IEc

MEMORANDUM | March 31, 2012

TO Neal Fann, U.S. Environmental Protection Agency, Office of Air and Radiation

FROM Lindsay Ludwig and James Neumann, Industrial Economics, Incorporated

SUBJECT Updating Income Elasticity Estimates in EPA's BenMAP Air Pollution Benefits Estimation System

INTRODUCTION

When quantifying the dollar value of changes in the risk of air pollution-related health impacts, the U.S. Environmental Protection Agency (EPA) often applies willingness to pay (WTP) estimates.[1] Economic theory argues that WTP for a reduction in the risk of an adverse health outcome will increase with the growth in real income. However, WTP may not change at the same rate as income. When performing an air pollution benefits analysis, EPA accounts for the effect of changes in real income on WTP in a two-step process: (1) projecting growth in real income to the analytical year of the benefit analysis; and (2) applying income elasticity estimates to adjust WTP estimate. These elasticity estimates represent the proportional change in WTP that results from a change in income, and are likely to vary depending on the severity of the effect and other factors.[2] Projections of income growth and income elasticity estimates are combined to generate growth adjustment factors for future years.

This memorandum includes five sections. First, we provide some background on past and current income-adjustment practices and older estimates of income elasticity that inform these practices, including the practices of agencies other than EPA. Second, we summarize the Science Advisory Board (SAB) advice to EPA on income elasticity and valuation studies more generally, and the standards of methodological practice that emerge from that advice. In the third section, we provide a review of the newer studies that generally meet these emerging standards. The memorandum concludes with our initial recommendations of specific updated income elasticity values to be used by EPA to adjust morbidity and mortality estimates for income growth. EPA's Benefits Mapping and Analysis Program (BenMAP) uses these income elasticity estimates to adjust WTP values for avoided premature mortality and severe and minor morbidity from a variety of studies. Four appendices to this memorandum provide additional detail. Appendix A provides additional detail on the morbidity and mortality studies included in the literature reviews that informed EPA's past and current income-adjustment practices. Appendix B provides additional detail on the morbidity and mortality studies reviewed in this memorandum. Appendix C provides income growth adjustment factors for 2000 through

[1] We would like to acknowledge and thank Lisa Robinson for her advisory role on this project.

[2] More specifically, assuming that elasticity is constant over the income levels of concern, it can be used to estimate the change in WTP as: $WTP_B = WTP_A * (Income_B/Income_A)^{elasticity}$.

2030 calculated using the income data and elasticities recommended in this memorandum. Finally, Appendix D provides a review of alternative sources for medium-term (two to three decade) income growth projection data and our recommendation for use in EPA air pollution benefits assessment.

BACKGROUND

In June 1999, IEc prepared a memorandum for EPA reviewing valuation studies that provided income elasticity estimates; the memo included a series of recommendations for implementing income-growth adjustments to health-related WTP measures (IEc, 1999). In September 2004, IEc updated the 1999 literature review and provided new recommendations as part of a memorandum responding to SAB Council comments on the May 2003 Draft Analytical Plan for the Section 812 Section Prospective Analysis (IEc, 2004). BenMAP relies on the recommendations made in these two memorandums to allow users to adjust WTP estimates to account for the growth in income over time. In particular, BenMAP includes income growth factors derived from:

1. Per-capita Gross Domestic Product (GDP) calculated using population estimates from the U.S. Census Bureau and estimates of real GDP from the Bureau of Economic Analysis (BEA) and the Congressional Budget Office (CBO). BEA provides annual estimates of historical real GDP and CBO provides annual projections of real GDP.
2. Income elasticity estimates for three types of health effects: minor, severe, and premature mortality. Exhibit 1 summarizes the income elasticity estimates currently found in BenMAP, which are based on those recommended in IEc's 1999 memorandum.

EXHIBIT 1. CURRENT BENMAP INCOME ELASTICITY ESTIMATES

HEALTH ENDPOINT	LOW ESTIMATE	CENTRAL ESTIMATE	HIGH ESTIMATE
Minor Health Effects[a]	0.04	0.15	0.30
Severe and Chronic Health Effects[b]	0.25	0.45	0.60
Premature Mortality[c]	0.08	0.40	1.00

Notes:
(a) Includes asthma exacerbation, acute bronchitis, acute respiratory symptoms (minor restricted activity days), lower respiratory symptoms, and upper respiratory symptoms.
(b) Includes chronic bronchitis and chronic asthma.
(c) Many analyses characterize this range with a triangular distribution with a resulting mean estimate of approximately 0.48.

STUDIES INCLUDED IN IEC'S 1999 AND 2004 REVIEWS

The income elasticity estimates contained within BenMAP are based on studies previously reviewed by IEc in 1999 and 2004. The income elasticity estimates derived from these studies are summarized below. Additional detail on these studies is provided in Appendix A and B.

Morbidity

There are several approaches to the valuation of morbidity endpoints. The most commonly cited are stated preference studies and cost of illness (COI) studies.[3] Historically, stated preference studies were the primary source from which estimates of income elasticity of WTP were derived. The stated preference studies that are applicable in this context solicit ex ante estimates of WTP to avoid an adverse health effect based on a description of an illness' symptoms and severity. The health effects found in these studies can be loosely separated into two groups, minor and severe morbidity endpoints. Minor health effects typically have symptoms with short durations (e.g., a day to a few weeks) and tend to be labeled "acute." Alternatively, severe health effects are chronic and have longer durations.

Exhibit 2 summarizes the estimates of income elasticity of WTP to avoid adverse health effects from studies previously reviewed by IEc in 1999 and 2004. In these reviews IEc identified 12 sources of income elasticity estimates, including studies: (i) estimating the WTP to avoid morbidity, (ii) estimating the WTP to avoid injury, and (iii) estimating the demand for health care. Since the studies identified in Exhibit 2 were completed, many new studies have become available, and the standards for methodological acceptance have evolved significantly as discussed in detail below.[4] Additional detail on these studies is provided in Appendix A.

Mortality

Both economic theory and numerous empirical studies indicate that the value per statistical life (VSL) increases as income increases.[5] The key question is whether the increase in VSL is proportionate to the increase in income, and if not, whether mortality risk reductions can be viewed as a "luxury" good (i.e., WTP for risk reductions grows faster than income, with an elasticity greater than 1.0) (Hammitt and Robinson, 2010). Multiple approaches have been used to estimate the income elasticity of VSL. IEc's previous literature reviews identified studies that use the following three approaches: (1) stated preference surveys; (2) longitudinal wage-risk studies; and (3) meta-analysis of (primarily) wage-risk studies. In addition, IEc identified two literature reviews (NERA/CASPAR, 1998 and Krupnick et al., 1995) that provide a recommended range for income elasticity of VSL. Exhibit 3 summarizes the estimates for WTP for reduced risk of mortality from studies previously reviewed by IEc in 1999 and 2004. As with the morbidity studies, many of the studies identified in Exhibit 3 no longer meet the current standards of methodological acceptance which are discussed in detail below. Additional detail on these studies is provided in Appendix A.

---

[3] Note that COI studies are not relevant to this discussion. Costs analyzed in these studies are driven by factors other than income growth and thus the elasticities derived from COI studies should not be used.

[4] Note that we have not evaluated the studies previously reviewed by IEc to determine if they meet the current standards of methodological acceptance. In some cases, such as studies conducted outside of the U.S., it is clear that they do not.

[5] VSL is defined as the WTP for a small mortality risk reduction in a defined time period divided by the change in risk. Note that in recognition of the confusion and controversy caused by the VSL term, EPA is considering a terminology change. The Science Advisory Board (SAB) has suggested replacing the term VSL with "value of risk reduction," or VRR.

EXHIBIT 2. INCOME OF ELASTICITY OF WTP TO AVOID MORBIDITY EFFECTS FROM STUDIES PUBLISHED PRIOR TO 2004

VALUATION STUDY	COUNTRY	INCOME ELASTICITY OF WTP[1]	
		MINOR HEALTH EFFECT ESTIMATE	SEVERE HEALTH EFFECT ESTIMATE
Alberini and Krupnick (1998)	Taiwan	0.41	N/A
Alberini et al. (1997)[2]	Taiwan	N/A	0.45
Chestnut *et al.* (1996)[3]	United States	N/A	1.25
Liu et al. (2000)	Taiwan	0.40 – 0.45	N/A
Loehman and De (1982)[2,3]	United States	0.26	0.60
Rowe and Chestnut (1985 and 1986)[2,3]	United States	0.06	0.51
Persson et al. (1995)[2]	Sweden	N/A	0.25 - 0.37
Holtmann and Olsen (1978)[2]	United States	0.06 - 0.30	N/A
Manning et al. (1981)[2]	United States	0.04	N/A
Phelps (1975)[2]	United States	0.11	N/A
Viscusi and Evans (1990)[3]	United States	0.67	1.10
Viscusi and Evans (1993)[2,3]	United States	0.17	0.38

Notes:
1. N/A = Not Applicable
2. Used in developing IEc's 1999 recommendations.
3. Used in developing IEc's 2004 recommendations.

EXHIBIT 3. INCOME ELASTICITY OF WTP TO AVOID MORTALITY FROM STUDIES PUBLISHED PRIOR TO 2004

VALUATION STUDY	COUNTRY	INCOME ELASTICITY OF WTP	
		LOW ESTIMATE	HIGH ESTIMATE
Alberini *et al.* (2004)[2]	United States	0.69	0.90
Corso, Hammitt, and Graham (2000)[2]	United States	0.41	0.41
Blomquist (1979)[1,2]	United States	0.30	0.30
Johannesson and Johansson (1997)[1]	Sweden	0.22	0.25
Jones-Lee *et al.* (1985)[1]	United Kingdom	0.32	0.40
Miller and Guria (1991)[1]	New Zealand	0.30	0.60
Mitchell and Carson (1986)[1,2]	United States	0.35	0.35
Persson *et al.* (1995)[1]	Sweden	0.46	0.62
Costa and Kahn (2004)	United States	1.50	2.07
Hammitt *et al.* (2000)	Taiwan	1.47	3.13

VALUATION STUDY	COUNTRY	INCOME ELASTICITY OF WTP	
		LOW ESTIMATE	HIGH ESTIMATE
Viscusi and Evans (1990)[1]	United States	0.67	1.10
Bowland and Beghin (2001)	Multiple (US and non-US)	1.66	2.27
Krupnick *et al.* (1995)[1]	Multiple (US and non-US)	0.35	1.0
Liu, Hammitt, and Liu (1997)	Multiple (US and non-US)	0.53	0.53
Miller (2000)	Multiple (US and non-US)	0.85	1.00
Mrozek and Taylor (2002)	Multiple (US and non-US)	0.46	0.49
NERA/CASPAR (1998)[1]	Multiple (US and non-US)	0.30	1.1
Viscusi and Aldy (2003)	Multiple (US and non-US)	0.51	0.61

Notes:
1. Used in developing IEc's 1999 recommendations.
2. Used in developing IEc's 2004 recommendations.

ELASTICITY RECOMMENDATIONS BY FEDERAL AGENCIES

Currently the U.S. Department of Transportation (DOT), Customs and Border Protection (CBP) within the Department of Homeland Security (DHS), and EPA have developed approaches to adjust VSL for changes in income. DOT recently updated their 2008 guidance on how to adjust VSL to reflect past and future income growth. (DOT, 2011). In their 2008 guidance (DOT, 2008), DOT suggests adjusting VSL for both inflation and income growth from the dollar year reported in each underlying study to current (2007) dollars. DOT uses the Consumer Price Index (CPI) to adjust for inflation and an income elasticity estimate of 0.55 based on Viscusi and Aldy (2003). It applies the elasticity estimate to changes in the wages and salary component of the Employment Cost Index.[6] The 2011 guidance adds recommendations for adjusting VSL to account for future income growth. To estimate income growth, it uses the Congressional Budget Office's estimate of long-term annual growth rate of labor productivity, 1.6 percent, and then applies an income elasticity of 0.55.

DHS currently uses a VSL expressed in 2007 dollars, based on a 2008 analysis conducted for CBP (Robinson, 2008). In determining their recommendations, CBP focuses on estimates of elasticity and real income growth that rely on similar data and methods as their base VSL which is derived from Viscusi (2004). Specifically, CBP relies on income elasticity estimates from Viscusi and Aldy (2003) Model 6. This model controls for the largest number of variables that may influence the estimates and also includes an adjustment for outliers that may distort the results. The income elasticity estimates from

[6] The Employment Cost Index measures the change in the cost of labor. This index is calculated on a quarterly basis and not projected into the future. Note that this index differs from the earnings data presented below.

this preferred model include a mean of 0.47 and a 95 percent confidence interval ranging from 0.15 to 0.78. CBP relies on data from the Current Population Survey to estimate the past change in real income over time. The agency uses this data because it is the same source used in the underlying Viscusi (2004) study, so relies on a comparable definition of income. The Current Population Survey income data represent earnings before taxes and other deductions and include any overtime pay, commissions, or tips usually received (BLS, 2011a). It should be noted that while the data provided by the Current Population Survey are sufficient to adjust the VSL estimate to the base dollar year used in homeland security regulatory analyses, they do not include projections for future years.

CURRENT ADVICE TO EPA AND STANDARDS RELATED TO INCOME ELASTICITIES

This section discusses the SAB's recent advice to EPA on the appropriate range of income elasticities to be used when adjusting estimates of WTP for reduced risks to mortality. In addition, this section reviews the more general valuation research standards that emerged from the SAB's review of criteria proposed by EPA. Although the SAB's advice and the emerging standards relate specifically to mortality, many are also applicable to morbidity studies. EPA has not yet determined, however, whether to accept the SAB recommendations and incorporate them into its official guidance.

SAB ADVICE TO EPA

EPA's current method to adjust VSL for changes income is described above and references IEc's 1999 memorandum. This guidance was most recently re-stated in EPA's 2010 Guidelines for Preparing Economic Analyses (EPA, 2010a). These guidelines note that EPA was engaging in a consultation with the Science Advisory Board-Environmental Economics Advisory Committee (SAB-EEAC) on both VSL and on the appropriate range of income elasticities.[7]

The White Paper prepared for that consultation (EPA, 2010b) suggests that EPA's currently recommended estimate of the income elasticity of VSL (mean value 0.48) appears to be on the low end of the range of estimates and may need to be updated to a higher value or range of values. In their response, SAB-EEAC (2011) suggests that the income elasticity of VSL may vary with risk and individual characteristics. Although this observation is likely true, the current body of literature on VSL income elasticity is not sufficiently robust to warrant matching elasticity estimates to the type of risk. SAB-EEAC also recommends that EPA attempt to characterize the distribution of income elasticity. In advance of EPA's comments on this memorandum, it is unclear to us whether the literature supports a distribution or it would be better to provide a range of values with a central estimate.

CURRENT RESEARCH STANDARDS

Recently, EPA has reviewed its approach to valuing the reduced risks of mortality. This review was prompted by the quantity of new research on the subject and significant methodological improvements. This section discusses these methodological improvements and explores EPA's current standards of methodological acceptance. In

[7] The SAB was established to provide independent scientific and technical advice to the EPA on the technical basis for Agency positions and regulations.

their recent White Paper (EPA, 2010b), EPA assembled two databases summarizing the two primary literatures used to assess WTP for mortality risk reductions: stated preference studies and hedonic wage-risk studies. EPA also outlined the selection criteria employed in creating these two databases. The objective of the selection criteria is to exclude low-quality studies and ensure applicability in the United States. SAB-EEAC reviewed these selection criteria and added to them in their 2011 advisory letter.

Stated Preference Studies

The selection criteria for stated preference studies as introduced by EPA and revised by SAB-EEAC are:

1. Minimum precision of the WTP estimate; [8]
2. Sample frame based on appropriate population;
3. Conducted in the United States;
4. Written in English;
5. Provides an estimate of WTP (estimates of WTA should not be used);
6. Provides estimates for WTP for risk reductions to adults (estimates for risk reductions to children should not be used except in the case of children's risks);
7. Provides enough information to calculate a WTP estimate if one is not reported in the paper; and
8. Provides evidence that estimated WTP is valid (e.g., evidence that study passes a weak scope test, i.e., that estimated WTP increases with the size of the risk reduction that is valued).

This last point is particularly important, because many of the published stated preference studies do not pass a scope test. A weak scope test demands only that WTP increases with the size of the risk reduction. A strong test demands that WTP increases in proportion to the size of the risk reduction. In addition, there are two types of scope test: internal and external. Internal scope tests compare WTP within a sample of survey respondents, while external scope tests compare WTP between subsamples of respondents. External scope tests are generally viewed as superior to internal scope tests because respondents could provide mutually consistent estimates of WTP for different risk reductions even if their response to the first valuation question is random (SAB-EEAC, 2011). Of the studies compiled by EPA in their 2010 White Paper only approximately half of the estimates were subject to a scope test. Of these, 90 percent of the VSL estimates passed a weak scope test (WTP increases with the size of the risk reduction), but only 15 percent passed a strong form of the test (WTP increases proportionally with the size of the risk reduction) (Cropper, Hammitt, and Robinson, 2011).

As much as possible, we applied the criteria listed above in our literature review and have only included studies in this memorandum that meet these criteria. In particular, criteria

[8] EPA originally proposed a criterion setting a minimum sample size of 100. In their review, SAB-EEAC suggested that setting a minimum acceptable sample size is not a useful criterion. Instead the criterion should be based on precision of the estimate although the Council does not suggest a specific precision level.

number three through seven are easy to apply. For the criteria that are open to interpretation, we report data that can be used to help determine whether the criteria has been met, but do not make any judgments at this time. As originally posed by EPA in their White Paper (2010b), criterion number one indicated a minimum sample size of 100. SAB-EEAC argued that setting a minimum acceptable sample size is not useful and instead argued in favor of a criterion based on precision of the estimate. SAB-EEAC does not indicate what minimum standard error would be considered acceptable. For simplicity, we have included sample size for all studies included in our literature review. Criterion number two seeks to eliminate studies where the sample does not represent the appropriate population. For most of their work EPA seeks to represent the general population and therefore seeks to exclude convenience samples. Indicators of a convenience sample include a small sample size or a focus on only a particular age group. We have included sample size and age range studied in our literature review. Criterion number eight states that studies should provide evidence that the WTP estimate is valid. Where available, we have included information on whether the study passes a scope test in our literature review.[9]

Note that in our literature review we also attempt to apply these criteria, meant for mortality studies, to the morbidity literature. We recognize that not all of the criteria are applicable. For example, the CFOI dataset includes only fatalities.

Hedonic Wage-Risk Studies

The selection criteria for hedonic wage-risk studies as introduced by EPA and revised by SAB-EEAC are:

1. Minimum precision of the WTP estimate;
2. Conducted in the United States;
3. Omit studies based on the Society of Actuaries risk data;
4. Omit studies focused on extremely dangerous jobs;
5. Include all WTP estimates arising from conceptually sound methods;
6. Exclude studies based on specific causes of death;
7. Exclude studies failing to report enough information to calculate the value or mortality risk reductions and/or the average probability of death;
8. Regression should include a measure for nonfatal-injury risk, or at least provide evidence concerning the sensitivity of the estimated value of mortality risk to the inclusion/exclusion of nonfatal risks;
9. Regression should include an appropriate level of industry and occupational control variable to address the problem of unobserved job characteristics;
10. Eliminate any study that relies on risk measures constructed at the industry level (not by occupation within an industry);

[9] Where sample size, age range studied, and scope test passed are blank, we were unable to easily find these pieces of information in the literature reviewed. In particular, many studies do not conduct a scope test or report results in a consistent way.

11. Sample frame based on appropriate population; and
12. Exclude studies that do not use adequate risk data (i.e., all studies that rely on data of lower quality than the Census of Fatal Occupational Injuries (CFOI)).

SAB-EEAC notes that excluding studies not based on the United State workforce and not based on risk data of comparable or superior quality to the CFOI data eliminates all studies prior to Viscusi (2003). For our literature review, we were able to easily apply criteria number two through ten and twelve. We had the same difficulties applying criterion one (related to minimum precision of WTP estimate) and criterion eleven (related to sample frame based on appropriate population) that we had when evaluating the stated preference studies. We have therefore again included data on sample size and age range studied in an attempt to shed light on these criteria.

Meta-Analyses

In 2007, the EPA requested the SAB's advice on how the Agency should use meta-analysis to combine estimates of the value of reducing mortality risk (EPA, 2007). In short, SAB advised that the Board "does not believe that meta-regression – a particular form of meta-analysis – is an appropriate way to combine VSL estimate for use in policy analysis" (EPA, 2007). In particular, SAB notes that to treat meta-regression as a reduced-form model that can be used for obtaining the VSL for a given sub-population or the VSL condition on an appropriate study design is problematic. Instead SAB suggests using statistical techniques to combine studies that satisfy appropriate criteria regarding their design.

The SAB again commented on the use of meta-analysis to combine VSL estimates in their 2011 advisory letter (EPA, 2011). In this letter the SAB argues for a move towards a structural preference function approach to combining VSL estimates, but cautions that additional research is necessary. In addition, the SAB notes that the appropriate statistical approach to be used in a meta-analysis varies and depends upon factors such as the total number of observations available in the meta-analysis and the number of VSL estimates to be drawn from each study.

Our interpretation of this guidance is that the criteria listed above for stated preference and hedonic wage-risk studies should also be applied to meta-analysis that draw on these bodies of literature. In particular it should be noted that, meta-analyses published through Bellavance et al. (2009) include only studies published only through 2004 and therefore do not meet EPA's criteria for hedonic wage-risk studies (Cropper, Hammitt, and Robinson, 2011).

REVIEW OF STUDIES THAT MEET CURRENT RESEARCH STANDARDS

This section reviews studies published since IEc's 2004 review that meet the current research standards outlined above. Although we note above that SAB has cautioned against the use of meta-regression to combine VSL estimates for use in policy analyses, their critique has mainly focused on wage-risk meta-analyses. We include stated preference meta-analyses in our review, however, because we believe they provide additional information that should be considered, along with the primary study evidence, in making our recommendations. In particular, for mortality, we include the recently published Lindhjem et al. (2011), which applies many of the screening criteria described above. Note that this meta-analysis does include many non-U.S. studies. For morbidity, we have included two stated preference meta-analyses. Although these two meta-analyses include non-U.S. studies, the majority of the WTP observations included in the models are from U.S. studies.

Our review of morbidity studies started with the Organization for Economic Cooperation and Development's (OECD's) 2010 "Review of recent policy-relevant finding from the environmental health literature." This review provides a broad overview of the monetary valuation of environmental health risks, with a focus on non-fatal health impacts. This is the most recent review of its kind that we identified. In addition, we considered recently published morbidity studies suggested by our subcontractor and expert in the field, Lisa Robinson. It is important to recognize, however, that a comprehensive review of the literature was not conducted. Our review of mortality studies started with EPA's 2010 White Paper which includes lists of stated preference and hedonic wage studies published through 2009. The SAB-EEAC review of this White Paper suggested some additional studies that were also included in our review. In addition, we considered the studies included in OECD's database of stated preference studies, which includes studies published through early 2010.[10] For both the morbidity and mortality literature reviews, article bibliographies provided additional sources. Exhibits 4 and 5 summarize the income elasticity estimates of WTP to avoid morbidity and mortality, respectively, derived from the reviewed studies. Additional detail on these studies is provided in Appendix B.

EXHIBIT 4. INCOME ELASTICITY OF WTP TO AVOID MORBIDITY EFFECTS FROM STUDIES PUBLISHED SINCE 2004 AND MEETING CURRENT RESEARCH STANDARDS

VALUATION STUDY	TYPE OF STUDY	COUNTRY	INCOME ELASTICITY OF WTP[1]	
			MINOR HEALTH EFFECT ESTIMATE	SEVERE HEALTH EFFECT ESTIMATE
Blomquist et al. (2011)[2]	Stated-preference	United States	N/A	0.47
Dickie and Hubbell (2004)	Stated-preference	United States	0.50	N/A
Dickie and Messman (2004)	Stated-preference	United States	0.08 - 0.22	N/A
Van Houtven et al. (2004)	Meta-analysis of stated-preference	Multiple (US and non-US)	0.70	N/A
Vassandumrongdee et al. (2004)	Meta-analysis of stated-preference	Multiple (US and non-US)	0.18 - 0.35	N/A

1. N/A = Not Applicable
2. Personal communication with G.C. Blomquist, March 2012. Value provided for average age adult in the sample.

[10] Database downloaded from www.oecd.org/env/policies/VSL on November 21, 2011.

EXHIBIT 5. INCOME ELASTICITY OF WTP TO AVOID MORTALITY FROM STUDIES PUBLISHED SINCE 2004 AND MEETING CURRENT RESEARCH STANDARDS

VALUATION STUDY	TYPE OF STUDY	COUNTRY	INCOME ELASTICITY OF WTP	
			LOW ESTIMATE	HIGH ESTIMATE
Kniesner et al. (2010)[1]	Wage-risk	United States	1.44	
Evans and Schaur (2010)	Wage-risk	United States	Not available	
Blomquist et al. (2011)[2]	Stated-preference	United States	0.37	
Cameron and DeShazo (2011)[3]	Stated-preference	United States	0.66	0.68
Carson and Mitchell (2006)	Stated-preference	United States	Not available	
Hammitt and Haninger (2010)	Stated-preference	United States	0.1 (pooled model)	0.3 (risk to child)
Van Houtven et al. (2008)	Stated-preference	United States	Not available	
Lindhjem et al. (2011)	Meta-analysis of stated-preference	Multiple (US and non-US)	0.34 (studies passing internal and external scope test)	0.75 (studies passing internal or external scope test)

Note:
1. This value is the mean income elasticity of VSL across quantiles.
2. Personal communication with G.C. Blomquist, March 2012. Value provided for average age adult in the sample.
3. Many recent studies have been published by Cameron and co-authors, including Cameron et al. (2009) and Cameron et al. (2010), which use same survey data. Here we have included estimates from what the authors consider to be the "flagship" paper from among this group of papers (Personal communication with T.A. Cameron, March 2012).

INCOME ELASTICITY RECOMMENDATIONS

Based on our review of the available income elasticity literature and the current practices of other Federal agencies, we propose income elasticity estimates that characterize how the valuation of human health benefits may increase over time with a rise in real U.S. income. Similar to our previous recommendations, we suggest separate high and low estimates for characterizing the uncertainty associated with the strength of an income effect on the valuation of morbidity and mortality effects. Exhibit 6 summarizes recommended income elasticity estimates for use in adjusting the values of health benefits that are manifested in future years.

MORTALITY RECOMMENDATIONS

EPA's recent review of its approach to valuing the reduced risks of mortality indicates that all studies published prior to 2003 and most studies published since 2003 do not meet current research standards. Therefore, our income elasticity of VSL recommendations are based only on the five more recent studies reviewed for this memorandum (see Exhibit 5). Our recommended central, lower, and upper estimates are based on means of the ranges provided in Exhibit 5. These mean values range from 0.2 to 1.44. We recommend using these two values as the lower and upper estimates for VSL income elasticity. For the central estimate, we suggest use of the average value across studies, 0.65. This central estimate is higher than those previously recommended in 1999 and 2004, but the increase is supported by the literature.

Recently, arguments for an income elasticity of VSL greater than 1.0 have been presented in the literature (e.g., Kniesner et al., 2010 and Hammitt and Robinson, 2011). Kniesner et al. note that their income elasticity estimates are consistent with risk preference theory, such as that described by Kaplow (2005). Kniesner et al. add that they are the first to establish this consistency between the risk preference theoretical models and the VSL literature. These recent arguments suggest that an increase in the income elasticity of VSL applied by EPA may be appropriate. Additionally, the income elasticity estimate recently adopted by DOT (0.55) is higher than that currently used within BenMAP (mean value of 0.48); though it nonetheless remains much lower than 1.0.

MORBIDITY RECOMMENDATIONS

For morbidity, we suggest using two different ranges based on whether the effects are minor or severe. With respect to minor health effects, we suggest low and high estimates of 0.06 and 0.70, respectively. The central estimate is 0.30. We determined these values by analyzing the studies included in IEc's 2004 memorandum as well as the literature published since that time (see Exhibits 2 and 4), for a total of seven studies. The low and high estimates reflect the lowest and highest estimates of these studies and the central estimate reflects the average value.

To characterize the income effect on WTP to avoid severe health effects, we recommend a low and high elasticity estimate of 0.38 and 1.25, with 0.68 as the central estimate. We determined these values by considering the six studies included in IEc's 2004 memorandum as well as the literature published since that time, the latter consists of only one study (see Exhibits 2 and 4). Similar to the recommended elasticities for minor health effects, the low and high estimates reflects the lowest and highest estimate of these studies and the central estimate reflects the average value.[11] We included the older morbidity studies due to a lack of more recent studies, particularly for severe health effects where only one recent income elasticity estimate was identified. We do limit the older studies those conducted in the U.S.

EXHIBIT 6. RECOMMENDED INCOME ELASTICITY ESTIMATES

HEALTH ENDPOINT	LOW ESTIMATE	CENTRAL ESTIMATE	HIGH ESTIMATE
Minor Health Effects	0.06	0.30	0.70
Severe and Chronic Health Effects	0.38	0.68	1.25
Premature Mortality	0.20	0.65	1.44

[11] Unlike the recommendations made in IEc's 2004 memorandum, we do not omit estimates from our range that are greater than 1.0, nor do we cap these studies at 1.0 when calculating the average values used to guide our central estimates.

INCOME GROWTH DATA

EPA accounts for the effect of changes in income on WTP to avoid adverse health effects by applying the income elasticity estimates discussed above to projected growth in real income. This section reviews possible sources of income data and makes initial recommendations for use in EPA air pollution benefits assessment.

Ideally EPA would use income data projections to be consistent with the data typically used in the underlying WTP studies; however long-term income projections are not readily available. In contrast, GDP projections are readily available, and so for this reason, we recommend using GDP projections as a proxy for income projections. We also recommend using historical GDP data (which are also readily available) instead of historical income data to maintain internal consistency in the model.

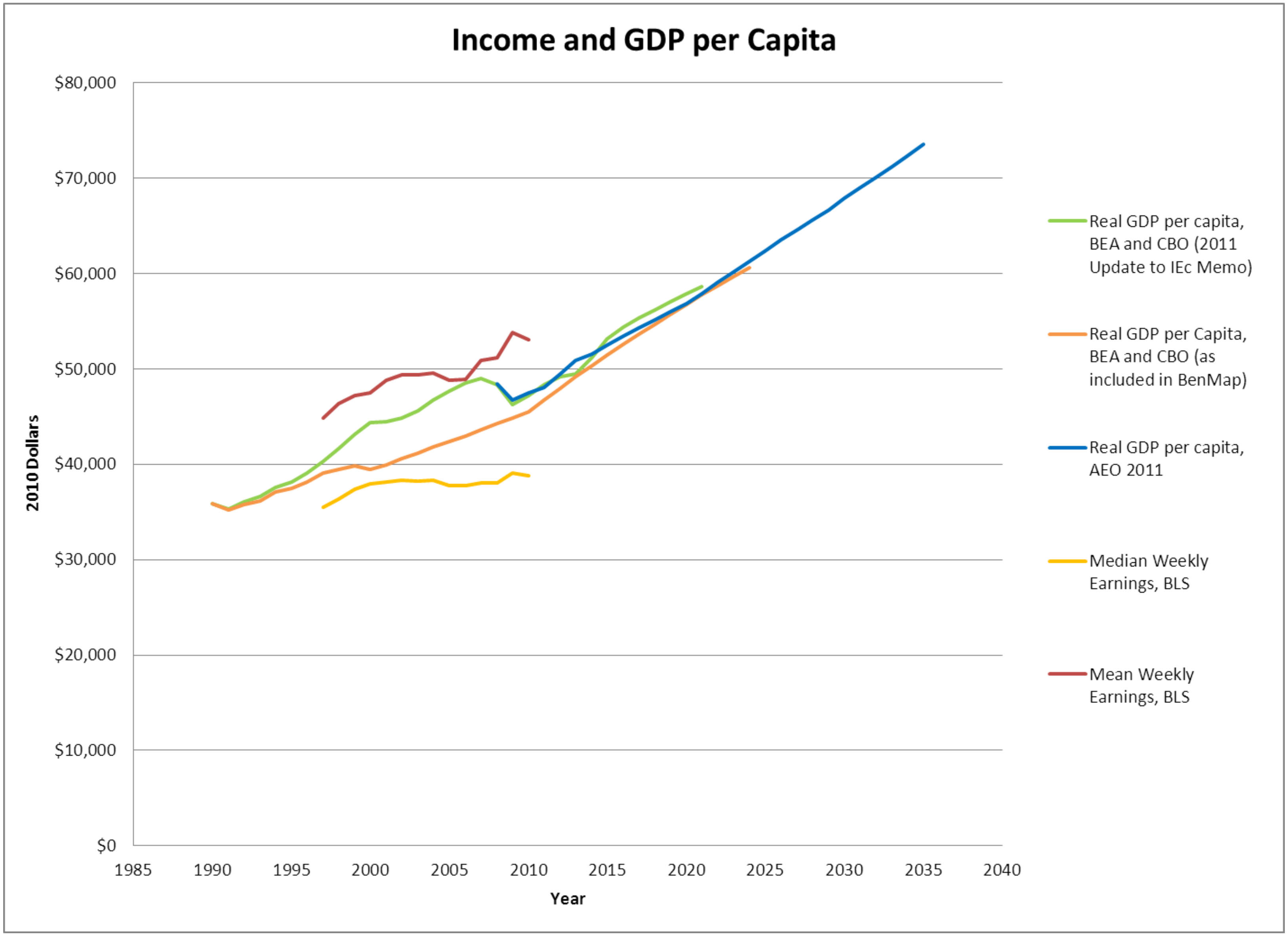
GDP or Gross Domestic Product is "the market value of the final goods and services produced in a country during a given period" (Frank, 2001). GDP can be measured as "(1) the market value of production, (2) total expenditure (consumption, investment, government purchases, net exports), or (3) total income (labor income and capital income)" (Frank, 2001). The concepts of GDP and income are therefore related. Our main interest is in the rate of change in income rather than in the absolute amount of income, so the rate of per capita GDP growth is used as a proxy for the rate of income growth.

Exhibit 7 presents several different sources of historical and projected GDP and income data which could be used to adjust WTP for changes in income. These various options, and a final recommendation on which data sources should be used, are discussed below.

BEA/CBO DATA

In IEc's 2004 income elasticity memo, income estimates were generated using estimates of real GDP per capita. Real GDP per capita was calculated using population estimates from the U.S. Census Bureau and estimates of real GDP from the Bureau of Economic Analysis (BEA) and the Congressional Budget Office (CBO). BEA provides annual estimates of historical real GDP and CBO provides annual projections of real GDP. The data presented in this memorandum represent an updated estimate of real GDP per capita, which relies on historical BEA data from 1990 through 2010 and projected CBO data from 2011 through 2021 (U.S. Census Bureau, 2008; U.S. Census Bureau, 2011; BEA, 2011b; and CBO, 2011). The current BenMap income growth numbers are also derived from the same main sources: Census population data, BEA historical GDP data, and CBO GDP data projections. Exhibit 8 provides some additional details about the source of this data.

EXHIBIT 7. INCOME AND GDP PER CAPITA



AEO DATA

GDP per capita projections are also calculated using data presented in the Annual Energy Outlook (AEO) 2011, a report prepared by the U.S. Energy Information Administration (EIA), the statistical and analytical agency within the U.S. Department of Energy (AEO, 2011b). AEO publishes annual GDP projections (among other statistics) through the year 2035. To estimate per capita GDP, these annual GDP projections are divided by AEO's own projections of annual population.[12] Exhibit 8 provides some additional details about the source of this data.

BLS DATA

For comparison, this section also presents a source of income data: the median and mean weekly earnings data from the Bureau of Labor Statistics (BLS) Current Population Survey (CPS), scaled up to an annual estimate (BLS, 2011b; and BLS, 2011c).[13] The CPS presents median and mean usual weekly earnings for full-time employed wage and salary workers. Exhibit 8 provides some additional details about the source of this data.

EXHIBIT 8. ADDITIONAL DETAILS ABOUT DERIVATION OF GDP AND INCOME ESTIMATES

DATA SOURCE	ADDITIONAL DETAILS[1]	SOURCE
BLS	The estimates in this release were obtained from the Current Population Survey (CPS), which provides basic information on the labor force, employment, and unemployment. The survey is conducted monthly for the Bureau of Labor Statistics by the U.S. Census Bureau from a scientifically selected national sample of about 60,000 households, with coverage in all 50 states and the District of Columbia. The earnings data are collected from one-quarter of the CPS monthly sample and are limited to wage and salary workers (both incorporated and unincorporated self-employed are excluded). The data, therefore, exclude self-employment income.	(BLS, 2011a)
AEO	EIA develops the AEO from an integrated economic forecasting model that generates projections of GDP, population, and other economic variables in a consistent manner. The rate of growth in real gross domestic product (GDP) depends on assumptions about labor force growth and productivity. In the Reference case, growth in real GDP averages 2.7 percent per year due to a 0.7 percent per year growth in the labor force and a 2.1 percent per year growth in labor productivity.	(AEO, 2011a)

[12] AEO population projections include armed forces overseas, while the Census population projections do not. We chose to use the AEO population projections despite this discrepancy, as by using both GDP and population projected by the same source, we maintain internal consistency in the GDP per capita projections.

[13] To scale up from weekly to annual earnings, the average median weekly earnings are multiplied by 52.

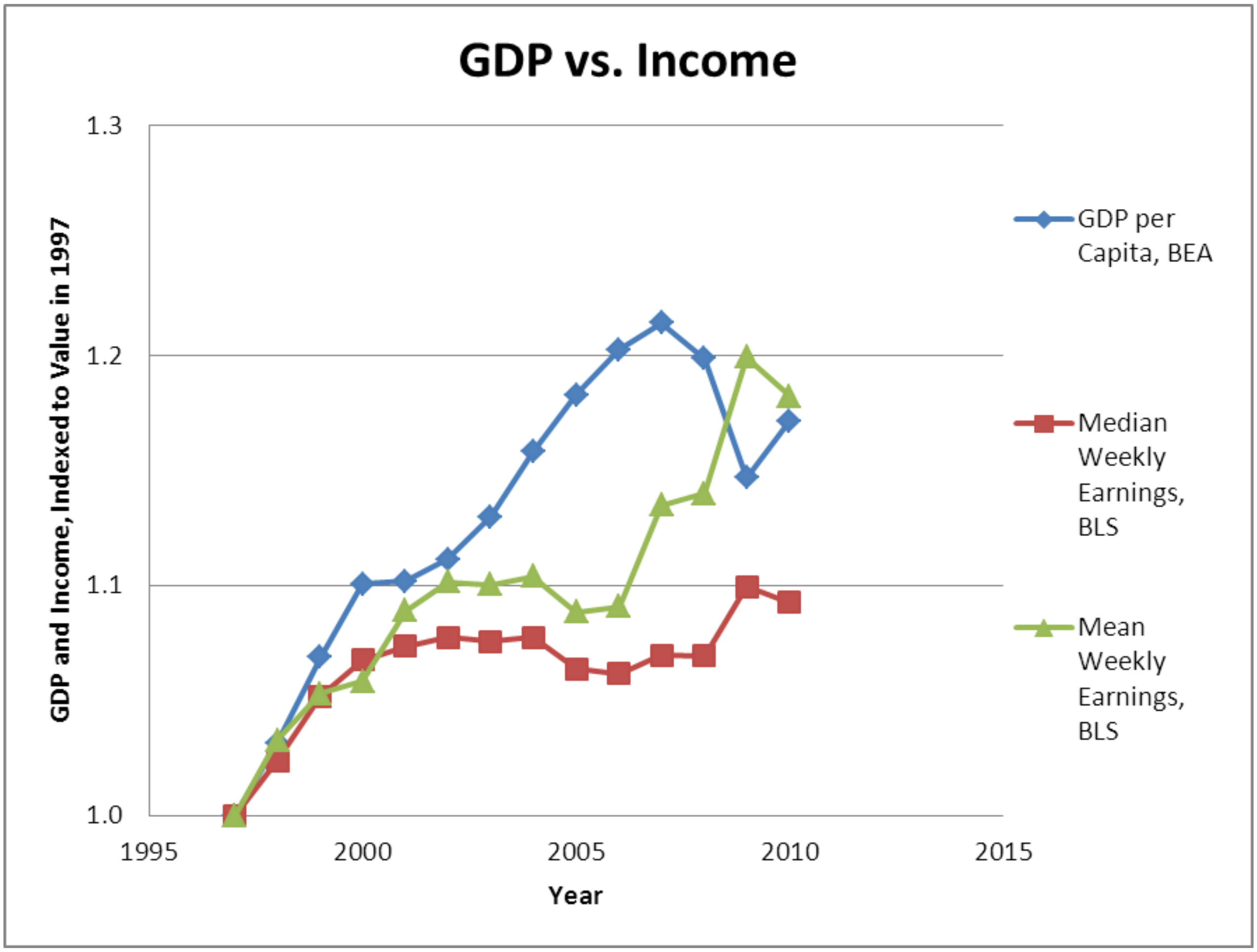
DATA SOURCE	ADDITIONAL DETAILS[1]	SOURCE
BEA	The National Income and Product Accounts (NIPA) [GDP] estimates are prepared by the staff of the Directorate for National Economic Accounts within the Bureau of Economic Analysis, an agency of the U.S. Department of Commerce. The process starts with identifying and obtaining source data that are appropriate as the basis for the estimates. These data largely originate from public sources, such as government surveys and administrative data, and they are supplemented by data from private sources, such as data from trade associations.	(BEA, 2011a)
CBO	Potential output plays a role in several aspects of CBO's economic forecast. In particular, CBO uses potential output to set the level of real GDP in its medium-term (10-year) projections. (…) There are many ways to estimate the trend in GDP (and other economic data) as well as to compute the economy's productive potential. Some methods rely on purely statistical techniques. Others, such as CBO's method, rely on models guided by economic theory. (…) CBO's estimate of potential output is based on the framework of a textbook model of long-term economic growth, the Solow growth model. The model attributes the growth of real GDP to the growth of labor (hours worked), capital (an index of capital services emanating from the stock of productive assets), and technological progress (total factor productivity). CBO estimates trends --that is, removes the cyclical changes--in the labor and productivity components by using a variant of a relationship known as Okun's law.	(CBO, 2004)
1. The notes in this table are direct quotes from the listed sources.		

DISCUSSION AND RECOMMENDATIONS

Exhibit 9 shows in recent years (1997 through 2010) per capita GDP growth has outpaced median income growth. Per capita GDP growth has also outpaced mean income growth, but to a lesser degree and not as consistently. [14] We believe that the mean values are likely to be more consistent with the income reflected in underlying studies, and the calculated income elasticities, as these studies attempt to generate representative samples which, in general, have mean incomes close to those in the general population. If per capita GDP continues to outpace mean income growth, the assumption that per capita GDP growth is a reasonable proxy for income growth may lead to an overstatement of benefits. However, in the absence of readily available income data projections, per capita GDP is the best available option.

[14] For this graph, both per capita GDP and income are indexed at their respective 1997 values.

EXHIBIT 9. GDP AND INCOME DATA INDEXED TO THEIR 1997 VALUES



IEc proposes that EPA uses the annual GDP per capita data from BEA (1990 through 2010) and AEO (2011 through 2035), as described above, to update BenMAP's income growth factors. The use of the BEA data is consistent with BenMAP's current procedure to adjust for income growth and the AEO data allows for the calculation of adjustment factors out to 2035. IEc recommends using AEO projection data over the CBO projection data used in the 2004 memorandum because AEO data is projected further into the future. In addition, both data sets are freely available and easily accessible from U.S. government websites. The final argument in favor of the use of these two data sets is the smooth transition between the historical and future data, as shown in Exhibit 7.

REFERENCES

Alberini, Anna and Alan Krupnick, "Air Quality and Episodes of Acute Respiratory Illness in Taiwan Cities: Evidence from Survey Data," *Journal of Urban Economics*, Vol. 44, pp. 68-92, 1998.

Alberini, A., M. Cropper, T. Fu, A. Krupnick, J. Liu, D. Shaw, and W. Harrington. 1997. "Valuing Health Effects of Air Pollution in Developing Countries: The Case of Taiwan," *Journal of Environmental Economics and Management* 34(2): 107-126.

Alberini, Anna, Maureen Cropper, Alan Krupnick, and Nathalie Simon. 2004. "Does the Value of a Statistical Life Vary with Age and Health Status? Evidence from the United States and Canada," *Journal of Environmental Economics and Management* 48(1): 769-792.

Annual Energy Outlook (AEO) 2011a, "Trends in Economic Activity", Released April 26, 2011, Available at http://38.96.246.204/forecasts/aeo/MT_economic.cfm#gross, Accessed December 2011.

Annual Energy Outlook (AEO) 2011b, "Table 20: Macroeconomic Indicators -- Macroeconomic Indicators, Reference case AEO2011-Macroeconomic_Indicators-Reference_case.xls", Available at http://38.96.246.204/forecasts/aeo/data.cfm#summary, Accessed October 2011.

Blomquist, G., 1979. "Value of Life Saving: Implications of Consumption Activity," *Journal of Political Economy* 87 (31).

Blomquist, G.C., M. Dickie, R.M. O'Conor, 2011. "Willingness to pay for improving fatality risks and asthma symptoms: Values for Children and adults of all ages," *Resource and Energy Economics* 33(2): 410-425.

Bowland, Bradley J. and John C. Beghin, "Robust Estimates of Value of a Statistical Life for Developing Economies." *Journal of Policy Modeling*, Vol. 23, pp. 385-396, 2001.

Bureau of Economic Analysis (BEA), 2011a, "Concepts and Methods of the U.S. National Income and Product Accounts", Published November 2011, Available online at http://www.bea.gov/national/pdf/chapters1-4.pdf, Accessed December 2011.

Bureau of Economic Analysis (BEA). 2011b. Table 1.1.6. "Real Gross Domestic Product, Chained Dollars," accessed by http://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1 on October 2011.

Bureau of Labor Statistics (BLS), 2011a. "Economic News Release, Usual Weekly Earnings Technical Note," accessed http://www.bls.gov/news.release/wkyeng.tn.htm on December 8, 2011.

Bureau of Labor Statistics (BLS). 2011b. "(Seas)- Median usual weekly earnings (second quartile), Employed full time, Wage and salary workers" (LES1252881500), accessed http://www.bls.gov/cps/earnings.htm on November 17, 2011.

Bureau of Labor Statistics (BLS). 2011c. Table A-1 (1997-2010), provided by Thomas Luke Spreen at BLS via e-mail on December 9, 2011.

Cameron T.A. and J.R. DeShazo. 2011. "Demand for health risk reductions," working paper.

Cameron T.A., J.R. DeShazo, and E.H. Johnson. 2009. "Willingness to pay for health risk reductions: Differences by type of illness." Under review; presented at 2008 AERE Workshop.

Cameron. T.A., J.R. DeShazo, and P. Stiffler. 2010. "Demand for Health Risk Reductions: A Cross-national Comparison Between the U.S. and Canada."*Journal of Risk and Uncertainty*, 41: 245–273.

Carson R.T. and R.C. Mitchell. 2006. "Public preferences toward environmental risks: the case of trihalomethanes." In Alberini A, Bjornstad D, Kahn JR, eds., *Handbook of Contingent Valuation*. Northampton, MA: Edward Elgar.

Chestnut, Lauraine G., L. Robin Keller, William E. Lambert, Robert D. Rowe, "Measuring Heart Patients' Willingness to Pay for Changes in Angina Symptoms," *Medical Decision Making*, Vol. 16, pp. 65-77, 1996.

Congressional Budget Office (CBO), "A Summary of Alternative Methods for Estimating Potential GDP", Published March 2004, Available online at http://www.cbo.gov/doc.cfm?index=5191&type=0, Accessed December 2011.

Congressional Budget Office (CBO). 2011. "Detailed Economic Projections, CY 2011-2021; Actual Data, 1950-2009 (xls)," accessed by http://www.cbo.gov/doc.cfm?index=12316 on October 2011.

Corso, Phaedra S., James K. Hammitt, and John D. Graham, "Evaluating the Effect of Visual Aids on Willingness to Pay for Reductions in Mortality Risks*," Journal of Risk and Uncertainty*, Vol. 23, pp.165-184, 2001.

Costa, Dora L. and Matthew E. Kahn, "Changes in the Value of Life, 1940-1980," *The Journal of Risk and Uncertainty*, Vol. 29, pp. 159-180. 2004.

Cropper, M., J.K. Hammitt, and L.A. Robinson, 2011. "Valuing Mortality Risk Reductions: Progress and Challenges," *Annual Reviews Resource Economics* 3: 313-336.

Dickie, M. and B. Hubbell, 2004. "Family Resource Allocation and the Distribution of Health Benefits of Air Pollution Control," Paper presented at the Association of Environmental and Resource Economists Workshop, *Distributional Effects of Environmental Policy*.

Dickie, M., S. Gerking, W. Schultze, A. Coulson, and D. Tashkin, "Value of Symptoms of Ozone Exposure: An Application of Averting Behavior Method," *Improving Accuracy and Reducing Costs of Environmental Benefit Assessments*, September 1986.

Dickie, M. and V.L. Messman, 2004, "Parental Altruism and the Value of Avoiding Acute Illness: Are Kids Worth More Than Parents?", *Journal of Environmental Economics and Management*, 48: 1146-1174.

Evans, M.F. and G. Schaur. 2010. "A quantile estimation approach to identify income and age variation in the value of a statistical life." *Journal of Environmental Economics and Management*, 59: 260-270.

Frank, Robert and Ben Bernanke. 2001. "Principles of Economics." Published by McGraw Hill.

Hammitt J.K. and K. Haninger. 2007. "Willingness to pay for food safety: sensitivity to duration and severity of illness." *American Journal of Agricultural Economics* 89(5):1170-1175.

Hammitt, J.K., J. Liu, and J. Liu. 2000. "Survival is a Luxury Good: The Increasing Value of a Statistical Life." Working paper prepared for the NBER Summer Institute Workshop on Public Policy and the Environment.

Hammitt, J.K. and L.A. Robinson. 2010. "The Income Elasticity of the Value per Statistical Life: Transferring Estimates Between High and Low Income Populations." *Journal of Benefit-Cost Analysis* Manuscript 1009.

Holtmann, A. and E. Olsen, Jr. *The Economics of Private Demand for Outpatient Health Care*. John E. Fogarty International Center for Advanced Studies in Health Sciences (Washington, D.C.: U.S. Government Printing Office). 1978.

Industrial Economics, Incorporated. "Recommended Approach to Adjusting WTP Estimates to Reflect Changes in Real Income," Memorandum to Jim Democker, Office of Policy Analysis and Review, Office of Air and Radiation, U.S. Environmental Protection Agency, prepared by Naomi Kleckner and Jim Neumann. June 3, 1999.

Industrial Economics, Incorporated. "Responding to SAB Council Comments on the May 2003 Draft Analytical Plan for the Section 812 Second Prospective - Options for Adjusting WTP Estimates to Reflect Changes in Real Income," Memorandum to Nona Smoke, Office of Policy Analysis and Review, Office of Air and Radiation, U.S. Environmental Protection Agency, prepared by Jim Neumann and Sarah Brennan. September 30, 2004.

Johannesson, M. and P. Johansson, "Quality of Life and the WTP for an Increased Life Expectancy at an Advanced Age," *Journal of Public Economics*, Vol. 65, pp. 219-228, 1997.

Johnson, F.R., E.E. Fries, and H.S. Banzhaf. 1997. "Valuing Morbidity: An Integration of the Willingness-to-Pay and Health-Status Index Literatures." *Journal of Health Economics* 16:641-665.

Jones-Lee, M.W., M. Hammerton, and P.R. Philips. 1985. "The Value of Safety: Results of a National Sample Survey." *The Economic Journal* 95: 49-72.

Kaplow, L., 2005. "The value of a statistical life and the coefficient of relative risk aversion." *Journal of Risk and Uncertainty* 31(1): 23-34.

Kniesner, T.J., W.K. Viscusi, and J.P. Ziliak. 2010. "Policy relevant heterogeneity in the value of statistical life: New evidence from panel data quantile regressions." *Journal of Risk and Uncertainty* 40: 15-31.

Krupnick, Alan et al., 2002. "Age, Health and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Study of Ontario Residents," *The Journal of Risk and Uncertainty* 24: 161-186.

Krupnick, Alan J., Kenneth Harrison, Erick Nickell, and Michael Toman. *The Value of Health Benefits from Ambient Air Quality Improvements in Central and Eastern Europe: An Exercise in Benefits Transfer*. Resources for the Future: Washington D.C. May 1995.

Loehman, E. and V. De. 1982. "Application of Stochastic Choice Modeling to Policy Analysis of Public Goods: A Case Study of Air Quality Improvements." *The Review of Economics and Statistics* 64: 474-480.

Liu, Jin-Tan, James K. Hammitt, Jin-Long Liu. "Estimated Hedonic Wage Function and Value of Life in a Developing Country," *Economic Letters*, Vol. 57, pp. 353-358, 1997.

Liu, Jin-Tan, James K. Hammitt, Jung-Der Wang, and Jin-Long Liu. "Mother's Willingness to Pay for Her Own and Her Child's Health: A Contingent Valuation Study in Taiwan" *Health Economics*, Vol. 9, pp. 319-326, 2000.

Manning, W., C. Norris, J. Newhouse, L. Orr, N. Duan, E. Keeler, A. Leibowitz, K. Marquis, M. Marquis, and C. Phelps, "A Two-Part Model of Demand for Health Care: Preliminary Results from the Health Insurance Study," in J. van der Gaag and M. Perlman, eds., *Health, Economics, and Health Economics*. (Amsterdam: North Holland), pp. 103-124, 1981.

Miller, Ted R. "Variations between Countries in Values of Statistical Life," *Journal of Transport Economics and Policy*, Vol. 34 Part 2, pp. 169-188, May 2000.

Miller, Ted and Jagadish Guria. *The Value of Statistical Life in New Zealand: Market Research on Road Safety*. Report for the Land Transport Division, May 1991.

Mitchell, R.C. and R.T. Carson. *Valuing Drinking Water Risk Reductions Using the Contingent Valuation Method: A Methodological Study of Risk from THM and Giardia*. Report for the U.S. Environmental Protection Agency, Washington, D.C., 1986.

Morris J. and J.K. Hammitt. 2001. "Using life expectancy to communicate benefits of health care programs in contingent valuation." *Medical Decision Making* 21:468-478.

Mrozek, Janusz .R. and Laura O. Taylor (2002), "What Determines the Value of Life? A Meta Analysis." *Journal of Policy Analysis and Management*, 21:253-270.

NERA/CASPAR. *Valuation of Deaths from Air Pollution.* A Report Prepared for the Department of Environment, Transport, and the Regions and the Department of Trade and Industry. National Economic Research Associates and the Centre for the Analysis of Safety Policy and Attitudes toward Risk. February 1998.

Organization for Economic Cooperation and Development, 2012, Mortatlity Risk Valuation in Environemnet, Health and Transportation Policies, OECD Publishing, http://dx.doi.org/10.1787/9789264130807-en.

Persson,U., A. Lugner Norinder, and M. Svensson, "Valuing the Benefits of Reducing the Risk of Non-Fatal Roads Injuries: The Swedish Experience" in Schwab Christe, N G, and Soguel, N C (eds) *Contingent Valuation, Transport Safety and the Value of Life*, Boston: Kluwer, pp. 63-83 (1995).

Phelps, C., "The Effects of Insurance on the Demand for Medical Care," in R. Anderson, cd., *Equity in Health Services: An Empirical Analaysis of Social Policy*, (Cambridge, MA: Ballinger press), 1975.

Robinson, Lisa A. June 2008. "Valuing Mortality Risk Reductions in Homeland Security Regulatory Analyses." Prepared for Elena Ryan, U.S. Customs and Border Protection, Department of Homeland Security.

Robinson, L.A., and J.K. Hammitt, 2009. *The Value of Reducing Air Pollution Risks in Sub-Saharan Africa*. Prepared for the World Bank under subcontract to ICF International.

Rowe, R.D. and L.G. Chestnut. *Addendum to Oxidants and Asthmatics in Los Angeles: A Benefits Analysis. Environmental Benefits Analysis Series*. Report for Economics Analysis Division, US EPA, Washington D.C., 1986.

U.S. Census Bureau. 2008. Table 1. "Projections of the Population and Components of Change for the United States: 2010 to 2050" (NP2008-T1).

U.S. Census Bureau. 2011a. Table 1. "Intercensal Estimates of the Resident Population by Sex and Age for the United States: April 1, 2000 to July 1, 2010" (US-EST00INT-01).

U.S. Department of Transportation (DOT). 2008. "Treatment of the Economic Value of a Statistical Life in Departmental Analyses." Memorandum to Secretarial Officers and Modal Administrators from T.D. Duvall, Assistant Secretary for Transportation Policy, and D.J. Gribbin, General Counsel.

U.S. Department of Transportation (DOT). 2011. "Treatment of the Economic Value of a Statistical Life in Departmental Analyses – 2011 Interim Adjustment." Memorandum to Secretarial Officers and Modal Administrators from Polly Trottenberg, Assistant Secretary for Transportation Policy, and Robert Rivkin, General Counsel.

U.S. Environmental Protection Agency (EPA), 2007. "SAB Advisory on EPA's Issues in Valuing Mortality Risk Reductions (October 12, 2007)." Office of the Administrator, Science Advisory Board.

U.S. Environmental Protection Agency (EPA). 2010a. *Guidelines for Preparing Economic Analyses*. National Center for Environmental Economics, Office of Policy, U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (EPA). 2010b. "Valuing Mortality Risk Reductions for Environmental Policy: A White Paper." SAB Review Draft. National Center for Environmental Economics, U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (EPA). 2011. "Review *of Valuing Mortality Risk Reductions for Environmental Policy: A White Paper (December 10, 2010)*." Office of the Administrator, Science Advisory Board.

Van Houtven, G., Sullivan, M.B., Dockins, C. 2008. "Cancer premiums and latency effects: A risk tradeoff approach for valuing reductions in fatal cancer risks", *Journal of Risk and Uncertainty* 36, 179-199.

Van Houtven, G., J. Powers, A. Jessup, J. Yang, 2004. "Valuing Avoided Morbidity Using Meta-Analysis: What Can Health Status Measures and QALYs Tell us about WTP?", RTI International, Working Paper.

Vassanadumrongdee, S., S. Matsuoka, H. Shirakawa, 2004. "Meta-analysis of contingent valuation studies on air pollution-related morbidity risks," *Environmental Economics and Policy Studies* 6: 11-47.

Viscusi W.K. 2003. "Racial differences in labor market values of statistical life." Journal of Risk and Uncertainty 27(3):239-256.

Viscusi, W.K. 2004. "The Value of Life: Estimates with Risks by Occupation and Industry." *Economic Inquiry*. Vol. 42, No. 1, pp. 29-48.

Viscusi, W. K. and J.E. Aldy. 2003. "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World," *Journal of Risk and Uncertainty*, 27(1): 5-76.

Viscusi, W.K., and W. Evans, "Utility Functions that Depend on Health Status: Estimates and Economic Implications," *American Economic Review*, Vol. 80, No. 2, pp. 353-374, 1990.

Viscusi, W.K., and W. Evans, "Income Effects and the Value of Health," *Journal of Human Resources*, Vol. 28, No. 3, pp. 497-518, 1993.

APPENDIX A - STUDIES INCLUDED IN IEC'S 1999 AND 2004 LITERATURE REVIEW

EXHIBIT A-1. MORBIDITY STUDIES WITH INCOME ELASTICITY OF WTP ESTIMATES

VALUATION STUDY	COUNTRY	CONTEXT	INCOME ELASTICITY OF WTP[1]	
			MINOR HEALTH EFFECT	SEVERE HEALTH EFFECT
STATED PREFERENCE STUDIES				
Alberini and Krupnick (1998)	Taiwan	CV study valuing avoided episodes of acute respiratory illness (e.g., headache, runny nose, sore throat, cough, "cold").	0.41	N/A
Alberini et al. (1997)	Taiwan	CV survey valuing avoided cases of acute respiratory illness (e.g., headache, runny nose, sore throat, cough, "cold").	N/A	0.45 (based on "general model" of health effects)
Chestnut *et al.* (1996)	United States	CV study valuing WTP to avoid 4 to 8 episodes of angina per month.	N/A	1.25
Liu et al. (2000)	Taiwan	CV survey of WTP to avoid suffering for a cold.	0.40 - 0.45	N/A
Loehman and De (1982)	United States	CV survey examining air pollution control in the Tampa Bay area of Florida mailed to Tampa Bay residents. The survey described respiratory health effects in terms of related symptoms (e.g., lung problems described in terms of shortness of breath).	0.26 (minor coughing and sneezing, eye irritation)	0.60 (severe shortness of breath)
Rowe and Chestnut (1985 and 1986)	United States	Study examining changes in behavior, expenditures and WTP for variations in asthma severity. Income is a significant explanatory variable for WTP for a better chance to participate in leisure activities and for reduced discomfort if asthma improved. Data collected in Glendora, California mainly through daily diary and CV questionnaire administered to asthmatics expected to be sensitive to ambient oxidant levels.	0.06 (better chance to participate in leisure activities)	0.51 (reduced discomfort)

VALUATION STUDY	COUNTRY	CONTEXT	INCOME ELASTICITY OF WTP[1]	
			MINOR HEALTH EFFECT	SEVERE HEALTH EFFECT
Persson et al. (1995)	Sweden	Purpose of study was to solicit WTP to avoid nonfatal traffic injuries and compare results to WTP to avoid fatal traffic injuries. All respondents answered same questions on fatal injuries. Group I was confronted with “real risk”; Group II was confronted with twice the risk of Group I (i.e., longer durations and increased severity of injury). Survey was administered in Sweden to individuals between the ages 18 and 74 beginning in 1993.	N/A	0.25 - 0.37
HEALTH CARE DEMAND STUDIES				
Holtmann and Olsen (1978)	United States	Income elasticity is derived from a demand for health care study. These results are cited in a paper by Dickie et al. (1986).	0.06 - 0.30	N/A
Manning et al. (1981)	United States	Income elasticity is derived from a demand for health care study. These results are cited in a paper by Dickie et al. (1986).	0.04	N/A
Phelps (1975)	United States	Income elasticity is derived from a demand for health care study. These results are cited in a paper by Dickie et al. (1986).	0.11	N/A
WAGE-RISK STUDIES				
Viscusi and Evans (1990)	United States	Wage-risk tradeoff analysis of 1982 chemical workers. Income elasticity of the value of an injury in the logarithmic case is 1.1, and in the Taylor's series case is 0.67.	0.67	1.10
Viscusi and Evans (1993)	United States	Consumer product safety study estimating the dependence of risk-dollar tradeoffs on income. Examined two products (insecticides and toilet bowl cleaner) and associated injuries. Reported income elasticities are: 0.17 for eye burns, 0.26 for inhalations, 0.35 for gassings, and 0.38 for skin poisonings.	0.17 (eye burns)	0.38 (skin poisonings)

1. N/A = Not Applicable

EXHIBIT A-2. MORTALITY STUDIES WITH INCOME ELASTICITY OF WTP ESTIMATES

VALUATION STUDY	COUNTRY	CONTEXT	INCOME ELASTICITY OF VSL	
			LOW ESTIMATE	HIGH ESTIMATE
STATED PREFERENCE STUDIES				
Alberini *et al.* (2004)	United States	CV study examining the effect of age and health status on WTP to reduce mortality risk. Survey administered to a nationally representative sample of U.S. residents using the Internet. Respondents were limited to people aged 40 and older.	0.69	0.90
Corso, Hammitt, and Graham (2000)	United States	CV study examining communication of risk and its implications on solicited estimates of WTP to reduce mortality risk.	0.41	0.41
Blomquist (1979)	United States	CV study on the WTP to reduce the risk of death through automobile seatbelt use. Estimate is based on 1972 data from *A Panel Study of Income Dynamics, 1968-1974.*	0.30	0.30
Johannesson and Johansson (1997)	Sweden	CV survey valuing life extension. Survey administered through telephone interviews with a random sample of individuals between the ages of 18 and 69.	0.22	0.25
Jones-Lee *et al.* (1985)	United Kingdom	CV questionnaire (37 questions) on the value of safe auto travel. Includes multiple estimates of income elastic of VSL. Low estimate reflects WTP for reduction in fatality risk for the driver (risk reduction= 5/100,000). High estimate reflects WTP for reduction in fatality risk for the driver (risk reduction= 2/100,000).	0.32	0.40
Miller and Guria (1991)	New Zealand	CV survey on the value of statistical life and the relative valuation of non-fatal injuries. Conducted as part of the Ministry of Transport's travel survey. Elasticity estimates are not presented in the report, rather based on values cited by NERA (1998).	0.30	0.60
Mitchell and Carson (1986)	United States	Study valuing drinking water risk reductions using CV methods.	0.35	0.35
Persson *et al.* (1995)	Sweden	Solicits WTP to avoid nonfatal traffic injuries and compare results to WTP to avoid fatal traffic injuries. All respondents answered the same questions on fatal injuries. Estimates reflect 50% reduction of risk.	0.46 (omits protest bids)	0.62 (includes protest bids)

VALUATION STUDY	COUNTRY	CONTEXT	INCOME ELASTICITY OF VSL	
			LOW ESTIMATE	HIGH ESTIMATE
LONGITUDINAL WAGE-RISK STUDIES				
Costa and Kahn (2004)	United States	Estimate VSL every ten years from 1940 to 1980. Data sources include U.S. Bureau of Census micro-data and BLS fatality data. Low estimate reflects elasticity of VSL with respect to per capita GNP, log-linear specification. High estimate reflects elasticity of VSL with respect to per capita GNP controlling for average fatality risk, linear specification.	1.50	2.07
Hammitt *et al.* (2000)	Taiwan	Prepared for the NBER Summer Institute Workshop. Estimates based on intertemporal labor data, 1982 to 1997 of full-time workers in the manufacturing sector (e.g., wages, industry fatality rates). Elasticity estimates are a function of sample mean risk and GNP (rather than average sample income). Low estimate reflects income elasticity with respect to economic growth (i.e., GNP), model pools data and allows VSL to shift with time. High estimate from model using sample mean risk and excludes variable for average occupational risk.	1.47	3.13
Viscusi and Evans (1990)	United States	Wage-risk tradeoff analysis of a 1982 chemical worker survey administered in the U.S. Income elasticity of the value of an injury in the logarithmic case is 1.1, and in the Taylor's series case is 0.67.	0.67	1.10
META-ANALYSES				
Bowland and Beghin (2001)	Multiple (US and non-US)	Conduct a meta-analysis of 33 VSL estimates, supplemented with external data on demographics and country characteristics. Bowland and Beghin note that the methodology used to create their dataset may have invalidated their conclusions.	1.66	2.27
Krupnick *et al.* (1995)	Multiple (US and non-US)	Based on review of published literature. The low estimate reflects the estimate presented by Mitchell and Carson (1986). The authors do not cite a study for the high estimate and write, "With very little data, one can assume the WTP for damage avoidance is proportional to income."	0.35	1.0
Liu, Hammitt, and Liu (1997)	Multiple (US and non-US)	Estimate income elasticity using 17 VSL estimates reported by Viscusi.	0.53	0.53

VALUATION STUDY	COUNTRY	CONTEXT	INCOME ELASTICITY OF VSL	
			LOW ESTIMATE	HIGH ESTIMATE
Miller (2000)	Multiple (US and non-US)	Examines 63 studies across 13 countries. Compares VSL for developing and developed countries to assess benefits transfer approach. Includes multiple estimates of income elastic of VSL. Low estimate from analysis of 38 studies excluding US wage-risk studies. High estimate from analysis using country-level regression models- averages VSL in individual studies for each country.	0.85	1.00
Mrozek and Taylor (2002)	Multiple (US and non-US)	Review 47 labor market studies. They conclude that 33 of these studies contain enough information to be included in a meta-analysis, producing 203 estimates of VSL. Based on these VSL estimates, Mrozek and Taylor conclude that income elasticity ranges from 0.46 to 0.49, using mean hourly earnings of the workers in each study as a proxy for income.	0.46	0.49
NERA/CASPAR (1998)	Multiple (US and non-US)	Based on review of published literature. The lower bound reflects the results of several studies (e.g., Blomquist (1979), Jones-Lee *et al*. (1985), Persson and Cerdarvall (1991)). Upper bound reflects: (i) Viscusi and Evans (1990) study, which solicits WTP to avoid work-related injury; and Kidholm (1995), which estimates the income elasticity for the marginal rate of substitution for wealth for risk of death.	0.30	1.1
Viscusi and Aldy (2003)	Multiple (US and non-US)	Using their dataset and a variable for annual labor income adjusted for purchasing power parity, Viscusi and Aldy replicate the regressions used by Liu et al (1997), Miller (2000), Bowland and Beghin (2001), and Mrozek and Taylor (2002). The specifications of these prior meta-analyses, when applied to the Viscusi and Aldy dataset, produce estimates of income elasticity ranging from 0.5 to 0.6. Viscusi and Aldy also estimate income elasticity within this range for six additional specifications.	0.51	0.61

APPENDIX B - STUDIES INCLUDED IN THIS MEMORANDUM

EXHIBIT B-1. MORBIDITY STUDIES WITH INCOME ELASTICITY OF WTP ESTIMATES

VALUATION STUDY	COUNTRY	SAMPLE SIZE	AGE RANGE STUDIED	SCOPE TEST PASSED?[1]	CONTEXT	INCOME ELASTICITY OF WTP[1]	
						MINOR HEALTH EFFECT	SEVERE HEALTH EFFECT
STATED PREFERENCE STUDIES							
Blomquist et al. (2011)[2]	United States	526	4-92		Study examine effects of age on valuation of mortality and morbidity risks using a two-stage contingent valuation survey and a sample including parents of children aged 4-17 years and adults aged 18- 92. The survey used a hypothetical improved asthma therapy to elicit (1) tradeoffs between asthma control and fatality risk, (2) willingness to pay (WTP) for reduced fatality risk, and (3) WTP for asthma control.	N/A	0.47
Dickie and Hubbell (2004)	United States	284	3+		Paper examines the distribution within and between families using a model of family resource allocation. The model is estimated using data from a stated preference survey. Four symptoms (cough with phlegm, shortness of breath with wheezing, chest pain on deep inspiration, and/or fever with muscle pain and fatigue) of short (two days or one week) duration were included in the design. Results suggest that economic benefits of a given acute health improvement vary markedly both within and between households, with a range exceeding 400% over groups defined by race, income, health status and age.	0.50	N/A

VALUATION STUDY	COUNTRY	SAMPLE SIZE	AGE RANGE STUDIED	SCOPE TEST PASSED?[1]	CONTEXT	INCOME ELASTICITY OF WTP[1]	
						MINOR HEALTH EFFECT	SEVERE HEALTH EFFECT
Dickie and Messman (2004)	United States	284	3+		A model describing parents' preferences to relieve their own and their children's acute illnesses is estimated using stated-preference survey data. Uses the same survey data as Dickie and Hubbell (2004), which measures WTP for acute health improvements.	0.08 - 0.22	N/A
Evans et al. (2011)[3]	United States	2,110	2+		The presence of dependency relationships among household members poses challenges for benefit estimation since it is unlikely that the conditions necessary for recovering the underlying individual preferences from household choices are satisfied in this setting. The authors of this study design a complementary stated preference survey that describes hypothetical dependency relationships for household members of different ages to test the implications of their conceptual model. The survey focuses on WTP to reduce "moderately severe" asthma.	N/A	0.255
META-ANALYSES							
Van Houtven et al. (2004)	Multiple (US and non-US)	236 WTP estimates	N/A	N/A	Using meta-analysis, this paper combines results from both WTP and health status measure (HSM) studies applied to acute morbidity and tests whether a systematic relationship exists between HSM and WTP estimates. This study builds upon the previous work of Johnson et al. (1997) and analyzes over 230 WTP estimates from 17 different studies.	0.70	N/A

VALUATION STUDY	COUNTRY	SAMPLE SIZE	AGE RANGE STUDIED	SCOPE TEST PASSED?[1]	CONTEXT	INCOME ELASTICITY OF WTP[1]	
						MINOR HEALTH EFFECT	SEVERE HEALTH EFFECT
Vassandumrongdee et al. (2004)	Multiple (US and non-US)	125 WTP estimates	N/A	N/A	This article uses a meta-analysis to attain insights from the literature on economic valuation of short-term health effects due to air pollution. Sixteen available contingent valuation studies on morbidity risk valuation were pooled to identify the relations between WTP estimates and possible influential factors. The results indicate that health risk characteristics expressed in terms of severity and duration of illness, population characteristics (e.g., income and education), and study features affect individuals' WTP to reduce or avoid a given morbidity. This study is an extension of the meta-analysis performed by Johnson et al. (1997).	0.18 – 0.35	N/A

1. N/A = Not Applicable; Blank = Information not readily available in literature.
2. Personal communication with G.C. Blomquist, March 2012. Value provided for average age adult in the sample.
3. This elasticity was calculated with the help of the authors for the $70 bid design point (Personal communication with V.K. Smith, March 2012). The authors note that the income elasticity estimated by this study represents the income elasticity of WTP for a caregiver time savings. This paper does not analyze a reduced morbidity risk directly, but rather asks survey respondents to consider the time savings associated with a switch from one form of asthma treatment to another (this switch is brought on by improved air quality). Ultimately we did not consider this study when making our recommendations due to the difference in the commodity being measured.

EXHIBIT B-2. MORTALITY STUDIES WITH INCOME ELASTICITY OF WTP ESTIMATES

VALUATION STUDY	COUNTRY	SAMPLE SIZE	AGE RANGE STUDIED	SCOPE TEST PASSED?[1]	CONTEXT	INCOME ELASTICITY OF VSL	
						LOW ESTIMATE	HIGH ESTIMATE
HEDONIC WAGE-RISK STUDIES							
Kniesner et al. (2010)	United States	2,036 individuals; 6,625 person-years	18-65	N/A	Study examines differences in VSL across potential wage levels in panel data using quantile regressions with intercept heterogeneity. The authors provide evidence on the relationship of VSL to income levels and to fatality risk levels. Income elasticity is estimated at different quantiles with respect to the real family income levels at these quantiles. In addition, an overall income elasticity across the quantiles of 1.44 is reported.	1.44 (Mean value across quantiles)	
Evans and Schaur (2010)	United States	11,306	30+ (mostly 51-61, average age 57)	N/A	Quantile regression approach to simultaneously explore the effect of income and age on marginal WTP for mortality risk reduction within the context of the hedonic wage model. Study results, based on data from the Health and Retirement Study (HRS), suggest that earnings heterogeneity contributes more to variation in VSL estimates than do differences in age.	Not available	
STATED PREFERENCE STUDIES							
Blomquist et al. (2011)[2]	United States	526	4-92		Study examine effects of age on valuation of mortality and morbidity risks using a two-stage contingent valuation survey and a sample including parents of children aged 4-17 years and adults aged 18- 92. The survey used a hypothetical improved asthma therapy to elicit (1) tradeoffs between asthma control and fatality risk, (2) willingness to pay (WTP) for reduced fatality risk, and (3) WTP for asthma control.	Not available	

VALUATION STUDY	COUNTRY	SAMPLE SIZE	AGE RANGE STUDIED	SCOPE TEST PASSED?[1]	CONTEXT	INCOME ELASTICITY OF VSL	
						LOW ESTIMATE	HIGH ESTIMATE
Cameron and DeShazo (2011)	United States	1,927	25+	Yes	The authors develop a structural model of utility defined over a sequence of prospective future health states which permits them to generalize the concept of the VSL. The authors estimate the marginal (dis)utilities of discounted prospective illness years, recovered/remission years, and lost life-years. For an individual of a given age and income, these estimates permit calculation of overall WTP to avoid a wide variety of arbitrarily specified illness profiles. Reported elasticity is over the income interval of $42,000 to $67,500 for a 42-year-old faced with the scenario of sudden death.	0.66	0.68
Carson and Mitchell (2006)	United States	121	18+		In-depth study in a small Southern Illinois town looking at the public's preferences with respect to reducing trihalomethanes (THMs) in their public drinking water system. Study finds VSL estimates that are low relative to most estimates in the literature; however, this can be explained by respondents discounting due to the long latency period. After allowing for discounting using commonly used rates, VSL estimates are well within the range commonly found in the literature for WTP to avoid current period fatal accidents. Note that although this study was published in 2006, the survey was conducted in 1985.	Not available	

VALUATION STUDY	COUNTRY	SAMPLE SIZE	AGE RANGE STUDIED	SCOPE TEST PASSED?[1]	CONTEXT	INCOME ELASTICITY OF VSL	
						LOW ESTIMATE	HIGH ESTIMATE
Hammitt and Haninger (2010)	United States	1,997	2+		The authors examine heterogeneity of WTP to reduce risks of fatal disease and trauma to adults and children. Using a stated-preference survey fielded to a large, nationally representative internet panel, the authors find that WTP to reduce fatal-disease risks (caused by consuming pesticide residues on foods) are similar for several types of cancer and non-cancer diseases and similar to WTP to reduce motor-vehicle crashes. The low elasticity estimate is derived from the pooled model and the high elasticity estimate is derived from the model for risk to child.	0.1 (pooled model)	0.3 (risk to child)
Van Houtven et al. (2008)	United States	788	18-93		Using a national survey, the authors elicit relative preferences for avoiding fatal cancer and auto-accident risks. They find strong preferences for avoiding cancer risks. With a 5-year latency, they are valued roughly three times greater than immediate accident risks, declining to 50% greater for a 25-year latency.	Not available	
META-ANALYSES							
Lindhjem et al. (2011)	Multiple (US and non-US)	856 VSL values	N/A	N/A	Global meta-analysis of stated preference surveys. Low estimate is low-end of range from regressions using subset of the data that satisfy the internal and external scope tests or use the same high-quality survey. High estimate is high-end of range from most of the regressions applying screening criteria.	0.34 (studies passing internal <u>and</u> external scope test)	0.75 (studies passing internal <u>or</u> external scope test)

1. N/A = Not Applicable; Blank = Information not readily available in literature.
2. Personal communication with G.C. Blomquist, March 2012. Value provided for average age adult in the sample.

APPENDIX C - INCOME GROWTH ADJUSTMENT FACTORS FOR 1990 THROUGH 2035

YEAR	GDP PER CAPITA (2010$)	MINOR HEALTH ENDPOINTS			SEVERE HEALTH ENDPOINTS			MORTALITY		
		LOW	CENTRAL	HIGH	LOW	CENTRAL	HIGH	LOW	CENTRAL	HIGH
1990	$35,904	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
1991	$35,344	0.99906	0.99530	0.98907	0.99405	0.98938	0.98056	0.99686	0.98984	0.97763
1992	$36,040	1.00023	1.00114	1.00266	1.00144	1.00258	1.00475	1.00076	1.00247	1.00547
1993	$36,583	1.00112	1.00563	1.01320	1.00714	1.01282	1.02369	1.00375	1.01225	1.02734
1994	$37,609	1.00279	1.01401	1.03300	1.01778	1.03205	1.05971	1.00932	1.03061	1.06910
1995	$38,098	1.00356	1.01795	1.04239	1.02279	1.04116	1.07698	1.01193	1.03931	1.08921
1996	$39,066	1.00507	1.02563	1.06084	1.03258	1.05905	1.11131	1.01701	1.05638	1.12932
1997	$40,320	1.00698	1.03538	1.08454	1.04502	1.08203	1.15615	1.02345	1.07827	1.18205
1998	$41,587	1.00884	1.04499	1.10823	1.05734	1.10498	1.20185	1.02977	1.10011	1.23616
1999	$43,097	1.01099	1.05616	1.13615	1.07168	1.13200	1.25685	1.03709	1.12581	1.30179
2000	$44,383	1.01275	1.06544	1.15967	1.08362	1.15475	1.30420	1.04316	1.14742	1.35873
2001	$44,421	1.01281	1.06571	1.16035	1.08397	1.15541	1.30558	1.04333	1.14804	1.36040
2002	$44,809	1.01333	1.06846	1.16739	1.08752	1.16222	1.31994	1.04513	1.15451	1.37776
2003	$45,554	1.01432	1.07370	1.18085	1.09428	1.17523	1.34765	1.04854	1.16686	1.41137
2004	$46,700	1.01581	1.08162	1.20140	1.10452	1.19508	1.39054	1.05368	1.18568	1.46366
2005	$47,692	1.01707	1.08835	1.21904	1.11324	1.21212	1.42798	1.05804	1.20182	1.50961
2006	$48,490	1.01806	1.09367	1.23313	1.12015	1.22571	1.45827	1.06149	1.21469	1.54698
2007	$48,950	1.01862	1.09671	1.24121	1.12410	1.23351	1.47581	1.06345	1.22206	1.56870
2008	$48,326	1.01786	1.09258	1.23023	1.11874	1.22292	1.45202	1.06078	1.21204	1.53925
2009	$46,234	1.01521	1.07842	1.19307	1.10038	1.18704	1.37306	1.05160	1.17805	1.44231
2010	$47,238	1.01649	1.08528	1.21098	1.10926	1.20434	1.41081	1.05606	1.19445	1.48850
2011	$48,055	1.01752	1.09078	1.22546	1.11640	1.21832	1.44174	1.05962	1.20769	1.52656
2012	$49,459	1.01924	1.10005	1.25012	1.12844	1.24211	1.49532	1.06560	1.23020	1.59293
2013	$50,908	1.02096	1.10937	1.27528	1.14059	1.26637	1.55118	1.07161	1.25313	1.66272
2014	$51,550	1.02170	1.11343	1.28633	1.14589	1.27702	1.57611	1.07422	1.26319	1.69407
2015	$52,492	1.02278	1.11931	1.30245	1.15357	1.29255	1.61293	1.07799	1.27785	1.74059
2016	$53,412	1.02380	1.12496	1.31808	1.16097	1.30760	1.64912	1.08161	1.29204	1.78658
2017	$54,291	1.02477	1.13029	1.33292	1.16795	1.32188	1.68395	1.08501	1.30551	1.83112
2018	$55,151	1.02569	1.13541	1.34732	1.17468	1.33573	1.71821	1.08828	1.31856	1.87515
2019	$55,948	1.02653	1.14011	1.36059	1.18085	1.34850	1.75019	1.09127	1.33058	1.91647
2020	$56,874	1.02750	1.14548	1.37591	1.18792	1.36322	1.78758	1.09469	1.34444	1.96506
2021	$57,906	1.02855	1.15137	1.39285	1.19569	1.37950	1.82955	1.09843	1.35974	2.01994
2022	$59,053	1.02969	1.15781	1.41153	1.20420	1.39744	1.87660	1.10251	1.37660	2.08192
2023	$60,170	1.03078	1.16397	1.42956	1.21234	1.41474	1.92280	1.10641	1.39285	2.14324
2024	$61,286	1.03184	1.17002	1.44742	1.22035	1.43187	1.96934	1.11022	1.40892	2.20549
2025	$62,420	1.03289	1.17605	1.46542	1.22836	1.44914	2.01707	1.11402	1.42511	2.26982

YEAR	GDP PER CAPITA (2010$)	MINOR HEALTH ENDPOINTS			SEVERE HEALTH ENDPOINTS			MORTALITY		
		LOW	CENTRAL	HIGH	LOW	CENTRAL	HIGH	LOW	CENTRAL	HIGH
2026	$63,515	1.03389	1.18178	1.48264	1.23597	1.46564	2.06351	1.11762	1.44057	2.33290
2027	$64,565	1.03483	1.18719	1.49904	1.24317	1.48135	2.10846	1.12101	1.45528	2.39442
2028	$65,619	1.03575	1.19252	1.51536	1.25028	1.49698	2.15391	1.12436	1.46990	2.45708
2029	$66,687	1.03667	1.19784	1.53178	1.25739	1.51269	2.20038	1.12769	1.48459	2.52165
2030	$67,842	1.03764	1.20350	1.54938	1.26496	1.52952	2.25103	1.13122	1.50032	2.59262
2031	$68,983	1.03858	1.20900	1.56662	1.27232	1.54601	2.30154	1.13464	1.51571	2.66398
2032	$70,063	1.03945	1.21412	1.58282	1.27919	1.56149	2.34981	1.13783	1.53015	2.73273
2033	$71,178	1.04033	1.21932	1.59940	1.28618	1.57733	2.40004	1.14106	1.54492	2.80489
2034	$72,350	1.04123	1.22470	1.61668	1.29341	1.59383	2.45329	1.14439	1.56029	2.88207
2035	$73,534	1.04213	1.23004	1.63399	1.30060	1.61035	2.50762	1.14770	1.57567	2.96153

APPENDIX D – DEVELOPING AND APPLYING INCOME GROWTH FACTORS TO THE LATE CENTURY

As part of our updated recommendations for applying new income elasticity and income estimates, we also researched approaches for developing and applying income growth adjustment factors to years beyond 2030, with a particular focus on the late century period (2080 to 2100). Extending adjustments for growth in real income may be relevant for future climate change regulatory analyses. In addition, we consider several sources of long-term income or GDP growth to assess which would be most appropriate, focusing mainly on published recent climate change economic assessments, such as integrated assessment modeling exercises, EPA CGE modeling, and UN-developed global and country-level income and population projections. Currently, no official government estimates have considered income adjustments this far in the future, to our knowledge.

This appendix describes approaches to developing income growth adjustments and alternate long-term income or GDP growth scenarios. We first review some general theory of economic growth, then review existing assessments for insights about projecting income and income adjustments, and finally summarize recommendations.

KEY ELEMENTS OF ECONOMIC GROWTH THEORY

Much of the theory on economic growth is fundamentally based on the Solow growth model, a theory of economic growth that was developed in the 1950s and 1960s.[15] A review of the key elements of the Solow model is useful for understanding some of the basic determinants of long-term growth, projections of which must ultimately be based on, or at least limited by, projections of fundamental elements of economic growth.

Solow's growth theory is based on three factors: growth in the capital stock, growth in the labor force (as affected by population and labor force participation), and advances in technology. Levels of capital stock are related to the savings rate – for a constant savings rate, levels of capital will over time approach a steady-state level of capital, but changes in savings rates can alter that steady-state. Changes in the savings rates also alter consumption (and therefore immediate output and income) and change the distribution of income among current and future generations over time. Population growth (or more accurately, labor force growth, which is the product of population and labor force participation) does not by itself raise (or necessarily lower) income per person, as long as capital stock accumulation keeps pace with population growth.

The key factor in the Solow model explaining increases in per capita income over time is advances in technology that increase the efficiencies of capital, labor, or both. Estimates of long-term income per capita growth are therefore effectively limited by technological progress. Historical rates of technological progress and per capita income growth are both about two percent per year, but there are no guarantees that this rate can be sustained over time.[16]

---

[15] See Robert M. Solow (1956). A Contribution to the Theory of Economic Growth. *Quarterly Journal of Economics*, 70(1): 65-94.

[16] This rudimentary review of economic growth is intended only to identify some fundamental elements that maybe important for long-term projections. There are a large number of qualifications necessary in assessing any long-term

RELEVANT LITERATURE

We were unable to identify any examples of analyses that have applied adjustments to WTP for health risk reductions based on income changes over periods of time past 2035. Most long term integrated assessments, which incorporate both cost and benefit estimates for greenhouse gas (GHG) control over time, apply an aggregated approach to benefit estimation, and therefore do not explicitly adjust WTP for benefits of GHG for differences in income of the beneficiaries, except potentially as part of other adjustments to standardize the time perspective of the analyses (which we describe below).[17]

One notable example of a high-profile long-term integrated assessment of climate change benefits and costs is the Stern Review – that analysis is illustrative of a common approach to global climate change economic analyses.[18] In these analyses, most of the discussion about intertemporal issues is focused on the choice of a discount rate – in part because the major focus of benefits of climate policies is on market effects, but also because the analyses are highly aggregated. Most benefits are converted to GDP equivalents in each time period, then discounted to the present to bring them to a common metric as costs. An illustration of the high level of aggregation of the benefits of GHG control policies is summarized in the following quote: "In practice, for this exercise, this means that we convert per-capita global GDP at each point in time into consumption, and then calculate the social utility of per-capita consumption. This is then multiplied by global population." (Stern 2007, p. 181) Critical factors in this type of analysis include the marginal utility of consumption and changes in the distribution of income over time and across countries, but the income elasticity of WTP for benefits does not come into the analysis.

Short term assessments of GHG control have applied adjustments for mortality and morbidity similar to those applied in EPA/OAR analyses. One recent example is an analysis of climate and non-climate benefits of controlling methane and black carbon (Shindell et al 2012).[19] The issue of whether these types of adjustments could be extended to 2100 appears not to have been explored. Further, the issue of whether income elasticity estimates could be expected to remain stable over time also appears not to have been explored, so we have no evidence or theory to rely on concerning the question of whether income elasticity ought to increase or decrease over time. It is clear that the application of a zero income elasticity (that is, no adjustment for income) suggests WTP for health would decline as share of income over time.

A recent US Global Climate Change Research Program report, *Analyses of the Effect of Global Change on Human Health and Welfare and Human Systems*, directly acknowledges the long-term nature of climate risks, and the challenge of valuing health

---

growth projection at a country level, but the main point is that many of the short-term influences on country-level growth per capita (e.g., the ability to borrow cheaply from other countries with high savings rates) tend to fall away over the longer term.

[17] We understand from anecdotal evidence that there has been much discussion in analyses involving income and benefits assessment concerning cross-sectional income adjustments, usually to standardize WTP for health reductions across countries, rather than longitudinal income adjustments.

[18] Nicolas Stern, The Economics of Climate Change: The Stern Review, Cambridge: Cambridge University Press. 2007.

[19] Drew Shindell et al., Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security, *Science* 335:183-189. 2012.

effects that will occur far in the future.[20] The report does not provide suggestions about how to meet that challenge, however.

AVAILABLE LONG-TERM PER-CAPITA INCOME PROJECTIONS

Our recommendation for per-capita income projections elsewhere in this memo is to adopt BEA estimates for historical data and Department of Energy, Energy Information Administration data from their published Annual Energy Outlook (AEO). The AEO 2011 report provides integrated income and population projections but only to the year 2035. The AEO estimates have also been used in several recent Regulatory Impact Analyses addressing GHG control, as well as EIA's recent published analysis of proposed legislation, the Clean Energy Standard Act of 2012, but those analyses do not project income or benefits past 2035.[21]

Several published EPA analyses also estimate benefits and cost of GHG legislation – the most recent example is EPA's analysis of the American Power Act (APA) of 2010, posted in June 2010.[22] EPA's analyses rely on AEO projections as the starting point for a reference case, and extend economic activity projections to 2050 based on the results of macro-modeling of the US (and world) economy. The macro-economic models applied in these analyses are the Intertemporal General Equilibrium Model (IGEM) and the Applied Dynamic Analysis of the Global Economy (ADAGE) model, both of which are described on EPA's website, and have been peer reviewed for application to these types of policy analyses. EPA's analysis of the APA uses these models to project costs of the standards and economic implications through 2050. Implications for GHG emissions and concentrations are projected through to 2100, but benefits analyses are not reported (beyond the emissions and concentration estimates consistent with those reductions).

The Intergovernmental Panel on Climate Change (IPCC), as part of its development of global GHG emissions scenarios, does generate long-term estimates of income and population growth. The IPCC approach has the advantage of reliance on integrated "storylines" for their scenarios, so projections of income and population are made on a consistent basis. The alternative - independent estimates of population and income growth - could be problematic for projections of the per-capita income estimates required for income elasticity adjustments. The key disadvantage of the IPCC estimates is they are reported at the regional level – with the US in OECD region – and so are not specific to the US.

We suggest that a better option as a source for the necessary long-term income and population data is a US focused study conducted for the Global Change Research Program.[23] The scenarios developed for Synthesis and Assessment Product 2.1 are based on three integrated assessment models:

[20] See US Climate Change Science Program Synthesis and Assessment Product 4.6, *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems*, September 2008, US Global Change Research Program: Washington, DC. Discussion can be found on page 132-133.

[21] See, for example, EIA's web page on their analysis of the Clean Energy Standard Act, http://www.eia.gov/analysis/requests/bces12/.

[22] See http://www.epa.gov/climatechange/EPAactivities/economics/legislativeanalyses.html.

[23] Leon E. Clarke, James A. Edmonds, Henry D. Jacoby, Hugh M. Pitcher, John M. Reilly, and Richard G. Richels. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations: Synthesis and Assessment Product 2.1. Washington, DC: U.S. Climate Change Science Program and the Subcommittee on Global Change Research. 2007.

- The Integrated Global Systems Model (IGSM) of the Massachusetts Institute of Technology's Joint Program on the Science and Policy of Global Change;
- The Model for Evaluating the Regional and Global Effects (MERGE) of GHG reduction policies developed jointly at Stanford University and the Electric Power Research Institute; and
- The MiniCAM Model of the Joint Global Change Research Institute, a partnership between the Pacific Northwest National Laboratory and the University of Maryland.

Scenarios were developed for both a reference scenario and four stabilization scenarios. The reference scenario was based on an assumption that no climate policies would be imposed beyond current commitments, namely the 2008-12 first period of the Kyoto Protocol and the US goal of reducing reduce GHG emissions per unit of its gross domestic product by 18 percent by 2012. A summary of the results for the reference case are provided in Exhibit D-1 below. As indicated in the table, the three models show sharply divergent paths of GDP and population growth after 2020, with the IGSM model being the most optimistic and the MERGE and MiniCAM models showing more moderate growth. MiniCAM also has the highest population projection, though it is similar to IGSM through 2060. Starting in 2040, MERGE has a much lower population projection.

EXHIBIT D-1. SUMMARY OF USGCRP GDP AND POPULATION PROJECTIONS

MODEL AND OUTPUT	2000	2020	2040	2060	2080	2100
IGSM (1997$)						
GDP (trillion $)	9.1	16.9	29.3	44.4	59.8	76.4
Population	283	334	379	396	395	393
GDP/Capita (000$)	32.2	50.6	77.3	112.1	151.4	194.4
MERGE (2000$)						
GDP (trillion $)	9.8	16.1	20.9	26.8	33.1	39.6
Population	276	335	335	335	335	335
GDP/Capita (000$)	35.5	48.1	62.4	80.0	98.8	118.2
MiniCAM (2000$)						
GDP (trillion $)	9.8	15.1	21.1	28.8	38.9	52.6
Population	283	334	371	396	412	426
GDP/Capita (000$)	34.6	45.2	56.9	72.7	94.4	123.5

Source: Leon E. Clarke, James A. Edmonds, Henry D. Jacoby, Hugh M. Pitcher, John M. Reilly, and Richard G. Richels. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations: Synthesis and Assessment Product 2.1. Washington, DC: U.S. Climate Change Science Program and the Subcommittee on Global Change Research. 2007. Note that the source document did not standardize to a single years dollars, so we have not standardized estimates here.

POSSIBLE APPROACHES TO LONGITUDINAL ADJUSTMENTS OF WTP FOR INCOME CHANGE TO LATE CENTURY

The lack of an identified precedent for application of the income adjustments described in this memo to analyses that extend beyond 2035 suggests that multiple approaches might be tested and evaluated. We view two possible approaches that are worth testing and which we anticipate would effectively bracket the range of potentially applicable projected values for morbidity and mortality:

1. With several precedents for application of longitudinal income adjustments through 2035, it is possible to use the AEO GDP per capita projections and the recommended income elasticity values through 2035, and then assume the 2035 values represent a "floor" for values to be applied through 2100. This approach likely underestimates WTP for health reductions beyond 2035.

2. Use one or all three of the per capita income projections from the USGCRP reference projections which apply through 2100, along with the recommended elasticity estimates from this memo.