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“Distributional Analysis of Infrastructure with Weighted BCA”

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ABSTRACT

Distributional analyses have long been recognized in federal benefit-cost analysis (BCA) guidelines but with little information on the best ways to perform such analyses or to combine the results with BCA when evaluating options. One form of distributional analysis, weighted BCA (wBCA), was endorsed by the U.S. Office of Management and Budget in 2023. A wBCA entails weighting individuals' benefits and costs, based on their incomes, to better capture the value of outcomes to them. The estimated weights of a wBCA account for individuals' diminishing marginal utility of income – that is, the assumed declining value of a dollar's worth of benefits as a person's income increases. Analytically, weights are combined with BCA results to determine an alternative societal value of a policy or project. This paper discusses the data, methods and issues that can arise in implementing wBCAs for infrastructure projects, especially when a conventional BCA has already been completed. The implementation method outlined here is then applied to an actual flood risk mitigation project. The paper concludes with comments on how wBCA and BCA may be jointly considered in project evaluation to support implementation decisions.

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1 INTRODUCTION

In the United States, federal benefit-cost analysis (BCA) guidelines have long recognized that distributional analyses could supplement benefit-cost analyses of public policy and capital investment initiatives (White House, 1996). But for many years, U.S. Office of Management and Budget (OMB), which establishes economic evaluation standards for most federal agencies, has provided limited guidance in its BCA-focused Circulars, A-4 and A-94, on how to perform such analyses and use results in decisions (Gaur and Schwartz, 2024). Yet, OMB's call for distributional analyses in its Circulars is arguably incongruous, since BCAs explicitly avoid consideration of the distribution of outcomes (Boadway 2016). BCAs compare *total* benefits to *total* costs, and are notionally justified as measures of social welfare by assuming that other public initiatives could offset any undesirable distributional effects whenever the gains to those who benefit exceed the losses to those who are harmed (the so-called Kaldor-Hicks compensation test). So, were distributional analyses included in BCA guidelines because of weaknesses in the conceptual foundation of a Kaldor-Hicks compensation test? Or was there a concern that BCA results can be biased towards wealthier persons' interests who may have greater willingness-to-pay (WTP) for outcomes?

Whatever the case, Robinson et al. (2016) and Cecot and Hahn (2024) found that distributional analyses were rarely performed, even though the analytical results could have revealed potentially regressive incidence of cost burdens that disproportionately impact lower income subpopulations and in so doing compromise some policy goals. And, with the lack of distributional analysis examples, methods on effectively using available data and interpreting results on actual policies and projects have remained largely unexplored.

In 2023, OMB broke new ground in its updates to Circulars A-4 and A-94 (OMB, 2023a and 2023b) by explicitly identifying weighted BCA (wBCA) as an acceptable form of distributional analysis.¹ A wBCA accounts for the distribution of benefits and costs

¹ Even though the Trump administration rescinded the 2023 Circular A-4 in February, 2025 (OMB 2025) and reverted to the 2003 Circular A-4 (OMB 2003), wBCAs may still be considered because 2003

across beneficiaries² with different characteristics, such as income. A wBCA assigns larger weights to some (e.g., lower-income) beneficiaries and smaller weights to other (higher-income) beneficiaries. Hence the total weighted net benefits are more sensitive to effects on lower-income beneficiaries, and less sensitive to effects on upper-income beneficiaries, than are net benefits of a BCA.

The weights in a wBCA account for individuals' values of a dollar's worth of benefits or costs (in terms of utility or wellbeing). Weights reflect the widely shared assumption that the incremental value of a dollar declines as a person's income increases. This assumption means that lower-income people place a relatively higher value on the same amount of monetized outcomes than persons with higher incomes. OMB's 2023 Circulars promoted wBCA as a form of distributional analysis, and stated that agencies could rely on results from either a wBCA or a BCA to justify implementation decisions – even if a BCA reveals that costs exceed benefits. However, little input is provided on how to perform or interpret wBCA results.

This paper contributes to growing interest in applying wBCAs to evaluate projects, policies and regulations, especially in cases when a BCA has already been performed. The principal focus here is to consider applications of wBCAs for infrastructure projects for which BCAs are much more commonly performed by agencies and economic consultants compared to regulatory impact assessments.³ The importance of wBCAs for infrastructure projects is also underscored for the many public infrastructure agencies that assert dual goals of improving total performance and distribution of benefits because BCAs and wBCAs provide alternative perspectives on project value. Through wBCAs, agencies can better understand the full value of a project to beneficiaries of diverse incomes. Furthermore, agencies are keenly aware that large projects can have long-lasting impacts on people and communities, possibly

Circulars recognize that distributional analyses can provide justification for funding projects and implementing policies.

² We use the term “beneficiaries” to describe anyone positively or negatively affected by a project.

³ Cecot and Hahn (2024) attempted to comprehensively identify regulatory impact assessments (RIAs) between 2003 and 2021 and found 184 that “monetized at least some benefits and at least some costs”. By comparison, over this same period of time just one U.S. firm (where the lead author is employed) conducted around three times that number of BCAs on infrastructure projects for clients seeking federal funds.

exacerbating existing disparities. In such contexts, distributional assessments can provide agencies with substantive input on which projects to build, when and where, especially if such input has been historically lacking. Thus, while this paper presents a case study for only one type of infrastructure, flood-risk mitigation measures, wBCAs could be relevant for many contexts, such as transit agencies determining where to improve service, utilities evaluating options for energy transmission corridors, or location decisions for public health clinics.

This paper aims to enable others to implement wBCAs adapted to the context of individual projects. To this end, the paper describes and then demonstrates a series of analytical steps and considerations for performing a wBCA. Conducting a wBCA in practice requires a large number of analytic choices about data sources, functional forms, parameter values, and other factors. Each of these choices may affect the results and it is not clear how to determine which choices are better. Sensitivity analysis can help identify which choices have larger or smaller effects on the results. Our main objective is to describe some practical methods to conduct a wBCA, without asserting the choices we made are the only “correct” or necessarily the “best” choices.

The paper begins with a brief discussion of the theoretical foundations of wBCA and an outline of computational steps – with two technical appendices providing more details. Next, it demonstrates how to apply these steps in a flood risk mitigation project for which a BCA has already been developed. The paper concludes with a discussion of the implications of considering wBCA and BCA results jointly and highlights areas for continued research.

2 THEORETICAL FOUNDATIONS OF WEIGHTED BCA

A wBCA stems from social welfare function (SWF) concepts developed by Bergson (1938) and Samuelson (1947) who framed the societal value of a project as depending on the change in the utilities of all those who are affected by it. Assuming a *utilitarian* SWF (uSWF),⁴ societal well-being (*SU*) is the sum of individual beneficiaries’

⁴ Adler (2019) discusses utilitarian SWFs as one from a “landscape of SWFs” that represent different ethical principles.

utilities, which are often assumed to be a function of individuals' real incomes. Other SWFs, including prioritarian and egalitarian, can be represented as the sum of transformed or weighted individual utilities. The weights corresponding to these SWFs can be obtained by adjusting the weights that correspond to a uSWF. This paper focuses on a uSWF because it is the most often considered in the applied literature and provides a building block for other SWFs. The utilitarian SWF is arguably conservative, in the sense that other SWFs (e.g., prioritarian, egalitarian) reflect stronger inequality aversion, meaning they put relatively more weight on equalizing the distribution of well-being across individuals than does the uSWF. Moreover, while SWFs can be defined using alternative measures of individuals' well-being (e.g., preference, objective-good) we follow the applied literature in using utility functions standard in microeconomic evaluation.

A uSWF may be written as $SU = \sum_i U(y_i(\bar{x}_i))$, where i indexes the individual and y_i denotes real disposable income including consumption⁵ of goods denoted by the vector $\bar{x}_i$. A uSWF measures the sum of individuals' utilities $U(y_i(\cdot))$, while a BCA measures a change in the sum of individuals' incomes $y_i(\cdot)$. The value of a proposed project is captured by the anticipated change in SU . When individual effects are small, the effect of a project on individual i can be represented as the derivative of SU , $\delta SU / \delta x_{ij} = \delta U / \delta y_i \cdot \delta y_i / \delta x_{ij}$, where j indexes elements of the vector $\bar{x}_i$ that may be affected by the project (e.g., nonmarket goods). The change in SU consists of the product of: (a) $\delta y_i / \delta x_{ij}$, the monetized values of the project outcomes (as estimated from a BCA); and, (b) $\delta U / \delta y_i$, the marginal utilities of individuals' incomes (MU_i). The link between a uSWF and a wBCA entails recognizing MU_i as a multiplicative weight (w_i) on $\delta y_i / \delta x_{ij}$. A wBCA *mimics* the results of a uSWF when project effects on beneficiaries are small compared with their utility, which often occurs in practice.⁶

Weights represent both practical and conceptual departures from a BCA. That is, weights analytically alter the value of outcomes originally estimated from a BCA for

⁵ Income includes money income as well as the monetary value of nonmarket goods.

⁶ For large changes in y_i , $\delta U / \delta y_i$ is not constant and hence cannot be represented by a constant weight.

each i and as a sum across all i . More conceptually, the impact of weights in transforming BCA is measurable along a continuum.⁷ That is, since a BCA sums $\delta y_i / \delta x_{ij}$ across all i , it is equivalent to an equal-weighted wBCA that treats a dollar's worth of benefits or costs as having the same effect on societal well-being, regardless of how the benefit or cost is distributed. However, when the weights for each i diverge from equality, the results of a wBCA deviate from a BCA depending on how the marginal utility of income and monetary value of outcomes differ among beneficiaries.

Analyses typically assume an isoelastic utility function,⁸ which implies that *utility weights* are proportional to $w_i = (1/y_i)^\varepsilon$, where ε equals the elasticity of the marginal utility of income.⁹ Utility weights capture the rate at which marginal utility changes with income (i.e., the curvature of the utility function). To improve interpretability, a second step is often taken to normalize utility weights relative to a “benchmark” income (y_α) that has an associated $MU_\alpha = (1/y_\alpha)^\varepsilon$.¹⁰ A utility weight normalized by the benchmark income equals $w_i^\alpha = (y_\alpha/y_i)^\varepsilon$, and here this is called an *income weight*. At the benchmark income y_α , the income weight $w_\alpha^\alpha = 1$; income weights are larger than 1 for individuals with incomes less than the benchmark and smaller than 1 for individuals with incomes greater than the benchmark. Income weights differ also from *equity weights*

⁷ Boadway (2016) explains that by incorporating individuals' utilities in project evaluations, SWFs and wBCAs depart significantly from BCAs because utilities introduce “interpersonal differences” into the evaluation that are not strictly observable.

⁸ It is common in theoretical and applied research to assume that individuals' utilities take an isoelastic form, $U(y) = y^{1-\varepsilon}/1 - \varepsilon$, where the elasticity of marginal utility of income $\varepsilon \geq 0$ is constant (e.g., H.M. Treasury 2026, OMB 2023, Adler 2016, Acland and Greenberg 2023). Isoelastic utility is consistent with experimental research of Kahneman and Deaton (2010).

⁹ For simplicity, utility weights are often calculated in practice using money income (possibly pre-tax) as opposed to real disposable income (that incorporates consumption of non-market goods). Future research could evaluate the effects of using alternative approximations.

¹⁰ It is important to note that a wBCA transforms BCA results from dollars to weighted dollars that are assumed to be units of societal utility (such units are sometimes called “utils”). Quantities of weighted dollars or utils can be used to rank project options and compare build to no-build decisions, but utils are not directly measurable.

that capture social aversion to income inequality (see Adler, 2016; Acland and Greenberg, 2023).¹¹

While wBCA is a reasonable conceptual framework, economic scholars have argued for many years against its use in prioritizing initiatives for implementation (Banzhaf, 2023). Common concerns about using wBCA in public decisions recognize accurately that analyses require assumptions about marginal utilities of different individuals' incomes. Such assumptions are problematic to some because utilities cannot be measured directly (Hammitt, 2026). Further, some argue that the use of wBCA results could lead to an inefficient use of resources, and that distributional interests could be better handled by tax policy (see for example, Mirrlees (1971), Harberger (1971; 1978), Atkinson and Stiglitz (1976), Kaplow (2008), and Weisbach (2015)). As a corollary, when income transfers through tax and transfer programs are limited (e.g., by incentive effects), choosing projects with more desirable distributional effects may improve distribution at lower cost (Johannsson-Stenman, 2005).

Many recognize that BCA is an incomplete measure of welfare (Brekke, 1997; Nyborg, 2014). Other economic scholars have highlighted the opportunities and potential importance of distributional perspectives in project or policy evaluations. For example, Adler (2016) and Robinson et al. (2016) emphasize that by accounting for distributional effects, wBCA can better estimate the total societal welfare of a project. Banzhaf (2023) notes that relying on WTP alone to determine project value is itself a normative decision. Acland and Greenfield (2023) more provocatively maintain that BCA is inherently biased towards those with higher incomes and that wBCA provides a full measure of welfare as a sum of individuals' utilities for project outcomes.

The 2023 Circular A-4 and A-94 significantly elevated the importance of distributional analyses in the U.S. and shifted discussions from *if* weights should be used to *how* weights should be computed and considered in implementation decisions. For instance, Circular A-4 states that results of distributional analyses (including

¹¹ Acland and Greenberg (2023) explicitly distinguish these utility weights from those that can be formed to represent social aversion to inequalities in utility, which may support project evaluations with re-distributional goals. Weights related to social aversion to inequities in utility are not discussed here.

wBCAs) could justify implementing an alternative with lower monetized net benefits over another with higher net benefits because of how those net benefits are distributed. The Circulars also took steps to standardize computation of weights by recommending: (a) an income elasticity of marginal utility of 1.4, and (b) a benchmark income equal to the U.S. median income. OMB also recommended against applying weights for benefits computed with common unit values (such as a single value per statistical life or value per hour of travel time) because those unit values implicitly weight benefits.¹²

Unfortunately, past arguments for and against wBCA have missed the opportunity to explore practical aspects of considering BCA and wBCA results together, as described in OMB (2023) and the U.K. Green Book (HM Treasury, 2026). Both measures can provide useful information about the societal value of an initiative. But less attention has been directed in the literature to contexts in which a wBCA provides actionable information. For instance, if wBCA is established as supplemental to a BCA, then a wBCA could be used to rank initiatives that exceed a minimum benefit-cost ratio (*BCR*). By setting a *BCR* threshold, concerns that wBCA could favor projects that lack substantive value-for-money to society could be diminished. Moreover, insight may be gained for decision makers by conducting wBCAs with alternative weights (Ferranna, et al. 2024). Ultimately, Robinson, et. al. (2016) argue that it is important to find a solution to considering wBCA results because accounting for distributional outcomes can bring important insights to decision-makers. Cecot and Hahn (2024) indicate that while some agencies have evaluated distributional effects in regulatory analyses, few such analyses have been systematically conducted so that the results can better inform regulators on the advantages or disadvantages of alternative policies towards a particular group.

Few applications of wBCA have been published and most perform illustrative demonstration analyses that mix actual data with hypothetical scenarios. For instance, illustrative applications have explored the impact of applying weights in topics related to employment programs (Fujiwara, 2010), social cost of carbon (Anthoff and Emmerling, 2016), natural resources disaster impacts (Hallegatte, et al., 2017), child care benefits

¹² While true, common unit values may only partially capture the implicit marginal utility of income as represented by standard weights. Instead, a partial weight should be computed, as shown below.

policy (van der Pol, Bos and Romijn, 2017), water quality improvements (Nurmi and Ahtiainen, 2018), public health (Ferranna, et al., 2024), and a series of policy cases (Acland and Greenfield, 2025). Overall though, wBCA has not been widely and systematically implemented for infrastructure projects in published and peer-reviewed studies.

With respect to the case study discussed below, papers by Kind, et al. are particularly relevant. Kind, et al. (2017) motivate the potential importance of applying income weights for flood risk. They develop hypothetical scenarios to assess how using weights on the same amount of damage to the poor and non-poor could change flood risk mitigation priorities compared to recommendations that follow from standard BCAs. As a follow-up, Kind, et al. (2020) further their discussion on how social vulnerability and resilience can be integrated into flood risk assessments and BCAs, including a discussion on data needs and analytical equations. This work formalizes the application of income weights and equity weights for flood risk evaluations and applies the weights to a simulated case study. Overall, Kind, et al. effectively motivate the importance of accounting for income differences in flood risk.¹³

Two U.S. federal agencies have begun to consider how to implement a wBCA for flood risk mitigation projects. For instance, in December 2024, the US Army Corps of Engineers (USACE, 2024) published revised BCA guidelines and recommended performing analyses of “distributional effects” using “income-weighting” in “sensitivity analyses.” More notably, the Federal Emergency Management Agency (FEMA) published a wBCA approach that could be used in analyses of flood risk mitigation projects (FEMA, 2024). FEMA explains that a wBCA more effectively captures flood risk reduction benefits in low-income areas and aligns with FEMA’s mandate to identify cost-effective solutions. Normally, standard analyses of projects in low-income areas find correspondingly lower property values which generate low benefits for flood risk mitigation. Low benefits may fall below the cost of structures to reduce flood risk and, in turn, reduce the federal interest in funding the project. In contrast, weights would

¹³ The case study evaluated in this paper builds from the same recognition as Kind, et al. but differs in that: (a) we only consider income weights (not equity weights); and, (b) we apply income weights to previously estimated benefits and costs that are allocated across incomes in the flood prone area.

capture the relatively higher value for flood risk reduction to lower income persons and could enhance the justification for federal funding.

While the FEMA approach to distributional analyses is practical and relatively easy to implement, it is a significant simplification of a theoretical wBCA. The FEMA approach computes weights as $w_i^{FEMA} = (y_{US\ Med.\ Inc.}/y_{CT\ Med.\ Inc.})^\varepsilon$, which is a ratio of the U.S. median income to the median income in the census tract (CT) and with $\varepsilon = 1.4$. This approach entails computing a single weight for all households in a census tract, irrespective of their actual incomes. The approach differentiates impacts between census tracts but ignore differences in the marginal utility of income between households within census tracts. FEMA's approach also constrains weights to be between 1.0 and 3.7,¹⁴ under the rationale that a maximum value “establishes a conservative baseline” for wBCAs (FEMA, 2024) and a minimum weight of 1.0 makes weighted values no less than unweighted values.

3 DESCRIPTION OF ANALYTICAL STEPS IN A WBCA

While OMB Circulars advanced the concept of distributional analyses and wBCAs, methodological standards remain to be developed. Currently, no explicit wBCA methodological guidelines exist even though textbooks and published papers have outlined the basic components (e.g., Circulars A-4 and A-94, the U.K. Green Book, Florio and Pancotti (2023), OECD (2018), and a transportation application ATAP (2016)). A partial exception is Acland and Greenberg (2025), who outlined and implemented several approaches to addressing issues in data analysis (e.g. conversion of money income to post-tax income, handling common unit values, and performing sensitivity analysis) – all useful contributions for future analyses.

In this paper, because a BCA is often conducted for a proposed infrastructure project, the process of implementing a wBCA uses information that is normally available

¹⁴ A minimum value of 1.0 means that any census tract with median incomes above the U.S. median would have a weight of 1.0 instead of a weight below 1.0. With the FEMA constraint, weighted property losses in higher income areas would have the same magnitude as nominal losses, not less. A maximum weight of 3.7, which corresponds to the 5th percentile of all census tract median incomes, means that the weighted losses in extremely low-income census tracts are not fully captured.

from a BCA, including characteristics of the project and beneficiaries, descriptions of data and methods, and present value results for each category of monetized benefits (B) and costs (C). With weights w^α , a wBCA transforms a BCA to generate new measures including a weighted Net Present Value ($wNPV^\alpha$) and a weighted Benefit-Cost Ratio ($wBCR^\alpha$):

$$\text{EQ. 1: } wNPV^\alpha = \sum_i [\sum_j w_i^\alpha \cdot B_{ij} - \sum_k w_i^\alpha \cdot C_{ik}]$$

$$\text{EQ. 2: } wBCR^\alpha = \frac{[\sum_i \sum_j w_i^\alpha \cdot B_{ij}]}{[\sum_i \sum_k w_i^\alpha \cdot C_{ik}]}$$

in which each measure sums weighted benefits across J benefit categories (e.g. cost savings, risk reduction, etc.) and weighted costs in K categories (e.g. product cost, source of governmental revenues, opportunity costs, etc.), for all I individuals, or as is commonly implemented, I groups of individuals with similar incomes.¹⁵

This section discusses a series of steps to implement a wBCA, primarily for infrastructure projects in the United States. These steps outline a systematic and sequential approach to performing a wBCA and are general enough to adapt to a wide range of applications and contexts. These steps include: (1) Review BCA; (2) Determine Income Groups; (3) Compute Income Weights; (4) Estimate Benefits and Costs per Income Group; (5) Compute Weighted Results and Perform Sensitivity Analysis; and, (6) Compare BCA and wBCA. These steps have been implemented in wBCAs that the first author has performed on various projects and policies in the transportation, water, energy, broadband communications, and health service sectors.

3.1 Step 1: Review BCA

An existing BCA is reviewed to assess features of the project context and analysis characteristics relevant to a wBCA. For instance, because a wBCA depends on

¹⁵ Note that in many contexts, agencies may not have any influence over the sources of resources to fund their projects, especially when general government revenue is allocated to agencies for spending. In this case, an agency may simply be interested in the ratio of social welfare improvement per unit of government spending. In that case, the weighted benefit-cost ratio EQ. 2 would change to divide weighted benefits by actual costs. The new ratio would be interpreted as the *cost-effectiveness* of public spending to increase social welfare because here, weighted dollars are divided by actual dollars. This ratio is analogous to the marginal value of public funds (Hendren and Sprung-Keiser, 2020).

the incomes of beneficiaries, it is important to identify the geographic region where beneficiaries reside or work since this set of individuals “has standing” and benefits and costs to them will be counted. In other words, the relevant region encompasses all people whose benefits and costs are captured directly or indirectly by the BCA. In some cases, the region reflects the operational domain of a project owner or funding agency. For example, the region associated with a transit project would encompass the entire service area of a transit agency because any single project represents a gain to some and lost opportunity to others in that service area. Similarly, for a state (or federal) funding agency, the region would comprise the entire state (or nation). The practical importance of specifying a region is that it defines the geographic boundaries for which income data are obtained from the US Census and analyzed to determine weights and allocations of benefits and costs.

Next, a BCA is reviewed to determine how benefits and costs are monetized. Specifically, a BCA is reviewed to determine the: (a) estimation approach per benefit category; (b) identification of beneficiaries per benefit category; and (c) types of project costs and sources of funding. This review determines if benefits are monetized with a common population-wide value or by using values that differ by sub-populations. This difference affects how income weights are determined (see Step 3). Differentiating beneficiaries per benefit category is important because subgroups of beneficiaries are likely to have different income distributions (see Step 4).¹⁶ Similarly, a wBCA accounts for income-differentiated costs including: (a) direct cost impacts on people (such as changes in product prices or opportunity costs); and (b) cost burdens of project or policy implementation on people relative to a source of funding (and originally as tax and fee payments by people).

3.2 Step 2: Determine Income Groups

Income groups are formed to establish a common income distribution for use in apportioning benefits and costs as well as computing income weights per income group. US Census household income distribution data consist of the percentages of

¹⁶ For example, a single transportation project can affect multiple modes (e.g., passenger vehicles, transit, and cycling), which may include subgroups of trip takers with different income characteristics.

households in specific income bands. Each band is defined by lower and upper *income cutoffs* (e.g., less than \$5 thousand, \$5 - \$10 thousand, etc.) and between these cutoffs, a midpoint income can be computed.¹⁷ The specification of regional income groups for a wBCA is arbitrary but a practical approach entails forming a modest number of equal-sized income groups (e.g., quintiles or deciles).¹⁸

Before forming groups, Census data may be adjusted to better account for households' total disposable incomes. At sub-national levels (i.e., state, county or census tract), the Census only reports "money income" (MI), which is primarily wages, before tax and tax credits are incorporated, and excludes other sources of income. While MI can be used in a wBCA, a better measure of households' resources underlying MU_i are households' total disposable incomes, which include MI, net of taxes and transfers (e.g., social security payments) and adds various sources of capital income. In addition, comparability across households is improved by equalizing across household composition (e.g. number and ages of household members).¹⁹

Adjustment factors (" A ") can be estimated for each income group that can be used to convert MI to equivalized, disposable income (EDI). Adjustment factors, defined here as $A_i = y_i^E / y_i^M$ for each i income group can be determined with statistical analyses (see Appendix B for more details). Data for estimating a set of A_i are available from: (a) US Census (2022), which includes MI and equivalized incomes; and, (b) the US Department of Treasury (2022), which includes data on a variety of equivalized income components (e.g. transfers, capital income, and post-tax adjustments). Inspection of the Census and Treasury income data indicates that A_i vary with MI levels. Once EDI cutoff levels and reference incomes are computed with A_i and the original MI values, then any

¹⁷ For the highest quintile, the maximum income is not known so a reference income is estimated statistically, as discussed in Appendix B.

¹⁸ In general, establishing more groups with smaller income bands would lead to a better approximation of the distribution of effects by income, but this could expose data gaps that are computationally challenging. Using more income groups may not appreciably change the overall findings from a wBCA. Future research could evaluate the sensitivity of wBCA results to numbers and sizes of bands.

¹⁹ Equivalization of income normalizes incomes of households relative to numbers and ages of members. This approach is recommended in the U.K. Green Book (2026).

number of equal-sized groups can be formed by interpolating or statistically analyzing EDI cutoff values and corresponding percentiles.²⁰

3.3 Step 3: Compute Income Weights

Standard income weights are determined from $w_i^\alpha = (y_\alpha/y_i)^\varepsilon$ for each y_i , as established in Step 2. Following Circular A-4 guidelines, ε can be set to 1.4,²¹ and sensitivity analyses can be performed for a range of elasticities. The choice of a benchmark income y_α has no theoretical significance and is made primarily to improve interpretation of wBCA for decision makers and so this parameter may depend on the decision context. Much of the literature, including Circulars A-4 and A-94 and the U.K. Green Book, recommends using a national median income. The median is a reasonable option since half the population makes either more or less than this level. But different median incomes can be considered depending on the region relevant to the project or investment decision, as discussed in Step 1. Alternative benchmarks have not been systematically explored, except in van der Pol, Bos and Romijn (2017). A “cost-normalizing” benchmark, which is defined so that weighted costs are equal in magnitude to actual project costs, can be useful.²²

Standard income weights are appropriate for many types of benefits, but they cannot be applied directly to benefit categories that are estimated using a common unit value because this neglects how WTP varies with income y_i .²³ To correct this, one

²⁰ This approach describes a static approach to forming income groups. If the sizes of income groups in a population are anticipated to grow at different rates, this could change the characteristics of the overall distribution. Analytical methods can be developed to handle those adjustments, but the impact would depend on how those income growth rates differ among groups of beneficiaries. In practice, this issue is assumed to be small relative to the impact of other types of assumptions.

²¹ The U.K. Green Book recommends a similar value of 1.3. In principle, the elasticity of the marginal utility of income may depend on whether income is measured by MI, EDI, or other concepts, and whether or not it is equivalized. We overlook this issue but recommend it be addressed by future research.

²² This benchmark, discussed in more detail in Appendix A, is derived from the income-based allocation of cost burdens and the marginal utility of those cost burdens for households. Its use reveals the absolute difference in unweighted and weighted benefits because costs are normalized. This benchmark depends on how costs are distributed, and would be applicable only when comparing projects with the same distribution of funding sources-

²³ As an example, common unit values appear in USDOT BCA guidelines for estimating travel time benefits, which are estimated by multiplying travel times of travelers (minutes per trip) by a function of U.S. median household incomes (\$/hour).

analytical approach could adjust the value of benefits to each individual using the income elasticity of WTP²⁴ for that benefit, and then apply standard income weights. Alternatively, the benefit calculated using a common unit value can be adjusted using *partial* income weights.

To compute partial weights, let $B_{ij}(y_{pop})$ denote the magnitude of benefit component j to individual i calculated using a common unit value and y_{pop} is the income at which the individual value equals the common unit value (e.g., the median income in some group of people). Using the first approach, the benefit to individual i would be estimated by multiplying $B_{ij}(y_{pop})$ by $(y_i/y_{pop})^\eta$ where η is the income elasticity of the WTP for that benefit category. Weighting this individual benefit by the income weight $w_i^\alpha = (y_\alpha/y_i)^\varepsilon$ yields the weighted benefit to individual i , $\tilde{w}_i^\alpha B_j(y_{pop})$, where the partial weight $\tilde{w}_i^\alpha = (y_i/y_{pop})^\eta (y_\alpha/y_i)^\varepsilon$ for individual i .

Further, in the many cases when common unit values are estimated for a non-equivalized measure of MI and income weights are derived from EDI, it is necessary to also adjust for differences in these income measures.²⁵ In this case, with MI-based benefit adjustment ratios $(y_i^M/y_{pop}^M)^\eta$ and EDI-based income weights $(y_\alpha^E/y_i^E)^\varepsilon$, income adjustment factors A_i are included to yield partial income weights as:

$$\text{EQ. 3: } \tilde{w}_i^\alpha = \left(\frac{A_{pop}}{A_i}\right)^\eta \left(\frac{y_\alpha^E}{y_{pop}^E}\right)^\eta \left(\frac{y_\alpha^E}{y_i^E}\right)^{\varepsilon-\eta}.$$

This equation shows that the partial weight combines an income adjusting ratio

$(A_{pop}/A_i)^\eta (y_\alpha^E/y_{pop}^E)^\eta$ and the original weights with a smaller elasticity $\varepsilon - \eta$ (which may

²⁴ Estimates of the income elasticity of WTP for non-market goods are varied. Drupp et al. (2025) conducted a meta-analysis to estimate the income elasticity of WTP for ecosystem services. They found an average value of 0.6 (95% CI 0.5-0.7) and that values by type of ecosystem service “range between about 0.4 (water purification and waste treatment) and 0.9 (spiritual and religious values).” Estimates of the income elasticity of the value per statistical life range from less than 0.5 to 2 or more (Hammit et al. 2022), with values around 1.0 often adopted (e.g., Masterman and Viscusi 2018).

²⁵ For instance, USDOT (2025) BCA guidelines recommends using the US household median wage (in MI units) to monetize the value of travel time savings, and the underlying estimate for the value of statistical life is based on a hedonic wage analysis, which is also in MI units. The literature often does not report clearly whether income is pre- or post-tax (Drupp et al. 2025).

be larger or smaller than zero). The smaller elasticity on the partial weight captures the *remaining* income weight that is not accounted for by using a common unit value.

Note that Circular A-4 recommends that weights should not be applied to population-valued parameters because distributional effects are already accounted for in the common unit value. But, as shown in EQ. 3, this could only be the case if $\varepsilon = \eta$ and $y_{\alpha}^E = y_{pop}^E$ (and the adjustment between MI and EDI is ignored). If y_{α}^E exceeds y_{pop}^E then (y_{α}^E/y_{pop}^E) is greater than 1, and this means that partial weights increase simply because the benchmark income is greater than common unit value income. This condition could occur if y_{pop}^E is the US median income and a project is located in a region with a higher median income y_{α}^E .²⁶

Lastly, note that after applying income weights to monetized benefits and costs, the results are converted from dollars to units of utility. These units are referred to here as *weighted dollars*, which are not actual currency but represent the utility value of an additional dollar to a person who earns the benchmark income. Weighted dollars are defined so that a weighted dollar has the same effect on the wellbeing of anyone who receives or pays it. Effects on individuals who earn less than the benchmark income would be weighted higher since one dollar would produce a larger increase in utility than for someone with the benchmark income. The sum of weighted net benefits for all individuals, $wNPV^{\alpha}$, represents the change in societal utility if all beneficiaries earned the benchmark income.

From a public decision-maker context, total weighted dollars represents a new measure of project value that can be *effectively* considered in implementation decisions. Effective, that is, in the sense that weighted dollar-based benefits are evidence-based, quantitative, comparable to costs, and enables an ranking of project alternatives beyond that of actual dollars alone. For decision-makers, weighted dollars are also starkly different from a dollar-based measure of value from a BCA. That is, dollars only partially reflect the total value of a project to beneficiaries because a dollar does not have the

²⁶ US DOT (2025) BCA guidelines recommend that the value of travel time savings is based on the US median income. Partial weights would be inflated in this way for projects in major US cities such as Washington DC or Boston MA, because the median incomes there are higher than for the entire US.

same effect on each beneficiary's wellbeing. Accordingly, with wBCA, project decisions can account for the distribution of benefits and costs among beneficiaries as well as the total impact on wellbeing.

3.4 Step 4. Estimate Benefits and Costs per Income Group

The most challenging step of a wBCA entails determining how previously estimated benefits and costs can be best apportioned across income groups that may differ by benefit category. Principally, this step entails assembling and analyzing data on the incomes of those who benefit or incur a cost. Analyses aim to make theoretically sound assumptions with available data to determine a set of *apportioning values*, p_i , where $\sum_i p_i = 1$, such that multiplying p_i by the total present values of benefits and costs determines the shares of benefits and costs per income group i .

Complications arise when income data are unavailable for explicitly estimating values of p_i for a subgroup of beneficiaries. In such cases, specifying the assumptions and implications are as important as processes to estimate values of p_i . Such complications are compounded in projects that have multiple subgroups of beneficiaries, since they must be analyzed separately. The discussion below elaborates on some of the issues that can arise for apportioning benefits and costs and considerations in handling analytical details and articulating assumptions. Applications in other contexts may contend with altogether new types of benefits and data gaps and require different analyses and assumptions.

Benefits per Income Group

Allocating benefits by income group entails estimating *apportioning values* p_{ij}^B for each income group i and each benefit category j . In the simplest form, where income data are available for beneficiaries in each benefit category and benefits are distributed independently of income, benefits per income group and benefit category are computed as $B_{ij} = p_{ij}^B \cdot B_j$, where B_j is the total present value of benefits for benefit category j and p_{ij}^B is the fraction of beneficiaries for benefit category j in income group i .

However, when factors other than income influence benefits per beneficiary, additional considerations are necessary. For instance, in transportation projects data

can be obtained on the incomes of travelers.²⁷ A simple analysis of benefits would use such data to apportion benefits based on traveler income groups defined in Step 2. But if travel characteristics (e.g. travel distance or time) also depend on income, then additional adjustment factors should be developed if data are available. For example, total travel time (TT) savings benefits B_{TT} , are often computed²⁸ as $B_{TT} = n \cdot f(y_{pop}) \cdot (\bar{T}_0 - \bar{T}_1)$, which simply monetizes the difference in average travel times $\bar{T}_0$ and $\bar{T}_1$ (before and after a project) for all n travelers as a function of the U.S. median hourly wage, $f(y_{pop})$. But if individual travel time T_t depends on income levels (e.g., if travel distances or speeds differ by income) then an additional factor may be warranted for apportioning benefits by income. Depending on data availability, a simple ratio of travel times by income could be computed as $AT_i = T_{0i}/\bar{T}_0$.²⁹ The apportioning approach to total benefits would become $B_{i,TT} = AT_i \cdot p_{i,TT}^B \cdot B_{TT}$.

Additional issues occur when incomes are not known for beneficiaries. For example, a core benefit of flood mitigation is the reduced damages to properties and damages that are principally a function of flood depth and baseline property values. Typically, household incomes are not available for individual residential properties - only the property value itself is available. Data on household income distributions are however available by census tract. In this case, it may be possible to compute apportioning values using income data by census tract, assuming that: (a) incomes are proportional to property value, and (b) the probability of flooding is independent of property value within each census tract.³⁰

Benefits associated with commercial activity occur in a variety of contexts, such as improvements in freight transportation (e.g. increasing speeds) or reduced flood damage at commercial establishments. While commercial benefits ultimately accrue to

²⁷ The lead author of this paper often uses data from Replica, a commercial data provider, to estimate incomes of surface transportation users.

²⁸ US DOT guidelines (2025) specify that travel time benefits for all travelers can be monetized as a function of the same hourly wage.

²⁹ This adjustment ratio simplifies a more complete adjustment of $AT_i = (T_{0i} - T_{1i})/(\bar{T}_0 - \bar{T}_1)$, by assuming that $T_{1i}/\bar{T}_1 = T_{0i}/\bar{T}_0$ since values of T_{0i} and $\bar{T}_0$ may be available from data on the existing roadway.

³⁰ This approach might be improved by projecting income as a function of housing value and the income elasticity of demand for housing.

someone, it is not always clear how to identify the beneficiaries. For instance, are commercial benefits passed on to consumers? Or are they retained within the enterprise and used for investing in the productivity of employees in the form of increased wages? Unfortunately, there are no simple standards to follow. Analytical approaches often are limited by the data available and whatever method is taken, assumptions should be consistent with economic theory.

In other cases, beneficiaries may be located well beyond the project boundaries. For instance, the benefits of decreasing greenhouse gas (GHG) emissions are monetized in the U.S. by the social cost of carbon (SCC), which accounts for global impacts, not just in the U.S., let alone the project area. In this case, since the federal government sets the SCC for estimating project and policy values, households are implicitly affected.³¹ To apportion GHG reduction benefits among people, options could include assuming equal allocation or identifying whether some income subgroups are more vulnerable to climate change compared to others. Data gaps are likely to complicate analyses and as such sensitivity analyses could be performed to evaluate the significance of assumptions.

Lastly, in many cases, it is reasonable to assume no intertemporal changes in the portions of benefits by income group. In general, a wBCA should account for the distribution of impacts at each point in time and weight them based on contemporaneous income. However, since most BCAs calculate the present value of impacts, it is assumed that potential changes in the distribution of income over time have a small effect on the results and weights applied to present values using initial income are sufficient. This assumption can be tested by exploring scenarios for changes in the trends of income distributions and computing weighted benefits for future years and then applying discount factors.

³¹ USEPA (2023) discusses issues in establishing U.S. policy on the social cost of carbon, including whether to incorporate damages from GHG that occur outside of the U.S. An alternative assumption would be that most climate impacts occur outside the region of analysis and so omitting this component could better approximate effects in the region.

Cost Burdens per Income Group

A complete wBCA also analyzes how different income groups contribute to government or agency revenues (e.g. through taxes or fees), which in turn may be spent to implement projects. As defined here, *cost burdens* represent households' contributions to general government revenues (e.g. taxes and fees) that can be spent to fund an initiative (i.e., project cost burdens exclude dedicated payroll taxes for Social Security and Medicare).³² Cost burdens per income level vary among households and sources of funds (e.g. agency, local, state, and federal).

The capital and annual costs to implement projects may be sourced from several funding agencies (e.g. at federal, state and local levels), which may have distinct but shared goals. *Funding-only agencies* at federal or state levels do not typically consider any opportunity costs of spending public money.³³ Instead, they aim to fund worthwhile projects from a budget allocation that can be traced to general revenues from a variety of sources, possibly including project beneficiaries (e.g. through income taxes, excises taxes, etc.). *Implementing agencies* at the state or local levels may have dedicated funding streams (e.g. fees or excise taxes) that could come directly from beneficiaries of potential projects.

The process for estimating apportioning values for project cost burdens is comparatively straightforward because data are available from several sources. Analytically, the task involves determining cost burden proportions, p_{ik}^C , for each income group i and source of funding k . Values of p_{ik}^C are multiplied by costs per funding source, C_k , to determine $p_{ik}^C \cdot C_k = C_{ik}$ in EQ. 1 and EQ. 2. Based on the data from US Treasury (2024), and ITEP (2024), which provide cost burdens for different income levels for federal, state and local sources (respectively), the values of $p_{i,Federal}^C$, $p_{i,State}^C$

³² Outside of a project context, costs of implementing a policy or regulation could propagate through the economy as a change in prices, and analyses would have to assess such differentiated cost burdens.

³³ Both OMB (2003, p. 61) and HM Treasury (2026, p. 38) recommend against incorporating the cost of public funds, in part because these agencies do not know what taxes will be modified. Future research could evaluate how the cost of public funds should be included in wBCA.

and $p_{i,Local}^C$ can be computed by interpolating between data on cost burdens per income level and the income groups defined in Step 2.

Differentiating cost burdens C_{ik} by source of funding is necessary because the burdens of revenue sources are distributed differently across income levels. For instance, federal income taxes are relatively progressive and high-income earners bear proportionally larger shares of costs financed by the federal government. In contrast, transit fees per trip are paid uniformly by users (there may be subsidies to some user categories). When multiple sources of funds are involved, the total cost burdens by income group are determined by combining shares of contributions for each source.

3.5 Step 5. Compute Weighted Benefits and Costs

Sub-totals of monetized benefits and costs per income group are estimated by multiplying the proportions of benefits (p_{ij}^B) and costs (p_{ik}^C) (Step 4) by the total present values for each type of benefit j and cost category k from the BCA. The analytical processes established in Step 4 enable straightforward computations in Step 5.

3.6 Step 6: Compare BCA and wBCA, Perform Sensitivity Analysis

In the final step, EQ. 1 and EQ. 2 are computed using weights and partial weights (Step 3), sub-totals of benefits and costs per income group (Step 5), and summing results across all income groups and benefit and cost categories. Values of $wNPV^\alpha$ and $wBCR^\alpha$ can be used to compare among project alternatives or with corresponding BCA results. Note that the benchmark income affects the magnitudes of the weights and hence the magnitude of $wNPV^\alpha$. In contrast, the $wBCR^\alpha$ is unaffected by the benchmark income, because the benchmark income has the same proportional effect on weighted benefits and weighted costs.³⁴ Therefore, since the $wBCR^\alpha$ is independent of any benchmark specification, comparisons with BCR results would show

³⁴ EQ. 1 and EQ. 2 can be reformulated to show: (a) proportionality of the benchmark income and $wNPV^\alpha$ (i.e., $wNPV^\alpha = (y_\alpha)^\varepsilon \sum_i [\sum_j w_i \cdot B_{ij} - \sum_k w_i \cdot C_{ik}]$); and, (b) independence of the benchmark and $wBCR^\alpha$ (i.e., $wBCR^\alpha = [(y_\alpha)^\varepsilon \cdot \sum_i \sum_j w_i \cdot B_{ij}] / [(y_\alpha)^\varepsilon \cdot \sum_i \sum_k w_i \cdot C_{ik}]$ since $(y_\alpha)^\varepsilon$ divides against itself.

clear differences in the value-for-money of a project based on a utility-based value compared to a monetary measure alone.

Sensitivity analyses should be undertaken at this stage to gain a deeper understanding of how different assumptions influence results and comparisons of project alternatives. Results could be affected by assumptions on structural-analytical features (e.g. numbers of income groups, definitions of regional incomes), specifications of income groups, income elasticities of benefit categories (and resulting weights) or approaches to apportioning benefits and costs. For instance, an *ex-post* BCA apportioning of benefits by beneficiary incomes could depend on underlying income distribution assumptions that could change over time (e.g. some beneficiary groups' income may grow at different rates than others).

In addition, sensitivity analysis could also be performed for alternative values of ε (e.g. based on specific studies or official guidance). In particular, for analyses where monetary costs exceed benefits, a *breakeven value of ε* may be estimated such that weighted benefits equal weighted costs.³⁵ A *breakeven ε* adds further insight to primary wBCA results based on say an officially recommended ε . For instance, when ε equals zero, wBCA results are equivalent to a BCA and as ε increases from zero, the results represent an increasing differentiation of beneficiaries' utility values of money. The breakeven ε reveals the minimum level of utility differentiation that would be required to conclude that the project could generate a net positive level of societal utility. Additional forms of sensitivity analysis with ε could also be explored where individual utility functions are *combined* with social aversion of inequality into a single parameter (see Adler, 2006).

4 CASE STUDY ANALYSES

This section demonstrates the analytical steps described above in an example of a flood risk mitigation project. This project is one of several that the Sacramento County Flood Control Agency (SAFCA), a local flood management district, is evaluating with the

³⁵ Such a breakeven value may not exist, e.g., if costs are born largely by low-income households and benefits are received largely by high-income households, then increasing ε will decrease wBCR.

U.S. Army Corps of Engineers (USACE) to reduce Sacramento River flooding near and within Sacramento, CA. SAFCA agreed to share these results for this analysis. This wBCA builds from a BCA that was prepared for one of the initial project designs.

The project analyzed here is called a Setback Levee and is designed to divert high flood waters into an agricultural area that can temporarily serve as a flood plain because it incurs smaller losses from flooding compared to City properties and infrastructure.³⁶ Normally, USACE and a proposing agency like SAFCA evaluate a series of alternatives. USACE evaluates project alternatives proposed by a local agency and aims to identify an alternative that could meet a federal interest for funding, which is typically established with a benefit-cost ratio above 1. In some cases, the project that USACE identifies for federal funding is not the same as that sought by the proposing agency. Differences in outlook can lead to further discussions between proposing agency and USACE about finding alternatives that are more acceptable to all parties.

A flood mitigation BCA entails computing levels of flood damage with and without a levee. In this case study, damages are computed within 49 separate and discrete geographically-defined flood impact areas. In each impact area, hydrologic models determine flood depths with and without the Setback Levee for a series of probabilistically-defined rainfall events. The economic analysis of flood damage is performed using the USACE model called HEC-FDA, which computes damage to 33 distinct types of land uses (e.g. residential) and assets (e.g. roadway). HEC-FDA converts flood depths into monetary losses with depth-damage functions, which determine the percentage loss in value for a given depth of flooding. Depth-damage functions differ by type of land use and building characteristics. Benefits of the flood mitigation project are computed as a reduction in damage on an expected annualized basis that incorporates the probability of flood-causing rainfall events.³⁷ Any increase in property value in areas where flood risk is reduced is excluded from benefit computations according to USACE policy (USACE, 2024).

³⁶ Losses to farmers impacted by diverted flood waters are accounted for as a reduction in net benefits. Total agricultural benefits combine both losses and gains across the floodplain.

³⁷ Flood mitigation measures that reduce health and mortality risks are reported as quantitative impacts and are not monetized as per USACE policy guidelines (USACE, 2024).

4.1 Summary of BCA

Table 1 shows BCA results for a 50-year period of reduced flood risk after the project is constructed, which is assumed to be in 2034. The project would provide flood risk reduction benefits in 260 census tracts within seven counties (Butte, Colusa, Sacramento, Solano, Sutter, Yolo, and Yuba). Accordingly, it is appropriate to define the project region as the seven counties affected by the project. Present value calculations apply a 2.75% discount rate, based on federal guidance, and dollar values are discounted to 2022. The present value of all capital and annual operating and maintenance (O&M) costs amounts to \$379.6 million. Total present value benefits across all damage categories and impact areas are estimated to be \$659.7 million. The project appears to generate substantial positive value with a net present value of \$280.2 million, and a 1.74 benefit-cost ratio. These results would indicate to USACE that the project could be eligible for federal funding.

Table 1: Summary of BCA Results (\$M, \$2022)

Breakdown in BCA Results	Total PV
Benefits per Damage Category	
Residential: Structures, Contents and Displacement, and Vehicles	\$262.1
Commercial: Structures and Contents, Business Income	\$54.8
Industrial: Structures and Contents	\$217.5
Agricultural: Structures and Crop Production	\$62.3
Public: Structures, Assets, and Services	\$63.1
Total Benefits (all Damage Categories)	\$659.7
Total Costs (including Capital and Annual Operating and Maintenance)	\$379.6
Net Present Value	\$280.2
Benefit Cost Ratio	1.74

The BCA review (denoted as Step 1, above) indicates that benefits of reduced flood risk are computed for a range of damage categories that are analyzed separately in each flood impact area. Intra-regional differentiation by flood impact area is important because income distributions vary across benefit categories (i.e., residential owners) in the census tracts where floods occur. The benefits per damage category in Table 1 are shown as aggregated sub-totals of damages within a sub-group (e.g. residential, commercial, etc.) and across all impact areas. For instance, the total values of damage reduction sub-totals include residences (e.g. single and multi-family), commercial (e.g. retail, restaurants), industrial (e.g. light industry, warehousing, etc.), and the public sub-category includes structures (e.g. schools), assets (e.g. roads), and services (e.g.

emergency services). Within each damage category, subtotals include “Structural” losses (representing the depreciated replacement value of the building, as per USACE guidelines), “Contents” losses (representing value of furnishings and goods inside a structure), and “Displacement” (representing the cost incurred by residents who must find alternative accommodation after a flood).³⁸ The analysis performed here differentiates incomes of beneficiaries across all of these sub-totals of benefits and within each geographic damage area.

4.2 Income Groups

US Census income data consist of the percentages of households in 11 MI income bands. Adjustment ratios (for both midpoint and upper incomes per band) are estimated for each of the original MI bands and then multiplied with the corresponding MI values to determine a series of 11 EDI bands. This analysis reduces the 11 Census income bands into five quintiles. To estimate quintile income midpoint and cutoff values, statistical models of EDI bands are estimated and the resulting parameters are used to compute midpoint and upper income-levels for the quintile percentiles.³⁹ Table 2 presents a comparison between MI and EDI incomes along with EDI-MI ratios for each quintile. Overall, EDI is higher than MI for all quintiles since EDI includes transfers and capital income. In addition, the results indicate that lower quintile households have significantly higher proportional increases in EDI compared to MI because of transfers and net taxes. These differences underscore the rationale for performing the analysis using EDI instead of MI.

Table 2: Estimated Income Groups, MI and EDI Income (\$2022)

		Income Groups (Quintile numbers)				
		1	2	3	4	5**
MI Income (Source: US Census)	Reference Income (\$000)	\$14.3	\$46.0	\$80.6	\$116.9	\$154.4
	Upper Bound Income (\$000)	\$37.2	\$74.1	\$111.0	\$147.8	\$184.6
EDI Income (Estimated)	Reference Income (\$000)	\$25.4	\$64.2	\$98.7	\$131.1	\$162.1
	Upper Bound Income (\$000)	\$54.8	\$92.7	\$126.1	\$156.9	\$185.8
EDI-MI Ratios (Estimated)	Reference Income	1.78	1.39	1.22	1.12	1.05
	Upper Income	1.47	1.25	1.14	1.06	1.01

³⁸ Note that USACE guidelines do not include benefits that arise from increased development in areas protected by a project, only avoided damage to existing structures and assets are included as benefits.

³⁹ Separate regression models of log-income on log-cumulative percentage of households are estimated to determine quintile boundaries and midpoints. These models have R-squared values above 0.90.

** Note: reference incomes and upper bound incomes are statistically estimated from available data. The reference and upper bound income for quintile five are computed using the parameters estimated from a statistical analysis, which excluded the highest income bands available in the Census. As a result, incomes for quintile five values are likely to be underestimated because incomes rise non-linearly at the highest income levels and this leads to a slightly higher-than-actual weight for the top quintile. However, the overall impact on results may be small because the highest quintile tends to rely less on public infrastructure.

4.3 Income Weights

Table 3 presents results for income weights per quintile using: (a) the values of y_i from Table 2, relative to the corresponding MI and EDI reference incomes; (b) a value of 1.4 for ε (based on Circular A-4, 2023), and (c) several different benchmark incomes y_α for comparison purposes. Weights for MI and EDI are proportional to their corresponding values of y_α^ε . For each benchmark income, EDI weights are smaller than MI weights for the first two quintiles and larger for the three higher quintiles. As such, compared to MI weights, EDI weights not only generate a more realistic measure of the value of monetized benefits per beneficiary but also a lower estimate and thus more conservative measure of weighted benefits. Regional EDI income weights are used in computing primary wBCA results while other weights are used for a sensitivity analysis.

Table 3: Estimated Weights Relative to Median Income Benchmark

Weights (Different Benchmarks)	Benchmark Income (\$000, \$2022)	Income Groups (by Quintile)				
		1	2	3	4	5
MI Weight (US Median)	\$74.58	10.10	1.97	0.90	0.53	0.36
EDI Weight (US Median)	\$93.13	6.16	1.68	0.92	0.62	0.46
MI Weight (Regional Median)	\$79.67	11.08	2.16	0.98	0.58	0.40
EDI Weight (Regional Median)	\$97.94	6.61	1.81	0.99	0.66	0.49
MI Weight (Cost Normalizing)	\$125.65	18.29	3.56	1.62	0.97	0.65
EDI Weight (Cost Normalizing)	\$142.67	10.34	2.83	1.55	1.04	0.77

4.4 Benefits and Costs per Income Group

Benefits per Income Group

Table 4 presents averaged income distributions by quintile for beneficiaries of each damage category. The proportions are estimated for EDI income groups shown in Table 2. Methods for estimating apportioning values differ by benefit category, including:

- **Residential:** Total damages are estimated from the sum of structural and contents damage costs at individual properties, which are based on each property's existing values. However, no information is available on household

incomes of any specific property. As an approximation, household income distribution data per census tract are used to apportion total residential damages per EDI income group within each tract. Losses to physical structures are apportioned based on the tract-based income distributions of *owner-occupied dwellings*⁴⁰, whereas losses related to contents of buildings are apportioned across incomes of *all residents* (i.e., including renters).⁴¹ The data in Table 4 combine these two distributions of residential impacts together.⁴² The key underlying assumptions for this approach are that: (1) property values are proportional to household EDI in a census tract and (2) the distribution of property values within a census tract is fully represented in the flooded areas of a census tract.⁴³

- **Commercial, Industrial, and Agricultural:** Structure, contents and income losses to businesses require a different approach because income-weighting must identify persons as beneficiaries. Accordingly, it is necessary to determine how households would be impacted by losses to businesses. The assumption implemented here is that the damage to businesses directly affects all employees of those business, and specifically impacts employee wages. The underlying assumption is that impacted businesses are unable to pass along losses to customers as higher prices because non-flooded businesses in the vicinity could still provide services. The wages of employees of flooded businesses are affected because their employers are assumed to divert expenditures from

⁴⁰ The distinction between losses to structures and contents recognizes that renters tend to have lower income than rental-property owners. Without this assumption, some share of physical structure losses would be attributed to an income distribution that is influenced by renters' incomes.

⁴¹ In cases where the flood impact area covers part of the Census Tract, income distributions in a partially flooded area can be adjusted based on the ratio of property values inside the flooded area compared to values in the entire Tract. Where a flood impact area covers multiple Census Tracts, the income distribution data of multiple Tracts can be combined in proportion to the average property values of flooded areas within affected Tracts.

⁴² The distinction between owner-occupied dwelling and all residents is important because owner-occupied incomes tend to be higher than all residents, which include renters.

⁴³ The second assumption may lead to conservative (i.e. lower) weighted benefits because it is conceivable that households with more resources would live outside of the inherent risks within a floodplain. If so, more households with lower property values and lower incomes would gain greater benefits from risk reduction. This would lead to a larger weighted value of such benefits.

payroll expenses (e.g. salary increases and increased employment) to cover costs of recovery (e.g., building repairs, inventory replacement, insurance costs, etc.). Data on the distributions of wages for all jobs at the county level are available from U.S. Bureau of Labor Statistics, Occupational Employment and Wage Statistics (OEWS). The analysis entails steps that include: (a) matching OEWS industrial sectors to the business types in HEC-FDA output; (b) forming OEWS wage quintiles for the multi-county region using the methods discussed above for household incomes, and (c) determining proportions of wages of jobs in flood-impacted businesses relative to regional wage quintiles. This approach assumes that wage profiles in jobs of flood-impacted businesses are similar to all businesses within a county.

- **Public:** Damages to public structures, assets and services are assumed to impact taxpayers whose tax and fee payments are ultimately used to cover these costs. Depending on the asset, funding could be sourced from some combination of the federal, state, or local tax base. Flood-affected public assets and services are primarily funded through the local tax base. The proportions of household cost burdens by income group are computed by interpolating cost burdens by income from ITEP (2024)⁴⁴ relative to EDI incomes.

Table 4 summarizes apportioning values for income and wage-based analyses of households and employees that would be affected by flood losses by benefit category. The results indicate that income distributions for losses to residences, commercial and industrial entities are similar, whereas agricultural losses disproportionately affect lower-income households. Impacts from public damages disproportionately affect higher-income households (since total taxes collected tend to be progressive). These results underscore the importance of performing detailed analyses of beneficiaries.

⁴⁴ ITEP (2024) has computed local and state tax cost burdens by income for every State.

Table 4: Proportions of Users by Mode and Location, by Quintile

Sub-groups of Beneficiaries	Proportions of Benefits by Quintile EDI				
	1	2	3	4	5
Residential: Structures, Contents and Displacement, and Vehicles	25.4%	28.5%	22.6%	13.0%	10.5%
Commercial: Structures and Contents, Business Income	18.3%	33.6%	18.8%	11.6%	17.7%
Industrial: Structures and Contents	12.5%	33.9%	21.0%	12.5%	20.0%
Agricultural: Structures and Crop Production	29.5%	69.6%	0.6%	0.3%	0.0%
Public: Buildings, Services, and Assets	5.0%	9.0%	8.0%	10.1%	67.8%

Note: The reported values are not those used in the wBCA – they are averages across impact areas. The full analysis is based on proportions p_{ijk}^B of sub-populations that are estimated and applied for each income group i , damage category j , and impact area k . The data used in the analysis are estimated separately for each type of loss across all 49 impact areas.

Cost Burdens per Income Group

Table 5 presents the cost burdens by income group (p_{il}^C) per quintile (i) for each source of funding (l), and the contribution of each funding source to the total project cost. The proportions of household cost burdens by income group are computed by interpolating cost burdens reported by US Treasury (2024) and ITEP (2024) for their respective income bands relative to the quintile EDIs in the analysis. It is also necessary to account for different sources of funding. In this case, it is assumed that federal funds cover 65% of capital costs and the state covers the remaining 35%. Data from the U.S. Treasury (2024) indicate that over 80% of federal discretionary funds are generated from the highest income quintile. Data from ITEP (2024) also indicate that the total cost burden is covered primarily by the highest quintile. ITEP (2024) data indicate that local taxes (primarily sales and property taxes) are more regressive than a mixture of state and local taxes. The shares of total costs by quintile are in the last row of Table 5.

Table 5: Present Value Costs and Cost Burdens by Quintile, Funding Source (\$M, \$2022)

Cost Burden Categories	Present Value Cost	Allocations of Cost Burdens by Quintile				
		1	2	3	4	5
Federal (65% of Tot. Capital Costs)	\$240.2	0.0%	2.3%	6.2%	11.0%	80.5%
Combined State & Local (35% of Tot. Capital Costs)	\$129.4	2.4%	5.0%	4.3%	5.8%	82.6%
Local (Total PV of O&M Cost)	\$10.0	5.0%	9.0%	8.0%	10.1%	67.8%
Total Costs	\$379.6	\$3.5	\$12.9	\$21.2	\$34.9	\$307.1
Total Share of Costs	100%	0.9%	3.4%	5.6%	9.2%	80.9%

Data Sources: (US Dept. of Treasury 2024), (ITEP 2024)

4.5 Weighted Benefits and Costs

Table 6 presents results for weighted benefits, costs and net benefits by quintile where the benchmark income is defined as the regional median household EDI. The results for the wBCA (top half of table) are presented alongside corresponding BCA results (bottom half of table). This type of breakdown in results, rarely reported in practice, reveals distributional differences that could be important in decisions. Further, the comparative representation of monetized outcomes as measures of utility (in weighted dollars) elevates a broader understanding of the impact of a project on social welfare. As noted above, weighted dollars have the same effect on the wellbeing of someone who receives benefits in contrast to the dollars measured in a BCA that do not have the same effect on someone's wellbeing.

Key observations include:

- Distributional effects of weighted benefits and costs are readily apparent. Overall, total weighted benefits decrease with income while total weighted costs increase with income. Accordingly, weighted net benefits decline even more dramatically (than weighted benefits alone) per quintile.
- Among weighted benefit categories, losses are highest for residential, industrial and agricultural damage. Low income residential households have the highest weighted benefits (W\$375M) across all categories and quintiles.
- For all categories except public damage, W\$ values decline with quintiles, an effect that is primarily explained by the impact of incorporating income weights with benefits apportioned by income.
- The distribution of BCA results alone reveals the underlying allocation of *unweighted* benefits and costs across categories and quintiles. Overall, the second income quintile gains the most benefits (\$213M) and net benefits (\$204M). The highest quintile would see a net *cost* of -\$185M, which means that these households pay more in taxes than they gain from this project.

Table 6: Weighted and Unweighted Benefits and Costs by Quintile (\$M, \$2024)

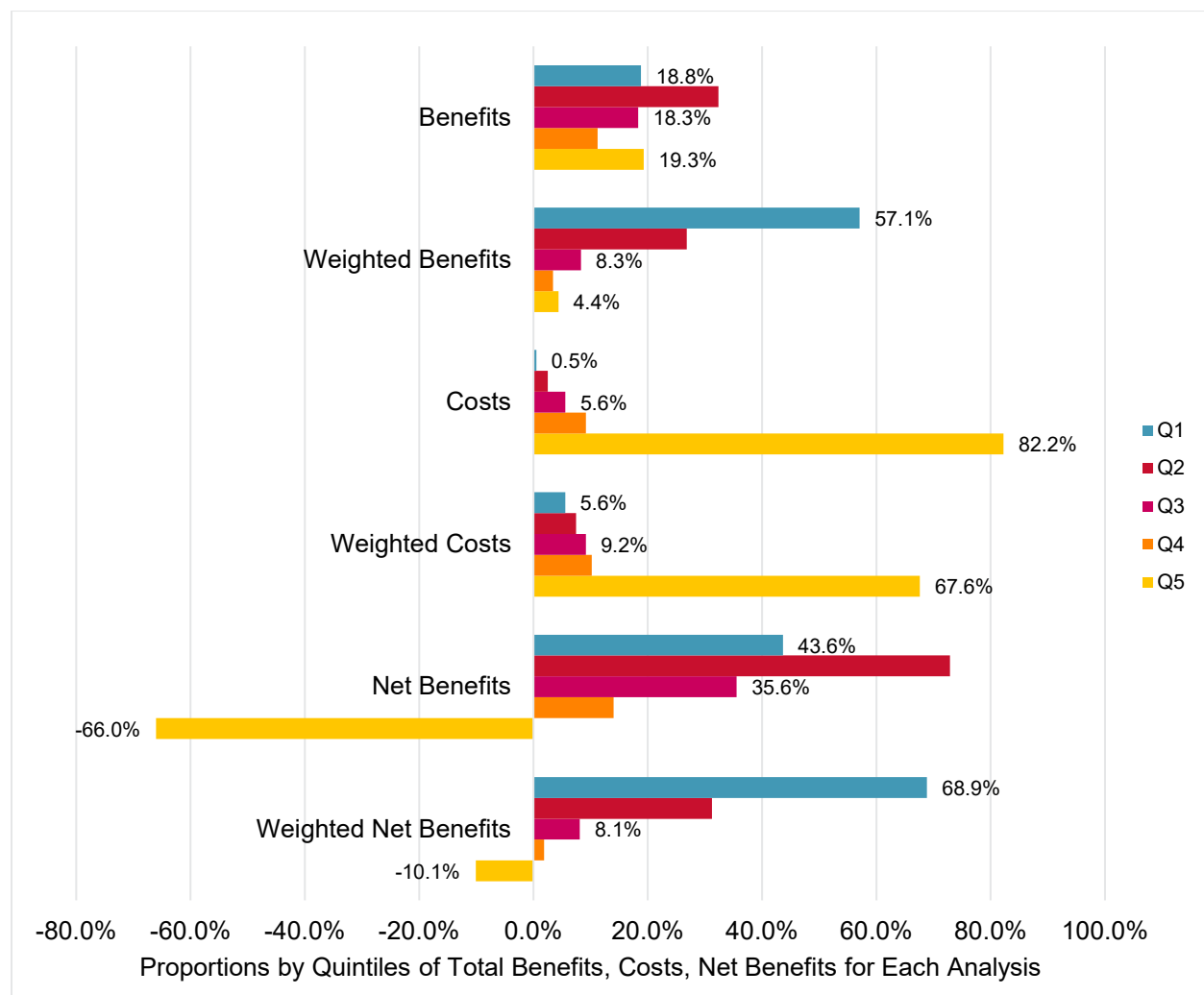
	Allocated Weighted Benefits and Costs by Quintile					
wBCA	1	2	3	4	5	Total
Residential	W\$374.7	W\$114.8	W\$50.0	W\$19.3	W\$11.6	W\$570.3
Commercial	W\$56.4	W\$28.3	W\$8.7	W\$3.6	W\$4.1	W\$101.1
Industrial	W\$153.4	W\$113.4	W\$38.6	W\$15.4	W\$18.3	W\$339.1
Agricultural	W\$103.5	W\$66.6	W\$0.3	W\$0.1	W\$0.0	W\$170.5
Public	W\$10.7	W\$5.3	W\$4.3	W\$3.6	W\$19.5	W\$43.4
Total PV Benefits	W\$698.7	W\$328.5	W\$101.8	W\$42.0	W\$53.5	W\$1,224.4
Total PV Costs	W\$12.7	W\$17.0	W\$20.9	W\$23.2	W\$154.2	W\$228.1
Total Net Benefits	W\$686.0	W\$311.5	W\$80.8	W\$18.8	-W\$100.7	W\$996.4
	Allocated Unweighted Benefits and Costs by Quintile					
BCA	1	2	3	4	5	Total
Residential	\$66.6	\$74.6	\$59.3	\$34.0	\$27.6	\$262.1
Commercial	\$10.0	\$18.4	\$10.3	\$6.4	\$9.7	\$54.8
Industrial	\$27.3	\$73.7	\$45.8	\$27.2	\$43.6	\$217.5
Agricultural	\$18.4	\$43.3	\$0.3	\$0.2	\$0.0	\$62.3
Public	\$1.9	\$3.5	\$5.0	\$6.4	\$46.3	\$63.1
Total PV Benefits	\$124.2	\$213.6	\$120.8	\$74.1	\$127.1	\$659.7
Total PV Costs	\$1.9	\$9.4	\$21.2	\$34.9	\$312.2	\$379.6
Total Net Benefits	\$122.3	\$204.1	\$99.6	\$39.2	-\$185.0	\$280.2

Figure 1 provides a different perspective on the comparison of weighted and unweighted results. The bar chart shows the proportions of total unweighted and weighted benefits, costs, and net benefits by quintile. The effect of weighting benefits is observed in the changes in the proportions of total weighted benefits for each quintile compared to the corresponding proportions for unweighted benefits. Key observations include:

- The total weighted benefits for the first quintile increase significantly from about 19% (unweighted) to over 57% (weighted). In contrast, the shares of weighted benefits for all other quintiles decline compared to unweighted benefits.
- The distribution of costs changes with income weighting. For instance, unweighted costs are borne primarily by the highest income quintile (over 80 percent of total costs). With income weighting, cost burdens for the highest quintile decline to around 67.6% and for other quintiles, the weighted cost burdens are more evenly spread (at around 9%).

- The proportion of weighted net benefits exceeds that of unweighted net benefits for both the first and fifth quintiles (which becomes less negative). While it is intuitive that weighting has its largest effects on the shares of benefits and costs allocated to the lower and upper ends of the income distribution, the effect on net benefits is less predictable because net benefits are the difference between benefits and costs.

Figure 1: Comparison of Unweighted and Weighted Benefits, Costs, and Net Benefits



4.6 Comparison of wBCA and BCA, with Sensitivity Analysis

Table 7 presents total benefits, costs, and net benefits for several different contexts. First, the results compare unweighted BCA (first column) with the wBCA results from Table 6. Several other wBCA sets of results are presented as part of a

sensitivity analysis of benchmark incomes and methodologies. The three different income benchmarks include the MSA median \$97.9 thousand (from Table 6) alongside a U.S. EDI median (\$93.1 thousand) and a cost-normalizing benchmark income of \$134.9 thousand. As discussed above, the benefit-cost ratios for each of the benchmark incomes are the same and all are about three times larger than the *BCR*. In contrast, the weighted net benefits for the different benchmarks are proportional to the benchmark.

Part of the reason the *wNPV* is larger than the *NPV* for median income benchmarks is that weighted costs are smaller than unweighted costs. This follows because the marginal utility at the median income is greater than the cost-share-weighted average of marginal utilities. In practice, the *appearance* of a smaller weighted costs in a *wBCA* could be misconstrued as implying a *wBCA* has a lower project cost. For agencies that are making funding choices with the same sources of funds, a cost-normalizing benchmark income more directly reveals the magnitudes of differences in weighted and unweighted benefits for a given cost.

The results of a *wBCA* such as those in Table 7 could change the evaluation approach by the project proposer, SAFCA, and their discussions with the federal funding agency, USACE. At present, USACE has no standard approach to perform distributional effects analyses nor a mechanism to consider the results in funding decisions. For SAFCA, performing *wBCAs* on all project alternatives could enable them to jointly consider *BCA* and *wBCA* values and identify the best option for reaching goals. At the same time, SAFCA would want to see an openness at USACE for considering *wBCA* in funding decisions, especially in light of their stated indication of using income-weighting in ‘sensitivity analysis’ (USACE, 2024). Institutionally, at the time of this writing, USACE remains in an evaluative process for determining how to provide guidance on income-weighting.

The last column of Table 7 shows the results using FEMA’s approach. These results are most directly comparable to results using the US EDI Median income benchmark. Both approaches indicate that weighted net benefits are greater than unweighted net benefits. However, FEMA’s approach produces significantly smaller weighted benefits and net benefits compared to a *wBCA* based on income quintiles.

The principal reason is that FEMA’s method computes and applies only a single weight for all beneficiaries in a census tract based on the median income in that tract. A single weight does not fully capture the relatively higher value of flood risk reduction for lower income persons. Incidentally, as a single weight, the FEMA method represents a partial sensitivity analysis of results when using just one income group per tract, not five quintiles, as indicated in the other results.

These results all assume that the allocation of benefits by incomes of beneficiaries does not change over time. In the context of a USACE-based BCA, no benefits are captured from future development that could bring changes to property values, income, and wealth to households in a newly protected neighborhood (including changes resulting from higher-income households moving in to newly protected areas). But, in other contexts, such assumptions and conditions on estimated benefits ought to be analyzed in sensitivity analyses.⁴⁵ That is, if the distribution of incomes changes after a project is implemented, alternative assumptions on future trajectories of income growth could be modeled to yield different allocations of benefits by income. Approaches to implement this type of analysis would be recommended areas of future research.

Table 7: Project Value Comparison by Benefit Category

Benefit Categories	Total Results (\$000)	Total Results (W\$000)	Total Results (W\$000)	Total Results (W\$000)	FEMA Results (W\$000)
Benchmark EDI (\$000)	Unweighted	Regional EDI Median: \$97.9k	US EDI Median: \$93.1k	Cost-Normalizing: \$134.9k	US EDI Median: \$93.1k
Residential	\$262.1	W\$570.3	W\$531.5	W\$949.2	W\$333.7
Commercial	\$54.8	W\$101.1	W\$94.2	W\$168.2	W\$59.1
Industrial	\$217.5	W\$339.1	W\$316.0	W\$564.3	W\$198.4
Agricultural	\$62.3	W\$170.5	W\$158.9	W\$283.8	W\$99.8
Public	\$63.1	W\$43.4	W\$40.5	W\$72.3	W\$25.4
Total Benefits	\$659.7	W\$1,224.4	W\$1,141.2	W\$2,037.8	W\$716.4
Total Costs	\$379.6	W\$228.1	W\$212.6	W\$379.6	W\$379.6
Total NPV	\$280.2	W\$996.4	W\$928.6	W\$1,658.2	W\$336.8
Total BCR	1.74	5.37	5.37	5.37	1.89

⁴⁵ The authors thank one of the anonymous reviewers for this insight.

5 CONCLUSIONS

A wBCA produces new insights and potentially important contributions to decisions on investments that have primarily relied on BCAs. By incorporating individuals' utility values, a wBCA corrects for biases embedded in BCAs in which a WTP-based valuation favors those with a higher *ability to pay*. It is important to emphasize though that weights are applied to normalize the monetized value of outcomes to people – weights are not applied to elevate or discount the significance of some groups of people relative to others.

For flood risk management evaluations, a theoretically sound wBCA can be implemented across a large number of geographically dispersed and diverse beneficiaries. New methods developed here can be replicated for other projects including: (a) conversion of MI to EDI; (b) apportioning benefits by benefit category and cost burden; and (d) sensitivity analyses of different methods. Institutionally, this analysis demonstrates to USACE that wBCAs represent practical additions to project evaluations, both as part of a sensitivity analysis with BCA results⁴⁶ as well as reporting results in a *Comprehensive Benefit Framework*.⁴⁷ This research also indicates that FEMA's method may not adequately reach its stated objective. Overall, the findings indicate that both USACE and FEMA could gain from additional case studies of this type. What could emerge from additional case studies is standardized guidance on methods for say estimating household incomes at individual properties, or indicators for how commercial losses impact households by income level. Further, additional wBCA case studies would enable federal agencies and local project sponsors to identify projects that generate the overall best value.

Fundamental questions though still remain on selecting projects or policies based on a wBCA over a BCA. Under what contexts is wBCA justified or not? For instance, could the prioritization of projects based on wBCA lead to lower potential economic

⁴⁶ USACE refers to project benefits as a measure of "National Economic Development."

⁴⁷ USACE defines a Comprehensive Benefit Framework to separately include economic, environmental and social measures of impact (USACE, 2023).

gains (as measured by a BCA)?⁴⁸ While Federal BCA guidelines recognize that distributional effects can contribute to decisions, agencies remain hesitant to implement wBCAs possibly because they could justify frivolous projects, as Harberger (1978) posited. But, if most project or policy options are more alike than different, could the use of wBCA be justified if BCA-based net benefits achieves a minimum BCA threshold? And then, what would be a reasonable BCA threshold?

Ultimately, the value of performing a wBCA is realized if its results are incorporated into project evaluations, especially where decision makers balance dual interests in maximizing total net benefits and improved distribution of outcomes. On-going work by the lead author involves applying wBCA on a range of project types. This work is leading to additional insights on the sources and uses of data, and devising sensitivity analyses to test the robustness of results. At the same time, this work is revealing both the interests and concerns of infrastructure owners and external funders on how to jointly consider wBCA and BCA results.

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⁴⁸ Reduced growth in market valued economic activity could lower potential market opportunities for low income persons.

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APPENDIX A - COST-NORMALIZING BENCHMARK INCOME

It is always possible to choose weights so that weighted and unweighted costs have equal magnitude but the resulting benchmark income would likely differ from the median income. A “cost-normalizing” benchmark income uses data on how costs are allocated. When part of the costs are borne by government, it requires knowing how governments raise money (e.g., through taxes and fees) which is used to cover project costs.

A cost-normalizing benchmark income is found from solving for y_α such that $\sum_i (y_\alpha/y_i)^\varepsilon \cdot C_i = C$, which sets the weighted cost side of EQ. 1, $\sum_i (y_\alpha/y_i)^\varepsilon \cdot C_i$, equal to total project costs C .⁴⁹ The total cost contributions C_i of income group i are simply the shares of total project costs C , or $p_i C = C_i$ where $\sum_i p_i = 1$. Accordingly, the cost-normalizing equation becomes $\sum_i (y_\alpha/y_i)^\varepsilon \cdot p_i = 1$, after substituting for C_i and dividing by C . This equation can be expressed as:

Eq.4

$$y_\alpha^\varepsilon = \left(\sum_i p_i y_i^{-\varepsilon} \right)^{-1}$$

Note that the value of y_α^ε is the reciprocal of the marginal utility of income at y_α . This cost-normalizing benchmark income y_α could be interpreted as the income at which marginal utility equals a weighted harmonic average marginal utility of income, where weights are based on how the project is funded.

The data to solve this formula come from the cost contributions p_i per income group i , which depend on the funding source for the project.⁵⁰ This benchmark income accounts for the value of money to people weighted by their cost contributions (via taxes and fees) to the funding sources for the project. It can be interpreted as the

⁴⁹ This equation applies when there is only one funding source. If multiple sources fund a project, the total cost burden C_i per group i must be determined as a weighted average of sources.

⁵⁰ Federal data on the incidence of taxes and fees per income level are available from the U.S. Department of the Treasury (2022). Data on the incidence of taxes and fees at the state and local level are available from ITEP (2024), a tax policy research organization.

average value of money across individuals' contributions to government revenue and reallocated to fund the project. In short, this benchmark is a direct reflection of the average value of how money is raised and spent on public works.

Van der Pol, et al. (2017) consider alternative income benchmarks that are based on a weighted average of beneficiaries' MU_i . They discuss a benchmark that equates the magnitudes of net benefits between wBCA and BCA. This reveals differences in how net benefits are distributed across the population. They determine a benchmark from the equation, $(\sum_i Pop_i y_i^{-\varepsilon})^{-1} = y_\alpha^\varepsilon$. The Van der Pol, et al. approach develops a weighted average MU_i based on the size of the population (Pop_i) in each income group. In contrast, the cost-normalizing benchmark weights MU_i by the proportions of cost contributions (p_i) used to fund the project. A benchmark income based on p_i would normally be larger than one based on Pop_i , since progressive taxes generate larger contributions from higher-income people.

APPENDIX B – INCOME ADJUSTMENT METHOD

Data from the US Census on income distributions in sub-national geographic areas (i.e., state, county or census tract) is reported as “money income” (MI), which is primarily wages, before tax and tax credits are incorporated and does not account for other sources of income, including transfers. As noted above, a better measure of households’ resources underlying MU_i are households’ total *disposable* incomes that account for wages, capital income, transfers and any net tax payments. In a project context then, the incremental marginal utility value of benefits to a household would depend on that household’s disposable income. In addition, comparability across households is improved by equalizing across household composition (e.g. number and ages of household members).⁵¹

This appendix outlines the data, methods and results that can be used to compute equivalized, disposable income (EDI) from MI. Here EDI denotes income that includes money income, transfers, capital income, and net-tax adjustments and equalizes disposable income across average household composition characteristics per income group. Note that since the income data for computing EDI from MI is aggregated at a national level, it is assumed that these income adjustments apply, on average, for money incomes earned at sub-national levels (e.g. incomes reported for a county or census tract). This procedure yields the average EDI within each MI band. It does not account for differences in household composition within an income band.

The approach to estimating EDI entails statistically estimating *adjustment factors*, A , that can convert MI to EDI. For instance, an adjustment factor A_i , for MI income y_i^M , computes adjusted income y_i^E as $y_i^E = A_i \cdot y_i^M$. The process outlined here involves two separate adjustment factors: (1) US Census (2022) data are used to convert MI to equivalized MI (EMI); and, (2) US Department of Treasury (2022) data are used to convert EMI to EDI. The two separate adjustment factors lead to a two-step computation process to first convert MI to EMI and then EMI to EDI.

⁵¹ Equivalization of income is recommended in the U.K. Green Book.

6.1 Conversion of MI to EMI

Data sources and computational steps for the first adjustment factors include:

- Total US income, as computed by the product of total households and mean income per household (see Census Table A-4b);
- Average money income per income group, as reported in US Census Table A-4b, as shown below in Table 8;
- Shares of total MI and EMI by quintiles in the US, (see Census Table A-3);
- Total MI and EMI per Group are computed by multiplying the Total US income, as discussed above, and shares of total income (see Census Table A-3), as shown below in Table 8, and;
- Ratios of Total EMI to Total MI per Group are shown in Table 8.

Table 8: U.S. Money Income and Equivalized Money Income

Income Groups	Mean of MI per Group	Total MI per Group (\$M)	Total EMI per Group (\$M)	Ratio: EMI to MI
Lowest quintile	\$16,120	\$419.4	\$489.3	1.17
Second quintile	\$43,850	\$1,146.4	\$1,272.3	1.11
Third quintile	\$74,730	\$1,957.3	\$2,041.2	1.04
Fourth quintile	\$119,900	\$3,145.7	\$3,089.8	0.98
Highest quintile	\$277,300	\$7,284.1	\$7,088.3	0.97

Adjustment factors for computing EMI for any MI are determined by statistically estimating a Log-Log linear model (i.e., $\ln(EMI/MI) = a + b \cdot \ln(MI)$). The resulting parameters are used to estimate an adjustment ratio $(EMI/MI)_i$ for a specific MI_i , and then multiplying this ratio with MI_i to compute a value for EMI_i . Parameters for estimating adjustment ratios are shown in Table 10. The linear model provides a good fit of the data – with statistically significant parameters and a high R-squared value (0.93). Note that the statistical analysis only uses data from the 5 quintiles.⁵²

⁵² Data also exist for the “Top 5 percent” data but are excluded because these values negatively affect the model fit and estimated parameters for adjustment factors, especially for lower quintiles. However, given the right tail of the income distribution is very long, excluding the highest income levels from the statistical analysis could lead to overestimating the appropriate weight for the 5th quintile. Including more quintiles and fitting a richer statistical model (more nonlinear) could be an area for future improvement.

6.2 Conversion of EMI to EDI

The second analysis incorporates data from U.S. Treasury (US Dept. of Treasury, 2022) that are updated annually on the sources of income and net tax payments (including income, payroll, tax credits and other taxes). These data are included in a pair of US Treasury tables called: (a) Distribution of Families, Cash Income, and Federal Taxes under 2022 Current Law; and (b) Distribution of Income by Source. All of the measures of income from the U.S. Treasury are in equivalized form.

Table 9: U.S. Incomes by Source and Net Tax Payments

Income Percentile	Total Income (\$B)	Transfer Income (\$B)	Labor Income (\$B)	Net Capital Inc. + Corporate Income Tax (\$B)	Total Federal Tax Burden (\$B)	Total Inc., Net Total Taxes (\$B)	EDI Ratio: EDI to EMI
0 to 10	\$107.1	\$52.3	\$56.8	-\$2.0	\$0.6	\$106.5	1.88
10 to 20	\$360.9	\$132.5	\$230.6	-\$2.3	-\$15.7	\$376.6	1.63
20 to 30	\$525.5	\$167.0	\$355.7	\$2.9	\$13.8	\$511.7	1.44
30 to 40	\$704.8	\$201.8	\$490.8	\$12.0	\$51.2	\$653.6	1.33
40 to 50	\$900.5	\$247.4	\$628.2	\$24.9	\$87.2	\$813.3	1.29
50 to 60	\$1,191.7	\$220.4	\$913.1	\$58.2	\$147.1	\$1,044.6	1.14
60 to 70	\$1,577.7	\$222.6	\$1,251.5	\$103.6	\$226.0	\$1,351.7	1.08
70 to 80	\$2,068.3	\$238.2	\$1,665.0	\$165.2	\$344.6	\$1,723.7	1.04
80 to 90	\$2,861.0	\$216.2	\$2,361.8	\$283.0	\$566.5	\$2,294.5	0.97
90 to 95	\$2,042.0	\$106.0	\$1,656.9	\$279.1	\$457.7	\$1,584.3	0.96
95 to 99	\$2,816.2	\$94.1	\$2,079.6	\$642.6	\$681.8	\$2,134.4	1.03

Adjustment factors for computing EDI from EMI are solved the same way by statistically estimating a Log-Log linear model (i.e., $\ln(EDI/EMI) = a + b \cdot \ln(EMI)$). Using these data, EMI is defined as “Labor Income” and EDI is defined as “Total Income” less “Total Federal Tax Burden.” The model results are used to estimate an adjustment ratio $(EDI/EMI)_i$ for a specific EMI_i . Similar to the approach above, this ratio is used to compute EDI_i . Parameters for estimating adjustment ratios are shown in Table 10. A log-log linear model yields highly statistically significant parameters and a high R-squared value (0.90). Note that data exist for incomes at the 99th to 99.9th percentile but are excluded from the analysis.⁵³

⁵³ Similar to the previous footnote, excluding the highest income levels from the statistical analysis likely leads to an overestimated weight for the 5th quintile. Including more quintiles and fitting a richer statistical model (more nonlinear) could be an area for future improvement.

Table 10: Estimated Parameters for Adjustment Factors

	EMI Adj: $\ln(\text{EMI}/\text{MI}) \sim f(\ln(\text{MI}))$	EDI Adj: $\ln(\text{EDI}/\text{EMI}) \sim f(\ln(\text{EMI}))$
Statistical results	Results (Estimate, SE)	Results (Estimate, SE)
Slope	-0.07 (0.01)	-0.18 (0.02)
Intercept	0.84 (0.126)	2.20 (0.23)
R-squared	0.93	0.90