of averting expenditures to show the conditions under which the income elasticities of private health care products could be used as a proxy for the income elasticity of the value of non-fatal health effects.

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APPENDIX A: THE EPA'S CHARGE QUESTIONS

Charge Questions for SAB-EEAC Review of an EPA White Paper: "Valuing Mortality Risk for Environmental Policy: A Meta-Analytic Approach" and Technical Memorandum: "Income Elasticity of VSL"

February 2016

White Paper: Meta-analysis dataset

The White Paper assembles a database of stated preference and hedonic wage estimates of the value of statistical life (VSL) and, where possible, their standard errors. Criteria for inclusion in the database are based on recommendations from the SAB-EEAC (U.S. EPA Science Advisory Board 2011) (see section 4.4, page 13-20). EPA requests comments on whether the selection criteria previously recommended by the SAB-EEAC were appropriately interpreted and applied both for selecting studies to include in the meta-analysis and for selecting estimates within studies. **In answering questions 1(a) – 1(c), in addition to responding to the specific questions, please comment, in general, on whether the selection criteria previously recommended by the SAB-EEAC have been appropriately interpreted and applied in the White Paper.**

- 1a. Evidence of validity for stated preference studies: The SAB noted in its earlier advisory report (U.S. EPA Science Advisory Board 2011) that each selected stated preference study "should provide evidence that it yields valid estimates" (page 16). The SAB did not, however, specify how validity should be assessed. In applying this criteria, EPA included studies and estimates that passed a weak scope test or provided other evidence of validity (e.g., a positive coefficient on the risk variable as in the appendix for Viscusi, Huber and Bell 2014) as explained in Appendix B of the White Paper. Please comment on whether the methods EPA used in the White Paper to assess the validity of studies and estimates are appropriate and scientifically sound.
- 1b. Construct of the risk variable in hedonic wage studies: The SAB noted in its earlier advisory that the EPA should "Eliminate any study that relies on risk measures constructed at the industry level only (not by occupation within an industry)" (U.S. EPA Science Advisory Board 2011, page 18). It is not clear whether the SAB's parenthetical addition was meant as an example or as a directive. Only four studies constructed the risk variable by occupation and industry and met other selection criteria. In applying this criteria EPA included studies and estimates where the risk measure is differentiated by industry and at least one other characteristic (e.g., occupation, gender, age). Please comment on whether the hedonic wage studies included in the White Paper constructed the risk variable in a manner appropriate for use in the meta-analysis.
- 1c. Estimates for immediate risk reductions: To estimate the average value of the marginal willingness to pay for reduced risk of immediate death, the EPA selected estimates from the Stated Preference literature that are most closely comparable to the accidental deaths from the hedonic wage literature. The EPA made several judgment calls in determining the appropriate estimates to use from the stated preference literature. Specifically, Viscusi, Huber and Bell (2014) estimate reductions in risk of bladder cancer that will occur in 10 years. The authors discount the estimates to derive a comparable estimate for an immediate

risk reduction. Alberini, et al. (2004) estimate a willingness to pay for an annual reduction in risk over 10 years. We include estimates from both of these studies in the meta-analysis. Please comment on whether appropriate estimates from the stated preference literature were used in the White Paper to estimate the marginal willingness to pay for reduced risk of immediate death.

2. Please comment on whether relevant empirical studies in the stated preference and hedonic wage literatures are adequately captured in the White Paper. If additional studies should be included in the White Paper please provide citations.
3. Some estimates in the meta-analysis dataset in the White Paper are constructed by weighting subpopulation-specific estimates within a study in order to approximate an estimate for the general population. The specific weights used are described in Appendix B of the White Paper. Please comment on whether the population-weighting approach used in the White Paper is appropriate and scientifically sound.
4. In some cases EPA estimated standard errors in the White Paper using information within studies or provided by the study authors, as described in Appendix B. Please comment on whether the methods used in the White Paper to estimate standard errors when such information was not readily available are appropriate and scientifically sound.

White Paper: Analysis

Section 4 of the White Paper describes methods used to estimate representative VSL estimates from the meta-analysis dataset and presents results.

5. Please comment on whether the methodology used in the White Paper to analyze the data represents an appropriate and scientifically sound application of meta-analytic methods to derive generally applicable VSL estimates for environmental policy analysis.
6. The White Paper classifies estimates into independent samples, also called groups, as described in Section 4. Estimates from some hedonic wage studies that use the same or very similar worker samples are grouped together for the analysis. Similarly, some of the stated preference estimates using the same sample are grouped together. Please comment on whether this methodology represents an appropriate and scientifically sound approach for accounting for potential correlation of results that rely on the same underlying data.
7. Section 4.1 of the White Paper presents an expression that characterizes optimal weights that account for sampling and non-sampling errors, a framework that guides EPA's approach. Please comment on whether this is an appropriate and scientifically sound approach for addressing sampling and non-sampling errors.
8. The analysis in the White Paper adopts both non-parametric and parametric approaches (sections 4.1 and 4.2, respectively). Please comment on whether these approaches span a reasonable range of appropriate, scientifically sound, and defensible approaches to estimating a broadly applicable VSL for environmental policy and whether there are other methods that are more appropriate than those used in the White Paper.

White Paper: Results

9. The White Paper presents estimates using parametric and non-parametric models, pooled across stated preference and hedonic wage studies as well as balanced (i.e., equal weight to each study type), and weighted using different approaches. Of the range of estimates presented (see Section 4) the White Paper proposes the use of estimates from the following models:
 - Non-parametric model, balanced, mean of study mean
 - Parametric, balanced

Please comment on whether these proposed estimates represent reasonable and scientifically sound conclusions from the analyses in the White Paper and whether there is a different set (or sets) of results that are preferable based on the data and analysis in the White Paper.

10. The results section of the White Paper concludes with an influence analysis. Please comment on whether this analysis is a reasonable way to characterize the influence of individual studies on the estimated VSLs, whether the results of the influence analysis suggest any changes or modifications to the estimation approach, and whether it is important to include an influence analysis.

Establishing a Protocol for Future Revisions:

11. In the previous SAB advisory report (USEPA Science Advisory Board 2011), the SAB endorsed the idea of establishing a standardized protocol and regular schedule for future updates to the Agency's mortality risk valuation estimates. Please comment on relevant statistical criteria for the inclusion of additional eligible estimates and/or the exclusion of older estimates that could help inform the development of a standardized protocol for future updates and the timing or frequency of those updates.
12. In its 2011 report the SAB-EEAC recommended "...EPA work toward developing a set of estimates...for policy-relevant cases characterized by risk..." (U.S. EPA Science Advisory Board 2011, pp. 10). Among the studies that meet the selection criteria in the current White Paper, three stated preference studies provide values for reductions in risks of cancer (i.e., Hammitt and Haninger 2010, Chestnut, Rowe, and Breffle 2012, and Viscusi, Huber and Bell 2014). Only two of those studies (Hammitt and Haninger 2010 and Chestnut, Rowe, and Breffle 2012) allow for a within study comparison of values for cancer and non-cancer risk reductions. However, EPA could augment the literature by modifying the selection criteria to include studies from other countries or from the grey literature, and/or using other methods (e.g., risk-risk studies). Please comment on whether, and if so how, selection criteria for identifying studies for estimating a cancer differential should differ from those used in the current White Paper. Does the literature support a non-zero cancer differential?

Technical Memorandum: Income elasticity

13. The EPA document *Technical Memorandum: Income Elasticity* presents a summary of the recent income elasticity literature based on a review presented in Robinson and Hammitt (2015). Please comment on whether Robinson and Hammitt (2015) and the EPA Technical Memorandum provide an appropriate and scientifically sound summary of the income elasticity of VSL (IEVSL) and income elasticity of non-fatal health effects literatures. If there are additional relevant empirical studies that should also be included in the summary, please provide citations.
14. Several reported mean income elasticity estimates from stated preference studies are quite low, sometimes even zero. The “balanced” approach in the EPA Technical Memorandum does not include reported mean estimates of zero, but does include very low reported mean estimates (e.g., 0.1). Please comment on whether this an appropriate and scientifically sound choice. How should very low, non-zero, mean reported income elasticity results be addressed in the analysis?
15. Please comment on whether the selection criteria applied by Robinson and Hammitt (2015) are clearly enumerated, appropriate, and scientifically sound and whether the additional inclusion of Viscusi, Huber, and Bell (2014) in the Technical Memorandum is appropriate based on results reported in the study’s on-line appendix (attached).
16. Given the relatively limited number of studies upon which to draw for estimating the income elasticity of VSL, the EPA Technical Memorandum describes two alternatives for arriving at a central IEVSL estimate and range for use in environmental policy analysis. Of these alternatives which is the most appropriate and scientifically sound? Please provide the rationale for your choice. Would it be appropriate to consider using the alternative as a sensitivity or uncertainty characterization?
17. As described in Robinson and Hammitt (2015), there are limited data on income elasticity of non-fatal health effects. As a result the Technical Memorandum recommends using the IEVSL to estimate income elasticity for the value of these non-fatal health risks. Please comment on whether this represents an appropriate and scientifically sound approach given the available data.

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APPENDIX B: BIBLIOGRAPHY ON WILLINGNESS TO PAY IN HEALTH AND HEALTH CARE

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APPENDIX C: BIBLIOGRAPHY ON BENEFIT-RISK AND RISK-RISK TRADE-OFF PREFERENCES IN HEALTH AND HEALTH CARE

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