Distributional policy impacts, WTP-WTA disparities, and the Kaldor-Hicks tests in benefit-cost analysis

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Abstract

I examine how inequality in the distribution of income and a quasi-fixed good (e.g. environmental quality or health) can affect the disparity between aggregate willingness to accept (WTA) and willingness to pay (WTP) for policies that induce joint, nonmarginal and heterogeneous changes to income and the quasi-fixed good. These disparities can generate divergent conclusions from benefit-cost analysis (BCA). In the case of Cobb-Douglas preferences, I show that greater inequality in policy impacts to the quasi-fixed good generally increases the range of conflicting conclusions from BCA using the Kaldor criterion (compensating variation) versus the Hicks criterion (equivalent variation). In two intuitive examples, I show that for any set of impacts to the quasi-fixed good there exists a degree of inequality in which the Kaldor-Hicks tests disagree. This disagreement arises because, with inequality, seemingly marginal policy changes can become nonmarginal when increasingly concentrated among marginalized or privileged groups in society, leading to a widening gap in aggregate WTP versus WTA. Extending the analysis to general CES preferences, I find that when the goods are complements, these same forces can render the Kaldor-Hicks tests inoperable (e.g. when the goods are distributed lognormally). When the goods are substitutes, attenuation of WTP by individuals' budget constraints can also push the Kaldor-Hicks tests in opposing directions. I conclude that greater inequality can increase the relevance of questioning whether to elicit WTP or WTA in nonmarket valuation for BCA.

1 Introduction

A growing body of recent research investigates the impact that income inequality can have on willingness to pay (WTP) for nonmarket environmental goods and services (Baumgärtner et al. 2017). This research is no doubt motivated in part by trends of increasing income inequality around the world and by recognition that such inequality can affect both the political economy and distributional impacts of environmental policies (Drupp et al. 2018; Piketty 2014; UNDESA 2020). In terms of methods for environmental valuation, it has also been shown that income inequality can have direct importance for the practice of benefit transfer (Baumgärtner et al. 2017; Meya et al. 2021).

In the context of environmental valuation, less well studied is how inequality affects the disparity between WTP for a prospective environmental benefit and willingness to accept (WTA) the forfeiture of that benefit. This gap in the research literature is somewhat surprising: Baumgärtner et al. (2017), in their theoretical analysis of how income inequality affects marginal WTP (MWTP), draws heavily on previous research showing that the income elasticity of MWTP should inversely relate to the elasticity of substitution between income and environmental goods (Ebert 2003; Kovenock and Sadka 1981). That same result continues to provide one of the only possible (albeit contested) explanations from rational choice theory for well-documented disparities between WTP and WTA (Hanemann 1991), a disparity which tends to be higher for nonmarket goods (Horowitz and McConnell 2002; Tunçel and Hammitt 2014).

Another active research question around inequality and the environment is the extent to which nonmarket environmental benefits are distributed unequally in society. Environmental degradation has often been found to be distributed regressively with income, to fall disproportionately on groups with lower socioeconomic status (Brooks and Sethi 1997; Mohai, Pellow and Roberts 2009; Hajat, Hsia and O'Neill 2015), and to fall on specific ethnic and racial groups even when controlling for socioeconomic factors (Mohai et al. 2009; Mikati et al. 2018; Banzhaf, Ma and Timmins 2019). However, little research to date has analyzed how these disparities empirically affect nonmarket economic valuation of these impacts (Meya 2020 provides a notable exception, which I address later in the paper). Drupp et al. (2018) observe that unequal distributions of nonmarket benefits, in conjunction with income inequality, can codetermine overall distributional effects of environmental policies.

These topics – how WTP, WTA and their difference are affected in distinct ways by joint inequality in income and nonmarket goods – are the focus of this paper. In addition to the above literature, a primary motivation for this study is how WTP-WTA disparities relate to benefit-cost analysis (BCA). As Hammitt (2015) and others have observed, since BCA was the original impetus for nonmarket valuation, it is important to consider how WTP-WTA disparities affect BCA. As Hammitt reminds readers, the WTP and WTA estimates underlying BCA are for evaluating "whether the benefits to some justify the harms of others." Intuitively, we would expect that inequality in the effects of environmental policies must directly relate to this question.

In this paper, I investigate how the degree of divergence between the Kaldor-Hicks compensation tests – which provide the theoretical foundations for BCA – depends on the degree of inequality in both income and nonmarket goods.[1] For the Kaldor test, the question for BCA is whether the beneficiaries of a policy could hypothetically compensate the losers so that no one is

[1] There is inconsistent terminology used in the literature: Some refer in the singular to the Kaldor-Hicks criterion/test, either as the joint test that benefits of a change outweigh costs when evaluated both with the CV and EV measures or sometimes without specifying whether the CV or EV measure (or both/neither) is assumed. Others refer to the plural (thus presumably remaining agnostic about whether both tests must be passed for the policy to be considered an improvement). I use 'Kaldor-Hicks tests/criteria' in this paper simply as an abbreviation for the 'Kaldor test/criterion and the Hicks tests/criterion.'

worse off following implementation, a test corresponding to the use of compensating variation (CV) as the valuation measure. The Hicks test is whether the potentially injured parties could hypothetically compensate the potential beneficiaries to a degree that the latter would be willing to forego policy implementation, corresponding to the use of equivalent variation (EV) as the valuation measure. De Scitovsky (1941) was the first to observe that results from these two tests need not agree with one another, due to their differences in which state of the world is given priority: As Hammitt (*ibid.*) and others (e.g. Knetsch 2010) have explained, these different criteria reflect different judgements on which parties – the beneficiaries or those injured – have a right to their preferred state of the world. I analyze here how the divergence of these two criteria relates to the distribution of income and nonmarket goods.

This paper proceeds by first laying out the general theoretical framework I use throughout the analysis and establishing some basic results. I then apply this framework to the specific case of Cobb-Douglas preferences over income and an environmental good. Despite its restrictiveness, the Cobb-Douglas case is useful for obtaining clear results about how divergent conclusions from BCA relate to moments of the joint distribution of income and nonmarket goods. I illustrate the import of these results in two simple examples. In the penultimate section, I extend some of this analysis to more general preferences exhibiting a constant elasticity of substitution (CES). To conclude, I discuss what this collection of findings implies for nonmarket valuation used in BCA and related welfare analyses and what it suggests about the scope for bargaining when policies have distributional impacts.

2 General Model and Analytical Framework

I consider the BCA of an arbitrary policy that has potentially heterogeneous and nonmarginal effects to individual baseline income Y_i and a quasi-fixed good Q_i (e.g. environmental quality) for each individual i across a population. I use the term 'quasi-fixed' here, in the same fashion as Phaneuf and Requate (2017), to refer to any good or factor affecting utility whose provision is not endogenously determined by individuals' choices, e.g. purchase decisions or residential location, but which (a) may vary across individuals and (b) is the target of alteration by a proposed policy – to be analyzed here using BCA. For example, Q_i may represent individual-specific levels of ambient exposure to environmental pollution: While individuals may partially control their exposure through choice of residential location or other costly, averting behavior, utility is still determined by ambient pollution levels. Indeed, policy-induced changes to local public goods (e.g. green space) are likely to have complex effects on neighborhood sorting (e.g. Klaiber and Phaneuf 2010), and one source of inequality in the distribution of benefits from public goods (and their correlation with income or tastes) is from sorting processes (Meya 2020).

In this paper, I focus only on heterogeneity in the distribution of goods (i.e. inequality), and not on heterogeneity in preferences. I therefore assume each individual's preferences can be represented by a common indirect utility function $V(Y_i, Q_i)$.[2] Assuming identical preferences allows us to clearly see how inequality alone can affect the Kaldor-Hicks tests. However, it is worth noting that the assumption of a common utility function with a heterogeneous distribution of goods is less restrictive than it might first appear: For example, the following analysis can also accommodate a situation in which every individual is provided with the same non-rival quantity $\bar{Q}$ of a public good, but for which individuals have heterogeneous marginal utility from

[2] I assume the indirect utility function is the product of the individual optimizing purchases of a vector of market goods $\boldsymbol{x}$ with associated price vector $\boldsymbol{p}$ subject to the income constraint and the provisioned level of Q, i.e. $V(Y_i, Q_i, \boldsymbol{p}) \coloneqq \max_{\boldsymbol{x}} u(\boldsymbol{x}, Q_i)$ s.t. $\boldsymbol{p}'\boldsymbol{x} \leq Y_i$. For concision, I suppress the vector of prices $\boldsymbol{p}$ as an argument in the indirect utility function, since it plays no role in the present analysis.

this good: This could be modeled simply by specifying $Q_i \coloneqq \theta_i \bar{Q}$, where θ_i is a heterogeneously distributed preference parameter.

The arbitrary policy for which the BCA is to be conducted yields new levels of the goods $\tilde{Y}_i$ and $\tilde{Q}_i$ for each individual i. Beneficiaries of this policy are those for whom $V\left(\tilde{Y}_j, \tilde{Q}_j\right) \geq V\left(Y_j, Q_j\right)$, and injured parties of those for whom $V\left(\tilde{Y}_k, \tilde{Q}_k\right) < V(Y_k, Q_k)$. Importantly, this setup (and BCA generally) focuses on policies which are not strict Pareto improvements, capturing for example cases both of environmental degradation for some members of society ($\tilde{Q}_k < Q_k$) from economic development benefiting others ($Y_j < \tilde{Y}_j,\ j \neq k$), as well as environmental improvements benefiting some ($Q_j < \tilde{Q}_j$) with others bearing only costs ($\tilde{Y}_k < Y_k,\ j \neq k$). It is also obvious but important for the aims of this paper to observe the possibility that the policy yields marginal impacts in the aggregate, but not at the individual level: i.e. individual policy changes $\Delta_i \coloneqq \tilde{Q}_i - Q_i$ such that $\mathbb{E}\Delta_i / \mathbb{E}Q_i \to 0$ but for which $|\Delta_k|/Q_k \gg 0$ among a subset of individuals. In words, the policy may appear to have approximately small, first-order impacts in the aggregate, but still have relatively extreme effects on some individuals if impacts are unequally distributed. This is precisely the type of situation I wish to study in this paper (and I conclude with some applications where such considerations are likely to matter).

The non-marginal compensating variation (CV) welfare measures of the policy change are given by the WTP of the beneficiaries to obtain the policy change and the injured parties' WTA the change. These are respectively defined by $V\left(\tilde{Y}_j - WTP_j^{CV}, \tilde{Q}_j\right) = V\left(Y_j, Q_j\right)$ and $V\left(\tilde{Y}_k + WTA_k^{CV}, \tilde{Q}_k\right) = V(Y_k, Q_k)$. Equivalently, CV may be defined in terms of the expenditure function $e(u_i, Q_i)$, which is the inverse of $V(\cdot)$ with respect to income, i.e. $u_i = V(e(u_i, Q_i), Q_i)$:

$$WTP_j^{CV} = \tilde{Y}_j - e\left(V\left(Y_j, Q_j\right), \tilde{Q}_i\right) \qquad \text{for } j \text{ such that} \qquad V\left(\tilde{Y}_j, \tilde{Q}_j\right) \geq V\left(Y_j, Q_j\right) \qquad (1)$$

$WTA_k^{CV} = e\big(V(Y_k, Q_k), \tilde{Q}_k\big) - \tilde{Y}_k \quad$ for k such that $\quad V\big(\tilde{Y}_k, \tilde{Q}_k\big) < V(Y_k, Q_k)$

For concision, define B as the subset of the population who are beneficiaries. The Kaldor test asks whether the aggregate WTP of the beneficiaries outweighs the aggregate WTA of the injured parties, equivalently whether the aggregate net benefits (NB), measured using CV, criterion are positive. In terms of distributional operators, this test takes the form:

$$NB_{CV} \coloneqq \mathbb{E}\big[WTP_j^{CV} | j \in B\big] \Pr(j \in B) - \mathbb{E}[WTA_k^{CV} | k \notin B] \Pr[k \notin B] > 0 \tag{2}$$

Substituting (1) into (2) and simplifying, yields:

$$NB_{CV} = \mathbb{E}\tilde{Y}_i - \mathbb{E}\big[e\big(V(Y_i, Q_i), \tilde{Q}_i\big)\big] > 0 \tag{3}$$

The Hicksian test for the policy change corresponds to the equivalent variation (EV) welfare measures, which are given by $V\big(\tilde{Y}_j, \tilde{Q}_j\big) = V\big(Y_j + WTA_j^{EV}, Q_j\big)$ for the beneficiaries and $V\big(\tilde{Y}_k, \tilde{Q}_k\big) = V(Y_k - WTP_k^{EV}, Q_k)$ for injured parties. The following test statement for the EV-based NB to be positive can be derived using the same steps as in (1), (2) and (3):

$$NB_{EV} = \mathbb{E}\big[e\big(V\big(\tilde{Y}_i, \tilde{Q}_i\big), Q_i\big)\big] - \mathbb{E}Y_i > 0 \tag{4}$$

In words, this relation tests whether the aggregate WTA a forfeiture of the policy change, among the beneficiaries, outweighs the WTP of injured parties to avoid it.

To develop intuition for how the Kaldor-Hicks tests can vary with the distribution of the quasi-fixed good and income, Figure 1 illustrates a simple, two-individual example with three hypothetical policy changes $\big(\tilde{\boldsymbol{Q}}, \tilde{\boldsymbol{Y}}\big)$, $\big(\tilde{\boldsymbol{Q}}', \tilde{\boldsymbol{Y}}'\big)$ and $\big(\tilde{\boldsymbol{Q}}'', \tilde{\boldsymbol{Y}}''\big)$ and a single baseline position $(\boldsymbol{Q}, \boldsymbol{Y})$. To illustrate the importance of distributional effects, I make all three policies have equivalent effects to utility, each yielding a new utility level $\tilde{V}_i$ for individual i, to be compared with baseline utility V_i. Individual 1 experiences a welfare loss from the policy change $\big(\tilde{V}_1 < V_1\big)$, and individual 2 experiences a gain $\big(\tilde{V}_2 < V_2\big)$. The northwest quadrant of the figure plots the baseline and policy-induced levels of the quasi-fixed good for each individual. Because the new levels of the quasi-fixed good of each of the policies lie on the 45º line orthogonal to the origin, each policy has the same expected value for the quasi-fixed good ($\mathbb{E}\tilde{Q}_i = \mathbb{E}\tilde{Q}_i' = \mathbb{E}\tilde{Q}_i''$). So the three policies vary the joint distribution of Q and Y such that (a) utility impacts are equivalent and (b) mean Q is fixed. The northeast and southwest quadrants plot the indifference curves respectively for individuals 1 and 2, and also show their CV and EV associated with each policy. The southeast quadrant shows the resulting changes to each individual's income.

Also shown in the bottom right are the results of the Kaldor-Hicks tests for each of the policies. For the Kaldor (CV) test, these results show that the first two policies $(\tilde{\boldsymbol{Q}}, \tilde{\boldsymbol{Y}})$, $(\tilde{\boldsymbol{Q}}', \tilde{\boldsymbol{Y}}')$ pass a BCA test, with Individual 2's WTP for the change exceeding Individual 1's WTA the change. However, the third policy $(\tilde{\boldsymbol{Q}}'', \tilde{\boldsymbol{Y}}'')$ fails this test. This reversal in the CV-based BCA is striking, given that all three policies have the same impacts on utility (which, it is important to note, remains an ordinal and non-interpersonally comparable construct of wellbeing here and throughout the paper). This shows that the results of the CV-based BCA test depend on the distribution of the goods. In this example, we can intuit from the figure that when the policy-induced distribution of Q sufficiently favors Individual 1, then the policy always passes a CV-based test. But when the policy-induced distribution of Q sufficiently favors Individual 2 (at some point on the line segment $\tilde{\boldsymbol{Q}}, \tilde{\boldsymbol{Q}}''$), then the CV-based test of the policy fails.

For the Hicks (EV) test, WTP and WTA are constant across all three policies in Fig. 1, with Individual 1's (constant) WTP to avoid each of the policy changes less than Individual 2's (constant) WTA foregoing them. This invariance is precisely because the utility impacts of the three policies are identical: Once the policy-induced utility levels ($\tilde{V}_i$) are known, other aspects of the policy are irrelevant for EV, since it is evaluated with respect to Individual 1 paying to retain the baseline position. Therefore, in this example, the outcome of the EV-based BCA is insensitive to the policy-induced distribution of the goods.

Next, observe that the definitions of the baseline and policy-induced positions could be reversed, producing exactly the opposite results in Fig. 1, with Individual 1 now experiencing a gain from $\tilde{V}_1$ to V_1 and Individual 2 a loss from $\tilde{V}_2$ to V_2: Now, $(\tilde{\boldsymbol{Q}}, \tilde{\boldsymbol{Y}})$, $(\tilde{\boldsymbol{Q}}', \tilde{\boldsymbol{Y}}')$ and $(\tilde{\boldsymbol{Q}}'', \tilde{\boldsymbol{Y}}'')$ are three different baseline positions, and a single policy change $(\boldsymbol{Q}, \boldsymbol{Y})$ is under evaluation. An EV test favors the policy change only from the baseline position $(\tilde{\boldsymbol{Q}}'', \tilde{\boldsymbol{Y}}'')$, not from $(\tilde{\boldsymbol{Q}}, \tilde{\boldsymbol{Y}})$ or $(\tilde{\boldsymbol{Q}}', \tilde{\boldsymbol{Y}}')$. A CV test, meanwhile, always opposes the change, regardless of the baseline position. This demonstrates the general logic that whereas the CV criterion is sensitive to the policy-induced distribution of the goods, the EV criterion is sensitive to the baseline distribution.

A well-known inconsistency of the Kaldor-Hicks tests can be demonstrated using Fig. 1: Suppose we evaluate the policy change to $(\tilde{\boldsymbol{Q}}'', \tilde{\boldsymbol{Y}}'')$ from $(\boldsymbol{Q}, \boldsymbol{Y})$ using Hicks' test, which indicates such a change would be justified. However, once that position has been reached we evaluate the possible change back to our original position again using Hicks' test, the result of which would support a return to our baseline position, and so on without resolution. De Scitovszky (1941) was the first to observe such an "absurd result" (in his case with respect to the Kaldor criterion), on the basis of which he argued against relying only on the Kaldor-Hicks tests for welfare evaluation.

To establish more general and rigorous results regarding the distributional dependence of the Kaldor-Hicks criteria, return to the CV and EV expressions in (3) and (4) as applied to an arbitrary set of individuals: These relations can be rearranged in terms of thresholds $\bar{y}_{CV}$ and $\bar{y}_{EV}$ that the proportional change to mean income must exceed in order to pass a BCA test using respectively the Kaldor or Hicks criterion. These thresholds are summarized in the following proposition, the proof of which requires only simple algebraic manipulation of (3) and (4). To eliminate unnecessary notation, I drop the i subscript from this point forward, as it is by now clear I am examining the distribution of pre- and post-policy goods $(Y, \tilde{Y}, Q, \tilde{Q})$ across the population.

> Proposition 1: Given any joint distribution for the goods $(Y, \tilde{Y}, Q, \tilde{Q})$, and an indirect utility function $V(Y, Q)$ and associated expenditure function $e(V, Q)$ (and assuming all the moments used below are well-defined and positive) then the following are true:
>
> a. $NB_{CV} > 0$ if and only if $\frac{\mathbb{E}\tilde{Y}}{\mathbb{E}Y} > \bar{y}_{CV} := \frac{\mathbb{E}[e(V(Y,Q),\tilde{Q})]}{\mathbb{E}Y}$
>
> b. $NB_{EV} > 0$ if and only if $\frac{\mathbb{E}\tilde{Y}}{\mathbb{E}Y} > \bar{y}_{EV} := \frac{\mathbb{E}\tilde{Y}}{\mathbb{E}[e(V(\tilde{Y},\tilde{Q}),Q)]}$
>
> c. Inequality in baseline incomes Y (respectively, policy-induced incomes $\tilde{Y}$) does not affect $\bar{y}_{EV}$ (respectively, $\bar{y}_{CV}$).
>
> d. If marginal WTP is strictly decreasing in Q, then mean-preserving spreads of $\tilde{Q}$, conditional on Q, Y, will increase $\bar{y}_{CV}$, and mean-preserving spreads of Q, conditional on $\tilde{Y}, \tilde{Q}$, will decrease $\bar{y}_{EV}$.
>
> e. $\bar{y}_{CV} > \bar{y}_{EV}$ if and only if $\frac{\mathbb{E}[e(V(Y,Q),\tilde{Q})]}{\mathbb{E}Y} \cdot \frac{\mathbb{E}[e(V(\tilde{Y},\tilde{Q}),Q)]}{\mathbb{E}\tilde{Y}} > 1$
>
> *Proof: See manuscript text.*

Proposition 1 is useful for putting the Kaldor-Hicks tests in common terms, in order to evaluate their relative stringency. Part (a) of Proposition 1 says that the policy passes the Kaldor (CV) test if the proportional, policy-induced change to mean income exceeds the ratio between mean expenditure (i.e. income) maintaining original utility levels at the new levels of the quasi-fixed good $\tilde{Q}$ and mean baseline income. Part (b) says the policy passes the Hicks (EV) test if the proportional change in mean income exceeds the ratio between the policy-induced mean income levels and the expenditure needed to obtain policy-induced utility levels at baseline levels of the quasi-fixed good Q.

Parts (c) and (d) of Proposition 1 build intuition for the remainder of the paper about how the impact of inequality on CV and EV depends on the shape of the expenditure function: First, part (c) simply states an obvious (but important) implication of the fact that Y does not enter the expression for $\bar{y}_{EV}$, nor $\tilde{Y}$ the expression for $\bar{y}_{CV}$: Therefore, baseline income inequality cannot affect the outcome of the Hicks (EV) test, nor policy-induced income inequality the outcome of the Kaldor (CV) test.

Part (d) considers inequality as consisting of mean-preserving spreads in the distribution of the goods. Hence, by Jensen's inequality, the impact of inequality on NB depends on the curvature of the indirect utility and expenditure functions. If the expenditure function is convex in Q – i.e. indifference curves in (Y, Q) space are convex – then $\bar{y}_{CV}$ will be increasing in mean-preserving spreads of $\tilde{Q}$.[3] Recall that the curvature of the expenditure function is also the (negative of the) slope of the compensated inverse demand curve for the quasi-fixed good (e.g. Phaneuf and Requate, 2017, p. 406). Therefore, if the compensated inverse demand curve is downward-sloping, then greater inequality in the policy-induced distribution of the quasi-fixed good requires a more favorable change to income in order to pass a BCA test using the Kaldor criterion. By comparison, in the case of the EV criterion in part (b), a downward-sloping inverse demand curve implies that $\bar{y}_{EV}$ *decreases* with mean preserving spreads of baseline Q. That is, greater inequality in the baseline distribution of the quasi-fixed good places less stringent demands on the income changes required to pass a BCA test using the Hicks criterion.

Finally, part (e) of Proposition 1 summarizes the condition for evaluating the relative stringency of the Kaldor-Hicks tests: The conventional wisdom in the literature (as articulated

[3] One qualification noted in part (c) of Proposition 1, which I study in more detail in later sections, is that if the goods $(Y, \tilde{Y}, Q, \tilde{Q})$ are correlated in their distribution, then the basic impacts of inequality summarized here pertain to mean preserving spreads of each good that are conditioned on the other goods.

e.g. by Hammitt 2015) is that the Kaldor criterion, by favoring the status quo, is generally more stringent a test of the policy change than the Hicks criterion. Here, this intuition holds exactly when the CV income threshold exceeds the EV threshold. Part (e) simply combines (a) and (b) to state this condition in terms of mean incomes and counterfactual expenditures pre- and post-policy change. This type of relation is useful for some specific cases considered below.

Without placing more structure on the model, we cannot glean more about the relative effect of inequality on the Kaldor-Hicks tests. For instance, examining Proposition 1, it is unclear from part (a) what the curvature of the composite function $e\big(V(Y,Q),\tilde{Q}\big)$ is with respect to Q or in part (b) the curvature of $e\big(V(\tilde{Y},\tilde{Q}),Q\big)$ is with respect to $\tilde{Q}$. Without knowing more about the shape of $V(\cdot)$ and $e(\cdot)$, this precludes a further comparison of the CV and EV criteria in nonmarginal BCA. A central aim in this paper to see whether increased policy-induced inequality in $\tilde{Q}$ could move the $\bar{y}_{CV}$ and $\bar{y}_{EV}$ thresholds in opposing directions. Moreover, when the baseline and policy-induced levels of the goods are correlated with one another, then more care must be taken to consider how inequality in one of the goods pre- or post-policy change is mixed with inequality in the other goods (Meya 2020).

3 Results for Cobb-Douglas Utility

In this section, I apply Proposition 1 to obtain more detailed results for Cobb-Douglas preferences. While restrictive, such preferences are more relevant in this paper than they might first appear: First, as I show below, this case (unlike more general CES preferences I analyze later) admits easily interpretable formulas for the Kaldor-Hicks tests in terms of measures of inequality. Second, within the class of CES utility functions (the domain analyzed by Baumgartner et al. 2017; Meya 2020), Cobb-Douglas preferences capture a special but important situation in which (a) both income and the environmental good are essential for wellbeing (which is not the case for strict substitutes) and (b) *any* partial loss of one of the goods can be *fully* compensated by a *finite* increase of the other good (which is not the case for strict complements). Finally, Baumgartner et al. (2017) and Meya (2020) find that income and environmental inequality do not generally affect aggregate MWTP in the Cobb-Douglas case. So, it would be notable if (as I find here) nonmarginal valuation measures were affected by inequality in the Cobb-Douglas case.

The indirect utility function I use for this case is $V(Y,Q) = YQ^{\alpha}$. In this parameterization, the taste parameter $\alpha > 0$ determines the relative preference for the quasi-fixed good Q versus Y. The expenditure function in this case is $e(V,Q) = VQ^{-\alpha}$ (which is convex in Q), with α equaling the elasticity of the expenditure function with respect to Q. The NB equations for the EV and CV criteria in (3) and (4) become:

$$NB_{CV} = \mathbb{E}\tilde{Y} - \mathbb{E}[Yq^{-\alpha}] > 0 \tag{5}$$

$$NB_{EV} = \mathbb{E}[\tilde{Y}q^{\alpha}] - \mathbb{E}Y > 0$$

where $q \coloneqq \tilde{Q}/Q$ is the ratio between policy-induced and baseline levels of the quasi-fixed good. Applying Proposition 1 to this utility function, and expressing results in terms of coefficients of variation and correlation, I obtain Proposition 2:

<u>Proposition 2</u>: Given fixed Cobb-Douglas preferences $V(Y,Q) = YQ^{\alpha}$ and any joint distribution for $(Y, \tilde{Y}, q)$ with well-defined moments used below, then the following are true:

a. $NB_{CV} > 0$ if and only if:

$$\frac{\mathbb{E}\tilde{Y}}{\mathbb{E}Y} > \bar{y}_{CV} = \frac{\mathbb{E}[Yq^{-\alpha}]}{\mathbb{E}Y} = \mathbb{E}[q^{-\alpha}] \cdot [\rho(Y, q^{-\alpha})\nu(Y)\nu(q^{-\alpha}) + 1]$$

b. $NB_{EV} > 0$ if and only if:

$$\frac{\mathbb{E}\tilde{Y}}{\mathbb{E}Y} > \bar{y}_{EV} = \frac{\mathbb{E}\tilde{Y}}{\mathbb{E}[\tilde{Y}q^{\alpha}]} = \frac{1}{\mathbb{E}[q^{\alpha}]\cdot[\rho(\tilde{Y}, q^{\alpha})\nu(\tilde{Y})\nu(q^{\alpha}) + 1]}$$

where $\rho(X, Y)$ denotes the correlation coefficient between any random variables X and Y, and $\nu(X) \coloneqq \sqrt{\mathrm{Var}(X)}/\mathbb{E}X$ denotes the coefficient of variation for X.

The proofs of this proposition and all subsequent corollaries in this section are in the Supplementary Material. As we can see from (5) and Proposition 2, analysis in the Cobb-Douglas case is greatly facilitated by the fact that the quasi-fixed good enters BCA here only as the ratio q between baseline and policy-induced levels. I use Proposition 2 to obtain several subsequent results with practical relevance, including clearer results on how the CV and EV criteria are affected (if at all) by inequality in each of the goods, including how the relative stringency of the criteria is affected.

I first establish that existence of any qualitative gap between Kaldor and Hicks tests in the Cobb-Douglas case depends on whether the relative impacts to the quasi-fixed good are heterogeneous:

Corollary 1: If q is equal across the population (i.e. has a degenerate distribution), then $\bar{y}_{CV} = \bar{y}_{EV} = q^{-\alpha}$, $NB_{EV} = q^{\alpha} NB_{CV}$, and therefore $NB_{EV} > 0 \Leftrightarrow NB_{CV} > 0$.

This means that when the relative change in environmental good is fixed across the population (even if absolute levels $Q, \tilde{Q}$ of that good are unequally distributed) the net benefits estimated using EV are greater (less) than those using CV, provided there is a positive (negative) change in the nonmarket good with $q > 1$ ($q < 1$). However, this difference in net benefits between EV and CV is inconsequential for whether the policy yields positive net benefits.

When proportional impacts to the quasi-fixed good do vary across the population, but do so independently of the distribution of income, the following corollary shows CV is indeed more stringent than EV. It also establishes that income inequality does not affect either criterion in this case:

Corollary 2: If the distribution of q is nondegenerate and is independent of Y and $\tilde{Y}$, then the following are true:

a. $\bar{y}_{CV} = \mathbb{E}[q^{-\alpha}]$, $\bar{y}_{EV} = \mathbb{E}[q^{\alpha}]^{-1}$, and $\bar{y}_{CV} > \bar{y}_{EV}$

b. NB_{EV} and NB_{CV} are unaffected by mean-preserving spreads of Y or $\tilde{Y}$.

Part (a) of Corollary 2 means that if the policy change yields positive (negative) net benefits using CV (EV), then it also yields positive (negative) net benefits using EV (CV). Furthermore, there exists a range of proportional changes to mean income, $\mathbb{E}\tilde{Y}/\mathbb{E}Y$, between $\bar{y}_{EV}$ and $\bar{y}_{CV}$, within which the policy change yields positive net benefits under EV and negative net benefits under CV. Part (b) simply makes clear that income inequality has no bearing on BCA when the proportional impacts to the quasi-fixed good are independent of income (and when preferences are as assumed). Thus, the net impact of inequality on the divergence between the CV and EV is ambiguous.

In general, for CV to be strictly more stringent than EV, the necessary and sufficient condition is that $\frac{\bar{y}_{CV}}{\bar{y}_{EV}} = \frac{\mathbb{E}[Yq^{-\alpha}]}{\mathbb{E}Y}\frac{\mathbb{E}[\tilde{Y}q^{\alpha}]}{\mathbb{E}\tilde{Y}} > 1$, which follows directly from Proposition 2. This condition can easily be rearranged into the equivalent and somewhat more intuitive condition that $\text{cov}(\tilde{Y}q^{\alpha}, Yq^{-\alpha}) < \text{cov}(\tilde{Y}, Y)$. It is easy to show that $\text{cov}(q^{\alpha}, q^{-\alpha}) < 0$ by Jensen's inequality. Therefore, the condition that $\text{cov}(\tilde{Y}q^{\alpha}, Yq^{-\alpha}) < \text{cov}(\tilde{Y}, Y)$ can be interpreted as saying that the income redistribution must maintain this correlation structure when mixed with the proportional gain versus loss of the quasi-fixed good (respectively, q^{α} and $q^{-\alpha}$). However, a more intuitive and useful sufficient condition is as follows.

Corollary 3: Suppose that the distribution of q is nondegenerate. A sufficient condition for $\bar{y}_{CV} > \bar{y}_{EV}$ is that: $\rho(\tilde{Y}, q^{\alpha})\nu(\tilde{Y}) \geq \rho(Y, q^{\alpha})\nu(Y)$

I interpret this condition as indicating that if the policy is non-progressive in its effects on income, in relation to quasi-fixed good impacts, then this is sufficient for CV to be stricter than EV. The progressiveness of these income effects can be decomposed as:

$$\rho(\tilde{Y}, q^\alpha)\nu(\tilde{Y}) - \rho(Y, q^\alpha)\nu(Y) = \nu(\tilde{Y}) \underbrace{\left[\rho(\tilde{Y}, q^\alpha) - \rho(Y, q^\alpha)\right]}_{\Delta \text{ in correlation}} + \rho(Y, q^\alpha) \underbrace{\left[\nu(\tilde{Y}) - \nu(Y)\right]}_{\substack{\Delta \text{ in income} \\ \text{inequality}}} \quad (6)$$

Therefore, Corollary 3 implies that a more stringent CV versus EV threshold can arise from a policy that either increases how regressive the distribution of impacts to the quasi-fixed good is ($\rho(\tilde{Y}, q^\alpha) \geq \rho(Y, q^\alpha)$) or that changes income inequality in the same direction as the correlation between baseline income and quasi-fixed good impacts. For an example of the latter possibility, consider a policy yielding proportional impacts to the quasi-fixed good that are equally regressive with respect to both baseline and policy-induced incomes ($\rho(Y, q^\alpha) = \rho(\tilde{Y}, q^\alpha) > 0$); then if the policy also increases income inequality outright ($\nu(\tilde{Y}) > \nu(Y)$), we have $\bar{y}_{CV} > \bar{y}_{EV}$ according to (6). The contrapositive of Corollary 3 implies that, for the EV criterion to be more stringent than CV, income effects must be progressive in relation to quasi-fixed good impacts; I illustrate such a possibility in a specific example later with lognormally distributed goods.

Another, empirical perspective on Corollary 3 is that it makes a statement about policy-induced effects on sorting processes relate to the CV-EV ordering. Meya (2020) interprets the correlation between income and the environmental good as a reflection of neighborhood sorting, whereby higher income households sort into neighborhoods with greater endowments of environmental goods. He presents a simple equilibrium sorting model to illustrate how such behavior can generate a positive correlation between income and the quasi-fixed good, i.e. $\rho(Y, Q) > 0$.

Under this interpretation, $\rho(Y, q^\alpha) > 0$ would indicate that households with higher baseline incomes sort towards higher relative *policy changes* $q = \tilde{Q}/Q$ in the environmental good. This kind of statement says something more complex about the role of sorting in affecting BCA of the policy. As a trivial example, if the policy generates a fixed, common proportional change in the environmental good, then q's distribution is degenerate, $\rho(Y, q^\alpha) = \rho(\tilde{Y}, q^\alpha) = 0$, and (by Corollary 1) CV is more stringent than EV, even if there is sorting on the baseline distribution of the environmental good ($\rho(Y, Q) > 0$). As a less trivial example, suppose $\alpha = 1$ and that the proposed policy generates a common, fixed improvement $b > 0$ such that $\tilde{Q} = Q + b$. Then $\rho(Y, q^\alpha) = \rho(Y, 1 + b/Q) = \rho(Y, b/Q) = \rho(Y, Q^{-1})$. With baseline sorting of the type described by Meya (2020), we would naturally suppose that $\rho(Y, Q^{-1}) < 0$. Thus, in this case, when there is preexisting sorting of the environmental good on income, then a fixed, common environmental improvement constitutes a progressive policy impact. If policy impacts to income maintain this correlation, so that $\rho(\tilde{Y}, q^\alpha) = \rho(Y, q^\alpha) < 0$, then by Corollary 3 a reduction in income inequality as a result of the policy change ($\nu(\tilde{Y}) \leq \nu(Y)$) would maintain the relative stringency of the CV over the EV criterion.

We can go on to identify in general how increasing inequality in the distribution of the quasi-fixed good can affect the divergence between CV and EV. The following states how mean-preserving spreads of q affect the CV and EV thresholds in Proposition 2.

Corollary 4: Suppose conditions in Proposition 1 hold and that $\check{q}$ is a distribution of proportional impacts to the quasi-fixed good such that, conditional on Y or $\tilde{Y}$, $\check{q}$ is a mean-preserving spread of q, and that $\check{q}$ is a strict mean-preserving spread for some subset of incomes $A \subseteq (0, \infty)$ with $\Pr[(Y, \tilde{Y}) \in A \times A] > 0$. Then the following are true:

a. $\bar{y}_{CV}(\check{q}) > \bar{y}_{CV}(q)$

b. If the expenditure function is inelastic with respect to the environmental good ($\alpha < 1$), then $\bar{y}_{EV}(\check{q}) > \bar{y}_{EV}(q)$

c. If the expenditure function is elastic with respect to the environmental good ($\alpha > 1$), then $\bar{y}_{EV}(\check{q}) < \bar{y}_{EV}(q)$, and $\frac{\bar{y}_{CV}(\check{q})}{\bar{y}_{EV}(\check{q})} > \frac{\bar{y}_{CV}(q)}{\bar{y}_{EV}(q)}$.

This shows that mean-preserving spreads of the proportional impacts to the quasi-fixed good always increases the stringency of the CV criterion, but has ambiguous effects on the EV criterion depending on the value of α. In particular, if there is a greater relative preference for income versus the quasi-fixed good ($\alpha < 1$), then the EV criterion is also more stringent, and it is therefore not clear whether the gap between the CV and EV criteria grows or shrinks. However, when there is a greater relative preference for the quasi-fixed good ($\alpha > 1$), the EV criterion is *less* stringent, implying that the gap between the two criteria must increase. This effect, which may strike some readers as perverse, reflects the inherent insensitivity of conventional BCA to equity (Adler 2012): When quasi-fixed goods are relatively desirable, individual-level net benefits using the EV criterion, $\tilde{Y}q^{\alpha} - Y$, are convex in q when $\alpha > 1$, thereby in the aggregate favoring inequality in the distribution of q. This can never be the case with the CV criterion, where individual-level net benefits, $\tilde{Y} - Yq^{-\alpha}$, are always concave in q.

Example A: A policy with binary impacts on the nonmarket good

To understand the implications of the above results for Cobb-Douglas utility, consider an example in which a proposed policy will yield economic benefits, $\mathbb{E}\tilde{Y} > \mathbb{E}Y$, but with an average reduction in the quasi-fixed good, $\mathbb{E}q < 1$. Suppose that quasi-fixed good impacts are heterogeneously distributed, independently of income, such that a portion $\zeta \in (0,1)$ of the population experiences a relative reduction of $q = \lambda < 1$, whereas the other $(1 - \zeta)$ portion of the population experiences no change in the quasi-fixed good ($q = 1$). This highly stylized example is intended to represent a scenario that could arise in the environmental justice literature of the local development of a polluting industry, e.g. oil and gas refining (Carpenter and Wagner 2019) or hog farm intensification (Wing, Cole and Grant 2000), with potential economic benefits to some (e.g. via employment income, investment returns or consumer surplus) but environmental costs to others (e.g. those located near where the pollution is sited).

The distribution of impacts to the quasi-fixed good can therefore be represented as $q \coloneqq \lambda z + 1 - z$, where z is a binary random variable taking a value of one with probability ζ. To study the effects of inequality here (i.e. varying ζ with a fixed mean), I reparameterize this distribution to have a fixed mean of $\mu \coloneqq \mathbb{E}q = \lambda\zeta + 1 - \zeta < 1$, so that the impact to the injured parties becomes $\lambda = \frac{\mu - 1}{\zeta} + 1$ and the reparameterized distribution becomes $q = \frac{\mu-1}{\zeta}z + 1$. Keeping the mean μ fixed and decreasing the portion ζ who experience the negative impact of the policy is a strict mean-preserving spread of q.[4]

Because q is independent of income in this example, we can apply Proposition 2 and Corollary 2 to obtain the cutoffs for the CV and EV criteria as follows:

$$\text{CV:} \quad \frac{\mathbb{E}\tilde{Y}}{\mathbb{E}Y} > \bar{y}_{CV} = \mathbb{E}[q^{-\alpha}] = \left(\frac{\mu-1}{\zeta} + 1\right)^{-\alpha} \zeta + 1 - \zeta \tag{7}$$

$$\text{EV:} \quad \frac{\mathbb{E}\tilde{Y}}{\mathbb{E}Y} > \bar{y}_{EV} = \mathbb{E}[q^{\alpha}]^{-1} = \frac{1}{\left(\frac{\mu-1}{\zeta}+1\right)^{\alpha}\zeta + 1 - \zeta}$$

[4] To show this mathematically, define $\tilde{q} \coloneqq \frac{\mu-1}{\zeta\chi}zx + 1$, where x is a new Bernoulli random variable, independent of z, that takes a value of one with probability $\chi \in (0,1)$. Now define $\epsilon \coloneqq \tilde{q} - q$. It is easy to show that $\mathbb{E}[\epsilon|q] = \mathbb{E}[\epsilon|z] = 0$, satisfying the definition of a mean-preserving spread, with $\tilde{q} = q + \epsilon$. Then define the new mixture random variable $\tilde{x} = xz$, which takes a value of one with probability $\zeta\chi < \zeta$, i.e. this mean-preserving spread is simply a reduction in the portion of the population bearing the negative effects of the policy, while leaving their aggregate impact unchanged. Also, note that $\mathrm{Var}(q) = \left(\frac{\mu-1}{\zeta}\right)^2 \zeta(1-\zeta) = (\mu-1)^2(\zeta^{-1} - 1)$, which is strictly decreasing in the proportion ζ harmed by the policy.

Because q is independent of $\tilde{Y}$ and Y, Corollary 2 already establishes that $\bar{y}_{CV} > \bar{y}_{EV}$. Corollary 4 dictates what happens as the harm from the policy is concentrated within a smaller proportion of the population: As ζ decreases, $\bar{y}_{CV}$ increases; whereas the effect on $\bar{y}_{EV}$ is determined by whether $\alpha < 1$ ($\bar{y}_{EV}$ increases), $\alpha > 1$ ($\bar{y}_{EV}$ decreases), or $\alpha = 1$ ($\bar{y}_{EV}$ is fixed at μ^{-1}).

In this example, we can go beyond Corollary 5 to characterize bounds on $\bar{y}_{CV}$ and $\bar{y}_{EV}$. When the negative impacts of the policy are distributed equally, with $\zeta = 1$, then $\bar{y}_{CV} = \bar{y}_{EV} = \mu^{-\alpha} > 1$. In contrast, consider the maximum possible concentration of harm. In this example, this occurs at $\zeta = 1 - \mu$.[5] As the proportion harmed approaches this lower bound, the CV and EV thresholds have the following limits:

$$\lim_{\zeta \to (1-\mu)^+} \bar{y}_{CV} = \infty \qquad\qquad \lim_{\zeta \to 1-\mu} \bar{y}_{EV} = \mu^{-1} \tag{8}$$

This shows that, at the most extreme concentration of harm from this policy, according to the CV criterion there exists *no* level of income gain that would be worth the harm to the quasi-fixed good. In contrast, the EV criterion would be met if the proportional gain in mean income was simply greater than mean proportional loss to the quasi-fixed good, regardless of preferences (α). The intuition for this difference between CV and EV is that as a harm of fixed magnitude becomes concentrated among a vanishingly small subpopulation, the loss of the nonmarket good for that subpopulation becomes nearly complete ($\lim_{\zeta \to 1-\mu} \lambda = 0$). For this subpopulation, the minimum WTA compensation for such a complete loss – with Cobb-Douglas utility – approaches infinity, whereas the beneficiaries' WTP is simply equal to the income they gain from the policy; this is CV. For EV, the situation is reversed, with the injured parties' WTP to avoid the policy always bounded by their income, whereas the beneficiaries' WTA compensation

[5] Any ζ below this value yields $\lambda < 0$: This is infeasible, since this would require the quantity of the quasi-fixed good to take a negative value.

in lieu of the policy – in this example – is the same as their WTP under the policy, simply equaling the income they stand to gain.

To appreciate the import the result in (8), suppose the policy's gains in mean income are such that they pass a BCA test when the impact to q is distributed equally ($\zeta = 1$). In this case of perfect equality in q, the EV and CV criteria are equivalent. Then one can show, for this example, there must exist a level of inequality $\zeta < 1$ such that the policy fails a CV-based BCA test and yet passes an EV-based test. This can be seen in panels (A) and (B) of Figure 2, which plot the thresholds $\bar{y}_{CV}$ and $\bar{y}_{EV}$ defined in (7) for this example by the level of inequality ζ, for two cases: $\alpha > 1$ (elastic expenditure function) in Panel A and $\alpha < 1$ (inelastic expenditure function) in panel B. Returning to the stylized example, this result means that EV- and CV-based BCAs of establishing a polluting facility are more likely to be in agreement in cases where the facility's pollution damages, of a fixed magnitude, are more widely dispersed across the population.

Figure 2 also shows the CV and EV thresholds for the case when $\mu > 1$. This case could depict, for instance, a mean improvement in environmental quality, and the threshold income changes in (7) are therefore less than one: that is, what is the maximum cost (i.e. income loss) that passes a BCA test for a given $\mu > 1$ and level of inequality ζ? At maximal inequality, $\zeta \to 0$, the CV threshold becomes $\lim_{\zeta \to 0} \bar{y}_{CV} = 1$, meaning that no loss in mean income would justify the environmental improvement (Fig. 2C and 2D).[6] This means that a vanishingly small group of beneficiaries would never be willing to pay enough for their environmental improvement (also

[6] When $\mu > 1$, then $\lambda > 1$ for any $\zeta \in (0,1)$, and so any level of inequality is admissible, in contrast to $\mu < 1$.

accounting for their own income loss) to sufficiently compensate the injured parties for any income losses.

However, in this case of an environmental improvement, the limiting relationship between the EV and CV thresholds is qualitatively different from the case of an environmental loss. If $\alpha > 1$, then $\lim_{\zeta \to 0} \bar{y}_{EV} = 0$. In words, this means that, if there is a relative preference for environmental quality over income in this example, then *any* environmental improvement would pass the EV test, regardless of its cost, when maximally concentrated among a vanishingly small group within the population (Figure 2C). This stands in stark contrast to CV. This is because for $\alpha > 1$, the beneficiaries' individual WTA payment for the foregone improvement is convex in the environmental improvement therefore growing faster (and without bound) with an increasing concentration of the benefits than the proportion of beneficiaries is shrinking, i.e. as $\zeta \to 0$. In contrast, if $\alpha < 1$, then although the beneficiaries' WTA still approaches infinity as $\zeta \to 0$, the proportion of beneficiaries is shrinking faster than WTA is growing (because WTA is now concave in the improvement). In this case, shown in Fig. 2D, EV and CV agree under both maximal equality and maximal inequality, with $\lim_{\zeta \to 0} \bar{y}_{EV} = 1$.

Regardless of $\alpha \lesseqgtr 1$, for intermediate levels of inequality, $\zeta \in (0,1)$, the two criteria will always strictly diverge, with $\bar{y}_{CV} > \bar{y}_{EV}$. Therefore, studying Figure 2 closely we can see the same result we found when $\mu < 1$: For a nontrivial policy with $\mathbb{E}\tilde{Y} < \mathbb{E}Y$ and $\mu > 1$ that passes a BCA test under perfect equality in q (when $\zeta = 1$), there must exist a level of inequality $\zeta < 1$ such that the policy fails a CV-based BCA test and yet passes an EV-based test. In relation to Corollary 4, we also see our first clear instance in which mean-preserving spreads of q (decreasing ζ) have nonmonotonic effects on the gap between $\bar{y}_{CV}$ and $\bar{y}_{EV}$. In agreement with

Corollary 4, this gap is monotonically increasing when $\alpha > 1$ (panels A and C of Figure 2) but we see nonmonotonicity when $\alpha < 1$ (e.g. panel D).

Example B: A joint lognormal distribution of policy impacts

I next present an example where the distribution of policy impacts may be correlated with income, in which case previous results suggest that income inequality can affect the outcomes of BCA using either CV or EV. My motivation here is again to capture cases of primary interest in the environmental justice literature, where low-income communities often bear the disproportionate burden of pollution (references cited in the Introduction). To study how general correlations affect BCA outcomes, I specify $(Y, \tilde{Y}, q)$ as jointly distributed lognormal. In order to isolate the effects of inequality, I follow the parameterization used by Baumgärtner et al. (2017) and Meya (2020), and specify the arithmetic means of $\mathrm{M}_Y \coloneqq \mathbb{E}Y, \mathrm{M}_{\tilde{Y}} \coloneqq \mathbb{E}\tilde{Y}$ and $\mathrm{M}_q \coloneqq \mathbb{E}q$ of the joint distribution; their corresponding coefficients of variation $\nu_Y, \nu_{\tilde{Y}}$ and ν_q; as well as the arithmetic correlation coefficents $\rho_{\tilde{Y},q}, \rho_{Y,q}$ and $\rho_{\tilde{Y},Y}$. The Supplementary Material provides details on the parameterization and proves the results stated in this subsection.

Applying Proposition 1, the CV and EV thresholds for passing a BCA test in this example can be derived as follows:

$$\text{CV:} \quad \frac{\mathbb{E}\tilde{Y}}{\mathbb{E}Y} > \bar{y}_{CV} = \left[\frac{(1+\nu_q^2)^{\frac{1+\alpha}{2}}}{M_q(1+\rho_{Y,q}\nu_Y\nu_q)}\right]^{\alpha} \tag{9}$$

$$\text{EV:} \quad \frac{\mathbb{E}\tilde{Y}}{\mathbb{E}Y} > \bar{y}_{EV} = \left[\frac{(1+\nu_q^2)^{\frac{1-\alpha}{2}}}{M_q(1+\rho_{\tilde{Y},q}\nu_{\tilde{Y}}\nu_q)}\right]^{\alpha}$$

Thus, income inequality ($\nu_{\tilde{Y}}$, ν_Y) leads to more (less) stringent CV and EV criteria when incomes are positively (negatively) correlated with the proportional impacts to the quasi-fixed good. That is, when the distribution of q is progressive ($\rho_{Y,q}$ and $\rho_{\tilde{Y},q}$ negative), higher income inequality makes BCA unambiguously more stringent. Inequality in the distribution of effects to the quasi-fixed good q has ambiguous effects on CV and EV. When q is uncorrelated with income ($\rho_{\tilde{Y},q} = \rho_{Y,q} = 0$), the CV threshold is strictly increasing in ν_q, whereas the change in $\bar{y}_{EV}$ is determined by whether $\alpha > 1$, in accordance with Corollary 4.

From (9), the ratio between the CV and EV thresholds can be simplified to:

$$\frac{\bar{y}_{CV}}{\bar{y}_{EV}} = \left(1 + \nu_q^2\right)^{\alpha^2} \left(\frac{1+\rho_{\tilde{Y},q}\nu_{\tilde{Y}}\nu_q}{1+\rho_{Y,q}\nu_Y\nu_q}\right)^{\alpha} \quad (10)$$

From (10), we can obtain the following necessary and sufficient condition for $\bar{y}_{CV} > \bar{y}_{EV}$:

$$\alpha \ln\left(1 + \nu_q^2\right) + \ln\left(1 + \rho_{\tilde{Y},q}\nu_{\tilde{Y}}\nu_q\right) - \ln\left(1 + \rho_{Y,q}\nu_Y\nu_q\right) > 0 \quad (11)$$

We can see (11) is satisfied by $\rho_{\tilde{Y},q}\nu_{\tilde{Y}} \geq \rho_{Y,q}\nu_Y$, which is very similar to the sufficient condition in Corollary 3 except that here we need not worry about the preference parameter α. When $\rho_{\tilde{Y},q}\nu_{\tilde{Y}} = \rho_{Y,q}\nu_Y$ (which includes the case where q is uncorrelated with income), then (10) reduces to: $\frac{\bar{y}_{CV}}{\bar{y}_{EV}} = \left(1 + \nu_q^2\right)^{\alpha^2} > 1$. That is, when the policy has no net distributional effects on income, CV is more stringent than EV. Moreover, as in Example A above, if a policy passes a BCA test under these conditions when there is no inequality in q ($\nu_q = 0$), then there always exists a level of inequality (some value of $\nu_q > 0$), such that it fails a CV-based test but passes an EV-based one.

From (11), we also see the first specific instance in this analysis where the EV criterion can be *more* stringent than CV. As suggested by Corollary 3, this occurs when the income redistribution from the policy is sufficiently progressive in relation to impacts to the quasi-fixed good. That is, when the difference $\rho_{\tilde{Y},q}\nu_{\tilde{Y}} - \rho_{Y,q}\nu_Y$ is sufficiently negative, we can see that the condition in (11) fails. For example, using the same decomposition as in (6), if the distribution of q is regressive with respect to baseline income ($\rho_{Y,q} > 0$), and if baseline income inequality

ν_Y is large, then a sufficient reduction in income inequality (i.e. sufficiently reduced $\nu_{\tilde{Y}} \ll \nu_Y$, given $\rho_{\tilde{Y},q} = \rho_{Y,q}$) or in the correlation between new income levels and changes to the quasi-fixed good (i.e. sufficiently reduced $\rho_{\tilde{Y},q} \ll \rho_{Y,q}$, given $\nu_{\tilde{Y}} = \nu_Y$) or a mixture of the two, could produce a CV criterion that is more lax than EV.

4 Extension to CES Utility

While showing the potential effects of inequality on aggregate WTP/WTA disparities, the above results for the Cobb-Douglas case raise questions about the extent to which they generalize to other types of preferences. In this section, I examine the broader class of CES preference, with utility function given by:

$$V(Y,Q) = \left(Y^{\frac{s-1}{s}} + \alpha Q^{\frac{s-1}{s}}\right)^{\frac{s}{s-1}} \qquad (\alpha > 0) \tag{11}$$

where $s > 0$ is the elasticity of substitution. Section 3 already treated the threshold Cobb-Douglas ($s = 1$) case in detail, and so I here analyze the case of strict substitutes ($s > 1$) and complements ($s < 1$). Inverting $V(\cdot)$ with respect to Y, the expenditure function is given by:

$$e(V,Q) = \left(V^{\frac{s-1}{s}} - \alpha Q^{\frac{s-1}{s}}\right)^{\frac{s}{s-1}} \qquad \left(V^{\frac{s-1}{s}} \geq \alpha Q^{\frac{s-1}{s}}\right) \tag{12}$$

In the case of complements ($s < 1$), the condition that $V^{\frac{s-1}{s}} \geq \alpha Q^{\frac{s-1}{s}}$ is equivalent to $Q > Q^*(V) \coloneqq V\alpha^{\frac{s-1}{s}}$: In this case, $e(Q,V) \to \infty$ as $Q \to^+ Q^*(V)$. This means there is a threshold level of the quasi-fixed good $Q^*(V)$ at or below which no finite income/expenditure level can provide utility of V. As shown graphically in Figure 3A, this arises because the indifference curves for strict complements are quasi-Leontiff, with finite bounds on the degree to which utility can be improved through unilateral improvements in a single good. For the nonmarginal analysis in this paper (in contrast to the marginal WTP analysis of Baumgartner et al. 2017 and

Meya 2020), this observation is critical for understanding the effects of inequality with CES preferences. Fig. 3A depicts a situation in which an individual experiences a reduction in utility, due to a large decrease in the quasi-fixed good albeit with a slight increase in income, for which non-finite amount of compensation can return them to their original utility. Because the threshold level of the quasi-fixed good is a function of the reference utility level, there will be one threshold for the CV criterion ($Q^*(V)$) and one for the EV criterion ($Q^*(\tilde{V})$). Furthermore, for aggregation at the population level, these bounds must be satisfied *for the whole population* in order for net benefits to be finite, since a single individual's $WTA = \infty$ would preclude aggregation.

In the case of substitutes ($s > 1$), the CES indifferences curves intersect the $Y = 0$ and $Q = 0$ axes, so that if $Q = Q^*(V)$ then zero expenditure is required to maintain utility at the level V. And for any $Q > Q^*(V)$, there exists no level of non-negative expenditure yielding utility of V. In practical terms, this bounds WTP by income (Y for CV and $\tilde{Y}$ for EV). This is illustrated in Fig. 3B, in which an individual experiences a gain in utility from a large gain in the quasi-fixed good albeit at the cost of a slight reduction in income. The individual's WTP here – the distance from the open circle to the x-axis – is obviously much smaller than the vertical distance between the unconstrained indifference curves (i.e. if we erroneously continued plotting the V indifference curve for negative income levels). Ignoring the income constraint therefore would have severely overestimated WTP in this example. Note that both Figs. 3A and 3B depict boundary cases for the CV criterion, but that the definitions could be completely reversed (i.e. so that $\tilde{V}$ and V are now respectively baseline and policy-induced utility levels) to establish the same logic for the EV criterion. Applying Proposition 1 to the CES case, Proposition 3 summarizes these points:

Proposition 3: Given any joint distribution for the goods $(Y, \tilde{Y}, Q, \tilde{Q})$, and a CES indirect utility function $V(Y, Q)$ and associated expenditure function $e(V, Q)$ given respectively by (11) and (12), with $s \neq 1$, then the following are true:

a. If $s < 1$, then:
   i. NB_{CV} is finite if and only if $\Pr[\tilde{Q} > Q^*(Y, Q)] = 1$
   ii. NB_{EV} is finite if and only if $\Pr[Q > Q^*(\tilde{Y}, \tilde{Q})] = 1$

   where $Q^*(Y, Q) := \left(\alpha^{-1} Y^{\frac{s-1}{s}} + Q^{\frac{s-1}{s}}\right)^{\frac{s}{s-1}}$

b. If $s > 1$, then the CES expenditure function to be used in (3) and (4) and Proposition 1 is:

$$e(V, Q) = \max\left\{0, \left(V^{\frac{s-1}{s}} - \alpha Q^{\frac{s-1}{s}}\right)^{\frac{s}{s-1}}\right\}$$

Proof: See manuscript text.

In contrast to the Cobb-Douglas case, Proposition 3 makes clear that the more general CES specification is complicated by several factors: First, as discussed above, when income and the quasi-fixed good are complements, part (a) shows there exist distributions of $(Y, \tilde{Y}, Q, \tilde{Q})$ for which the BCA criteria are inoperable. In terms of economic intuition, part (a) means that for the CV criterion to be operable, when the goods are complements no injured parties can experience a policy-induced reduction in the quasi-fixed good so large that no amount of income compensation can return them to their original utility level. A case in point: If the goods are lognormally distributed with full support on $(0, \infty)$, e.g. as assumed by Baumgärtner et al. (2017) and Meya (2020), then complementarity implies that aggregate, nonmarginal WTA is infinite.

In the case of substitutes, part (b) states that the Kaldor-Hicks tests must account for the income constraint: This will in general have the effect of attenuating WTP – for the policy change in the case of CV and to preserve the status quo in the case of EV. Consequently, adjusting for the income constraint in the case of substitutes further drives CV and EV criteria in opposing directions.

In general, with the qualifications articulated in Proposition 3, Proposition 1(c) can still be used to determine the response of $\bar{y}_{CV}$ (resp. $\bar{y}_{EV}$) to increased inequality in $\tilde{Q}$ (resp. Q). Because CES indifference curves are convex (for $s < \infty$), MWTP for Q is decreasing and therefore Proposition 1(c) applies: Greater inequality in $\tilde{Q}$ increases the stringency of the Kaldor test ($\bar{y}_{CV}$ increases), whereas greater inequality in Q decreases the stringency of the Hicks test ($\bar{y}_{EV}$ decreases).

However, we cannot go beyond these observations, as was done in the Cobb-Douglas case, to determine a general monotonicity result for how baseline levels of the goods (Y, Q) affects the outcome of the Hicks test, nor how inequality in $(\tilde{Y}, \tilde{Q})$ affects the Kaldor test. I conclude this section by stating these facts in the final proposition of the paper:

<u>Proposition 4</u>: In the case of CES preferences, the composite function $G\left(\tilde{Y}, \tilde{Q}, Q\right) \coloneqq e\left[V\left(\tilde{Y}, \tilde{Q}\right), Q\right]$, with $V(\cdot)$ and $e(\cdot)$ given by (11) and (12), has the following properties for any $s \neq 1$: There exist values $\tilde{Y}, \tilde{Q}, Q$ at which $G(\cdot)$ is strictly convex in $\tilde{Q}$ and other values of $\tilde{Y}, \tilde{Q}, Q$ at which $G(\cdot)$ is strictly concave in $\tilde{Q}$. Likewise, there is a range of values of $\tilde{Y}, \tilde{Q}, Q$ over which $G(\cdot)$ is strictly convex in $\tilde{Y}$ and others over which $G(\cdot)$ is strictly concave in $\tilde{Y}$.

Proof: See supplementary material

This result is important because, by ruling out the global concavity/convexity of the composite expenditure function $G\left(\tilde{Y}, \tilde{Q}, Q\right)$ (equivalently, $G\left(Y, Q, \tilde{Q}\right)$), it precludes any further generalizable statements about the effects of inequality on the Kaldor-Hicks tests. The effect on $\bar{y}_{EV}$ of increasing inequality in $\left(\tilde{Y}, \tilde{Q}\right)$, likewise the effect on $\bar{y}_{CV}$ of increasing inequality in (Y, Q), will therefore depend in the case of EV on the distributional impacts of the specific policy under evaluation and in the case of CV on the status quo distribution.

5 Discussion

In the above analysis, I have shown that policy-induced inequality in the distribution of a quasi-fixed good can generate a consequential disparity between aggregated WTP and WTA, for policy changes of arbitrary aggregate magnitude. This disparity has qualitative effects on the outcomes of the Kaldor-Hicks compensation tests in BCA. In the case of Cobb-Douglas preferences, as I show in Example A, the economic intuition for this basic result is that, as an injury of predetermined magnitude to the quasi-fixed good becomes concentrated among a smaller portion of society, their WTA that injury in the CV calculation can approach infinity. Whereas their WTP in the EV calculation is naturally bounded by income. Because the net benefits calculation in BCA is based on totaling (or averaging) WTP for the benefits and WTA losses across society, this unbounded WTA – even for a small, but measurable portion of society – has an outsized effect on the CV calculation. I then show that for more general CES preferences the Kaldor-Hicks tests for BCA may simply be impracticable when, for a measurable portion of the affected parties, the policy yields either infinite WTA (in the case of complements) or an undefined WTP (in the case of substitutes).

Taken together, these findings have important implications for nonmarket valuation work conducted by environmental economists (Mitchell and Carson 1989; Hammitt 2015). The research literature and conventional wisdom generally have coalesced behind the practice of eliciting MWTP for an environmental benefit or to avoid a loss, rather than MWTA payment in lieu of the benefit or as compensation for the loss (Johnston et al. 2017). At the same time, there has been a strong countercurrent in the literature establishing significant empirical discrepancies between MWTP and MWTA for environmental goods (Tunçel and Hammitt 2014), theorizing that these discrepancies arise from preferences that go beyond conventional utility theory, and as a result arguing that in the domain of losses MWTA may in fact be more accurately measured than MWTP (Nguyen, Knetsch et al. 2021). Authors of this literature also argue there may be an important normative argument in some cases (again, namely in the domain of losses) for using MWTA instead of MWTP in environmental valuation (e.g. Knetsch 2010; Hammitt 2015, 2020).

For example, Knetsch (2020) discusses the selection of WTP v. WTA measures with reference-dependent preferences, using as an example Bishop et al.'s (2017) stated preference valuation of damages from BP Deepwater Horizon (DWH) oil spill in the Gulf of Mexico in 2010. Bishop et al. elicited survey respondents' WTP to avoid a future oil spill. Knetsch observes (p. 179): "Instead of the result of the spill being considered as a loss, with the WTA then being the appropriate measure of its monetary value, the purpose of the manipulation [in the survey] was to have respondents evaluate a positive change of preventing a similar spill that was said would otherwise be certain to occur, with the WTP measure then seeming to be justified as the correct measure of the consequences of the Deepwater spill."

My analysis here reveals a deeper issue with this type of framing, in that even if individual preferences were to adhere to the assumptions of conventional utility theory, significant aggregate WTP-WTA disparities may still arise for distributional reasons. My analysis shows that such disparities can be consequential for determining the favorability of policies evaluated using BCA. This finding suggests that, beyond debating the selection of MWTP and MWTA as the proper valuation measure, environmental economists should also consider *nonmarginal* WTP and WTA across the population, particularly when there is significant inequality present. In the DWH example, my analysis here suggests that the selection of WTP v. WTA as the valuation metric should not only consider the reference-dependent preferences but also simply the fact that the damages from the DWH spill may have fallen on some subpopulations so intensively that their WTA those damages was likely nonmarginal (e.g. those dependent on fishing/seafood-related livelihoods, Keating, Becker et al. 2020), possibly to the extent of altering aggregate damages. Without explicitly designing the valuation to elicit nonmarginal WTA from disproportionately affected subpopulations, we cannot say more about the importance of this discrepancy. Note that this line of critique also applies to revealed preference estimates of DWH damages (e.g. using recreation demand methods, English et al. 2018).

The potential relevance of nonmarginal valuation measures is also addressed by Hammitt and Treich (2007), in their distinction between valuing “statistical vs. identified lives” in BCA. These authors study how information about heterogeneity in fatal risks affects the CV-based and EV-based WTP/WTA valuation measures of risk- decreasing/increasing projects: Their setup is analogous to my conceptual framework, with increasing information about risk specificity (i.e. identified lives) having a similar effect on a state-dependent expected utility function as does greater inequality (i.e. increasing concentration of a fixed harm) in my analysis. They find similarly divergent effects on EV-based v. CV-based measures from increasing the identifiability of individuals’ risk; if baseline risk is also heterogeneous (analogously in my case, inequality in the baseline distribution of the quasi-fixed good), the effects of information become ambiguous. My analysis can therefore be viewed as extending Hammitt and Treich (2007) to a non-VSL context.

As Knetsch (2010) and Hammitt (2015) discuss, the choice of whether to implement an EV or CV approach ideally should be based on a legal, customary or ethical understanding of who has a right to which state of the world. In the case of DWH, this would argue for having based the framing of the damage assessment on the question of whether the parties injured by the oil spill had a right to a clean environment. My analysis suggests that greater inequality in the distribution of damages increases the saliency of answering this normative/institutional question prior to designing the economic evaluation.

Another application where the results of this analysis may be relevant is in the context of proposed largescale climate policies, which involve significant intergenerational and intragenerational heterogeneity in the distribution of benefits and costs (Gazzotti et al. 2021). It is feasible that conclusions from economic evaluation of such policies could be qualitatively altered by considering future generations' WTA nonmarginal, status quo damages instead of their WTP to reduce them. Because such economic evaluations are used to generate estimates of the social cost of carbon (SCC) – itself an important quantitative ingredient in BCAs of specific government policies (e.g. Pizer et al. 2014) – it is thus reasonable to ask whether these SCC estimates could be sensitive to intergenerational and intragenerational (in)equity in ways that are not currently understood or recognized. For example, intuitively one would think the SCC to be higher (possibly significantly so) if future generations' WTA were used as a basis to assess future damages, particularly if income inequality is likely to be even higher among future generations than among current ones. Indeed, based on the analysis in section 4 above for the CES case when the environmental good and income are complements, it is feasible that future generations' WTA currently projected climate damages is simply infinite, making BCAs of little practical use for evaluating largescale climate change scenarios. Beyond these observations (which were prompted by a reviewer comment), I leave such questions as topics for future research.

One important aspect of the problem I have omitted from this paper is the consideration of non-utilitarian, welfarist evaluation frameworks. Indeed, some readers may view (as did one reviewer) the results of this paper providing further support for the argument against using BCA for welfare evaluation. Alternatives, such as a ‘prioritarian’ social welfare function (Adler 2012) and ‘equivalent income’ (Fleuerbaey et al. 2013), have been advanced explicitly for the purpose of including a social preference for equality, whereas BCA is typically viewed as indifferent to these aspects. The results in this paper should not be interpreted as a discovery of some independent social preference for (in)equality built into CV and EV criteria. Rather, the analysis here provides a mechanistic description of how BCA’s evaluation of policy impacts in terms of aggregated monetary/consumption equivalents is necessarily affected by the distribution of goods in society.

There are also political economy implications of my finding that the joint distribution of policy impacts can alter the natural CV-EV ordering assumed by economists. To recapitulate, I find that, in the Cobb-Douglas case, EV can end up being more stringent a test of a policy than CV when the policy carries with it sufficiently progressive income effects (e.g. by directly reducing income equality or by ameliorating income-based residential sorting on the environmental good, Meya 2020). The instance of an EV-CV reversal highlighted in Example B shows that an institution (implicitly or explicitly) granting injured parties rights to the status quo, as opposed to granting beneficiaries rights to the policy change, can *increase* the likelihood of taking action, *if* the proposed income redistribution is progressive enough in relation to the nonmarket impacts. This result, though contrary to conventional economic intuition, evokes discussions of progressive carbon taxation (Klenert and Mattauch 2016; Dissou and Siddiqui 2014), as well as other largescale, multidimensional policy proposals, such as the Green New Deal in the US and the European Green Deal, which couple climate change and other environmental policies with economic equity objectives (European Commission 2019; US Congress 2019).

As discussed above, CV and EV represent opposing assignments of property rights. If the winners from the policy change compensated the losers in reality (rather than just hypothetically, as in a BCA), Coase (1960) argues that such property rights assignments should have negligible effects on bargaining outcomes when income effects and transactions costs are absent. In this regard, my analysis suggests that increasing inequality in the distribution of the quasi-fixed good adds another factor that may render the CV and EV institutions non-equivalent.

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Figures

Figure 1. Kaldor-Hicks tests for a two-individual model for policies with equivalent utility effects.

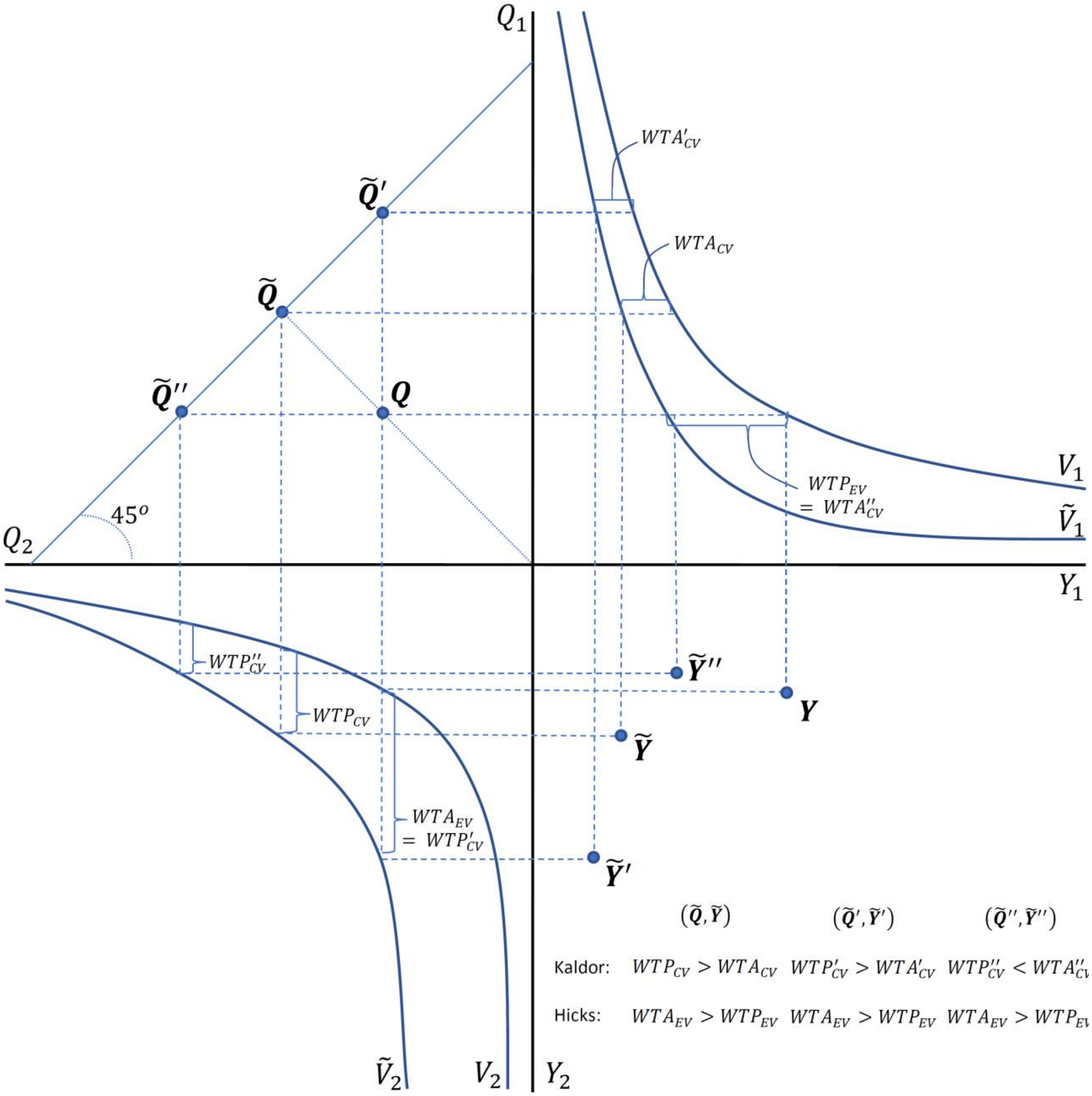

Figure 2. BCA thresholds for proportional changes to mean income ($\mathbb{E}\tilde{Y}/\mathbb{E}Y$) for Example A, by portion of the population (ζ) experiencing the change in the quasi-fixed good. *α is relative preference for the quasi-fixed good (see eq. 1) and μ is the mean proportional change to the quasi-fixed good (see eq. 7).*

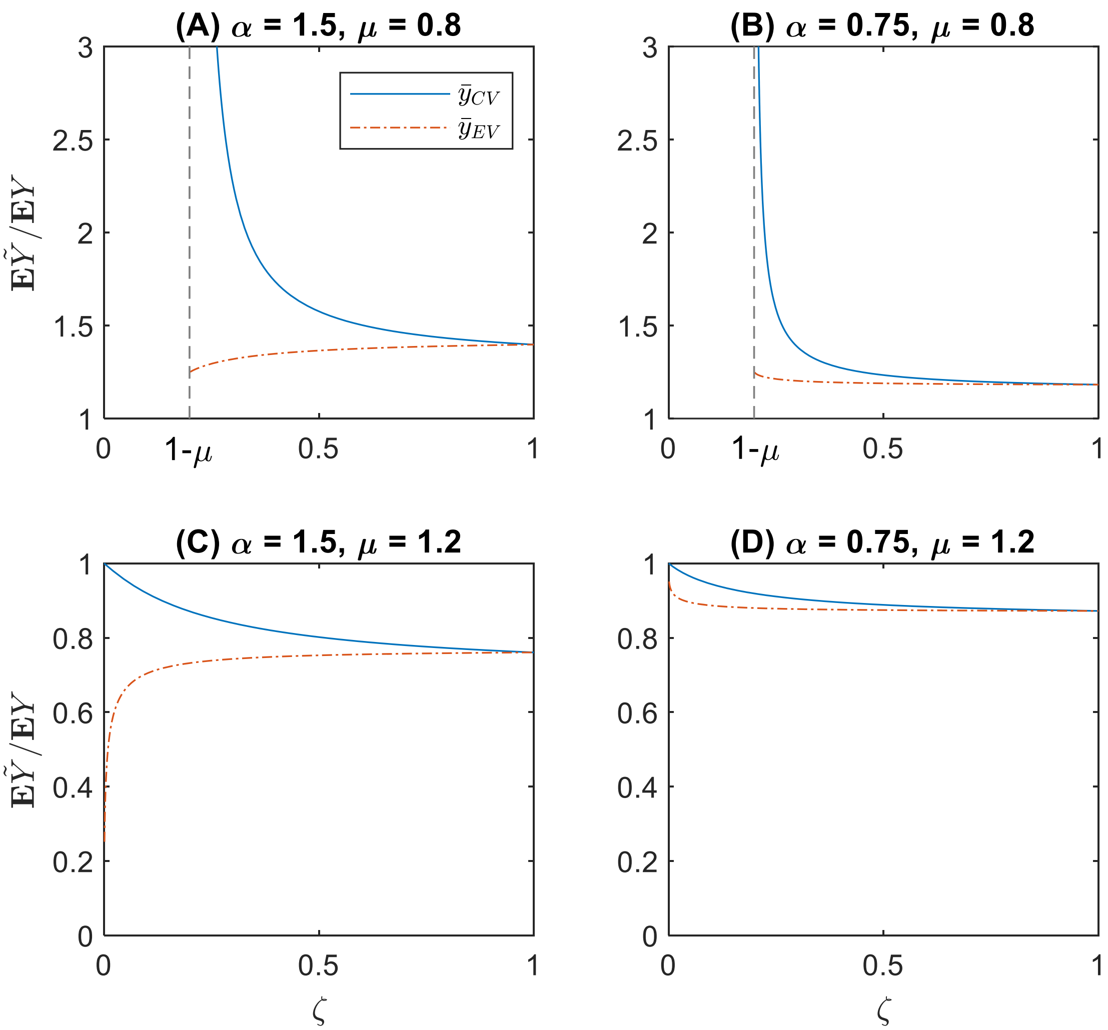

Figure 3. CES expenditure functions for complements and substitutes. *Thick (thin) lines correspond to baseline (policy-induced) utility levels; closed (open) circles correspond to baseline (policy-induced) positions.*