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# Alternative Risk Metrics to Evaluate Tradeoffs between Efficiency and Equity of Risk Reduction

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ABSTRACT: A common criticism of traditional benefit-cost analysis (BCA) is that benefit-cost ratios (BCRs) are reductive, in the sense that they aggregate all benefits and costs into a scalar value; decision rules that aim to maximize BCRs ignore distributional impacts in favor of pure economic efficiency. In the context of flood risk management, all else equal, benefit-cost analysis favors protection of affluent communities comprised of assets with higher replacement costs. Allocations of scarce resources for flood protection based on BCA could therefore lead to inequitable provisions of risk reduction.

This paper analyzes ranked preferences for flood protection projects included in Louisiana's Comprehensive Master Plan for a Sustainable Coast, a 50-year, $50 billion USD suite of infrastructure investments primarily targeting risk reduction and coastal restoration. In addition to BCRs, we also estimate cost effectiveness measures such as the reduction, per unit of project cost, in the expected number of residential structures inundated over the planning horizon. Measures like this intentionally ignore the replacement costs of structural assets, implicitly valuing protection of each household equally regardless of wealth. In a sense, we consider how preferences vary, depending on whether decision makers' preferences are to protect wealth or to protect households. We then overlay census data to estimate the risk reduction which would be afforded across different demographic categories by project portfolios of varying budgets, examining differential outcomes across income, race, and urbanicity. Our analysis suggests that the choice of metric has a substantial impact on the rank-ordered preferences for flood protection projects, and that dramatic increases in equity can be obtained by placing only a small weight on metrics that are wealth-agnostic.

In our experience, decision makers often want to incorporate equity and social vulnerability considerations into their planning processes, but they either do not know how or they worry about pushback if plans appear to explicitly favor one group over another. By incorporating alternative risk metrics into a cost effectiveness analysis of flood protection projects, our results indicate that more equitable outcomes can be achieved without explicitly optimizing for it and with minimal loss in economic efficiency.

## 1. INTRODUCTION

When designing policies to mitigate risk from natural hazards, governments commonly apply benefit-cost analysis (BCA) to rank preferences for alternative policy options. In many jurisdictions, BCA is required by law for all mitigation projects over a certain budget. Typically, this entails estimating a benefit-cost ratio, the ratio comparing the present value of project benefits to the present value of project costs (e.g., planning, engineering and design, operations and maintenance) over a specified planning horizon. In the context of natural hazards risk mitigation, the primary benefits are operationalized as the expected present value of avoided losses (i.e., economic risk reduction).

A common criticism of traditional BCA is that benefit-cost ratios are reductive, in the sense that they aggregate all benefits and costs into a scalar value; decision rules that aim to maximize benefit-cost ratios ignore distributional impacts in favor of pure economic efficiency. In the context of flood risk management this means that, all else equal, BCA favors protection of affluent communities comprised of assets with higher replacement costs. Allocations of scarce resources for flood protection based on BCA could therefore lead to inequitable provisions of risk reduction. This remains true whether losses are limited to physical damage to structures and their contents or more broadly to include direct economic losses such as temporary relocation and disruption costs incurred by homeowners during a reconstruction or repair period. This is no mere theoretical concern, as studies have shown that socially vulnerable populations are generally at greater risk of environmental harms such as flood risk (Chakraborty et al. 2014; Herreros-Cantis et al. 2020; Pallathadka et al. 2022; Sharkey 2007). Efforts to reduce these distributive inequalities are frustrated by challenges in how to define equity (Emrich et al. 2020; Thaler 2021) or by political barriers to achieving social justice goals (Shi 2020; Shively 2017; Vojinovic and Abbott 2012). BCA is a special case of cost effectiveness analysis, a broader economic decision-making paradigm that seeks to promote decisions that maximize the benefits of projects per unit cost of implementation. In BCA, the benefits are simply also monetized and aggregated to a scalar value, yielding a dimensionless benefit-cost ratio as the basis for decisions. In this paper, we present an alternative decision metric that is still rooted in cost effectiveness analysis but which conceives of benefits in non-monetary terms. We then apply it to a case study of coastal flood risk mitigation in Louisiana (USA) based on the state's 2023 *Comprehensive Master Plan for a Sustainable Coast* (Louisiana Coastal Protection and Restoration Authority 2023) (hereafter, Coastal Master Plan). We find that decisions which incorporate this new cost effectiveness measure have the potential to produce substantially more equitable outcomes in risk reduction across income levels and racial groups, while avoiding the explicit incorporation of said demographics into the decision process.

## 2. METHODS

In this analysis, we consider the residential elevation-in-place projects (i.e., raising the foundation of a home higher above topographic grade) evaluated as part of the Coastal Master Plan. Flood risk mitigation projects are commonly evaluated by their cost effectiveness at reducing direct economic damage (DED) over a planning horizon $T$, where the expected DED associated with elevating a home's foundation to height $h$ above the lowest elevation adjacent grade (LEAG) is expressed as

$$\mathbb{E}[DED(h)] = V\sum_{t=1}^{T}\frac{1}{(1+\delta)^t}\left[\int_{e\geq 0} f_t(e)L(e-h)de\right]$$

In this equation, $V$ represents the replacement cost (i.e., value) of the asset(s) being protected, $\delta$ is an annual discount rate, $e$ a potential flood elevation above LEAG, $f_t$ the probability distribution function for flood elevations in year $t$, and $L$ a loss function that relates flood depths to the resulting damage. For standardization, $L$ is commonly formulated as a *depth-damage curve*, expressed as a proportion of the building's replacement cost $V$. Assuming that the cost of mitigating the structure to a height $h$ is $C(h)$, the cost effectiveness associated with doing so is therefore

$$\Omega_{\mathrm{DED}}(h) = \frac{\mathbb{E}[DED(0)] - \mathbb{E}[DED(h)]}{C(h)}$$

As a simple alternative cost-effectiveness metric, we proposed residence-equivalent losses (REL), calculated in an identical fashion but without weighting the measure's value by the replacement cost of a structure, $V$:

$$\mathbb{E}[REL(h)] = \sum_{t=1}^{T}\frac{1}{(1+\delta)^t}\left[\int_{e\geq 0} f_t(e)L(e-h)de\right]$$

The cost effectiveness of reducing REL using home elevations is thus

$$\Omega_{\mathrm{REL}}(h) = \frac{\mathbb{E}[REL(0)] - \mathbb{E}[REL(h)]}{C(h)}$$

In effect, all houses are treated as if they have the same replacement cost. An appealing interpretation of this metric is that while traditional BCAs seek to mitigate risk to *houses*, this new approach evaluates projects on their ability to mitigate risk to *households*.

For consistency with the Coastal Master Plan, we also consider the possibility of the government acquiring the at-risk property if the mitigation target $h$ is greater than 14 feet, due to the engineering and livability challenges of elevating beyond this point (combined with the greater exposure to wind loading during tropical cyclone events at these higher elevations). In this case, the expected direct economic damage and residence-equivalent losses both are reduced to zero, and the cost function changes to a buyout subsidy proportional to the replacement cost of the structure. Costs are estimated using the cost functions developed for the Coastal Master Plan, and estimates of single-family home replacement costs $V$ and hazard curves $f_t$ are taken from the Coastal Louisiana Risk Assessment (CLARA) model (Johnson et al. 2013, 2023) used by the Plan. Replacement costs are structure-specific based on an inventory of all structures in the Louisiana coastal zone; the inventory includes attributes such as the number of stories, square footage, and the foundation type (e.g., pier or concrete slab) of each home. Valuations from CLARA adopt the same methods and unit costs as the FEMA Hazus-MH model (Federal Emergency Management Agency 2020), which is also the source of the depth-damage curves, $L$, that assume long-duration inundation from salt water.

### *2.1. Experimental Design*

Our analysis is restricted to elevation-in-place or acquisition of single-family homes in the Louisiana coastal zone. For illustrative purposes, benefits associated with mitigation projects are based on a single time period, reductions in DED or REL risk as projected in the year 2070. Cost effectiveness scores are calculated for two mitigation targets: 1) flood depths in 2020 with a 1% annual exceedance probability (AEP), plus two feet of freeboard; and 2) flood depths in 2050 of the Coastal Master Plan's Lower environmental scenario with a 1% AEP, plus two feet of freeboard. These correspond to the two mitigation targets used to develop the Coastal Master Plan's recommended budget for these types of projects. We rank order all single-family homes by their cost effectiveness, using DED and REL, then allocate funding to risk mitigation up to a total cost of \$3.64 billion (matching the budget of the Plan's first implementation period[1], i.e., projects recommended for construction in the next twenty years).

Because REL treats all houses as if they have the same replacement cost, we view it as an alternative metric that inherently embodies some concept of egalitarian equity; in this context, we view the egalitarian perspective as mandating that each individual is granted equal consideration by governing authorities, without explicitly aiming for equality of outcomes or final distribution of resources as a normative good (Parfit 2000). This contrasts with a prioritarian perspective wherein policies are preferred which prioritize the welfare of less affluent, or otherwise socially vulnerable, populations. Because policy makers may wish to evaluate the tradeoffs between economic efficiency and egalitarian equity, we also consider policies that allocate funding using a weighted average of DED and REL (applying a normalization factor to DED to put the two metrics on a similar order of magnitude). Results are presented for a total of 51 policies, each with a \$3.64 billion total budget allocated with weights

[1] The Coastal Master Plan also considers floodproofing non-residential buildings and buyouts for other residential categories (e.g., manufactured homes, multi-family), but the vast majority of spending is dedicated to single-family residences, given its predominance in the housing stock. For simplicity, we assume the entire budget is available.

on DED and REL that vary from 0 to 1 at 0.02 intervals (weights on the two metrics sum to 1).

We further investigate the equity outcomes associated with these policies by merging the risk to each structure with demographic data at the US Census block group level from the 2019 American Community Survey. We assign demographic categories proportionally to each structure before aggregating the results; for example, if a structure is located in a block group with population 80% White and 20% Black, we would assign 80% of its DED and REL values to White households and 20% to Black households. While we do not know the demographic makeup of any individual household, this provides an approximation of the coastwide outcomes when aggregating over a large number of homes. Note that this requires a simplifying assumption that the demographic makeup of populations living in single-family homes is the same as of those living in mobile homes and multi-family residences. Bias could result if this assumption is not approximately valid at the block group level.

## 3. RESULTS

We find a clear tradeoff between DED and REL on the Pareto frontier, and this tradeoff is favorable to the equity-focused REL metric. When departing from a traditional BCA that seeks to maximize economic efficiency (i.e., all weight on DED, marked red in Figure 1), it is possible to gain approximately 4.2 percentage points of marginal REL reduction at a sacrifice of only 1 percentage point in DED reduction; in other words, if policies favoring REL reduction are found to result in more equitable outcomes, then these outcomes can be substantially improved without great sacrifice in economic efficiency. Conversely, when starting from a policy focused solely on maximizing REL reduction, a 1 percentage point sacrifice of REL benefits only achieves a 2.7 percentage point increase in DED reduction in trade.

Previously, we argued that REL is inherently more egalitarian and hypothesized that policies based on REL cost effectiveness should make risk mitigation for less affluent households with less valuable assets more attractive. This would therefore yield outcomes that also satisfy a prioritarian perspective. To investigate this, we examine the baseline risk for households of different income levels and risk outcomes from the Pareto-efficient policies. To do this, we segment the population into four strata based on poverty-income ratio (PIR), an expression of household income as a multiple of their US poverty threshold (which varies by size of family and number of children under 18 years old). Table 1 shows the population counts and percentages by PIR, as well as the share of total DED and REL in the study population in a baseline future without action scenario. Because the CLARA model's domain is intended to span at least the 0.05% AEP (2,000-year) floodplain, we exclude block groups where no residences are selected for elevation or acquisition in at least one of the identified policies.

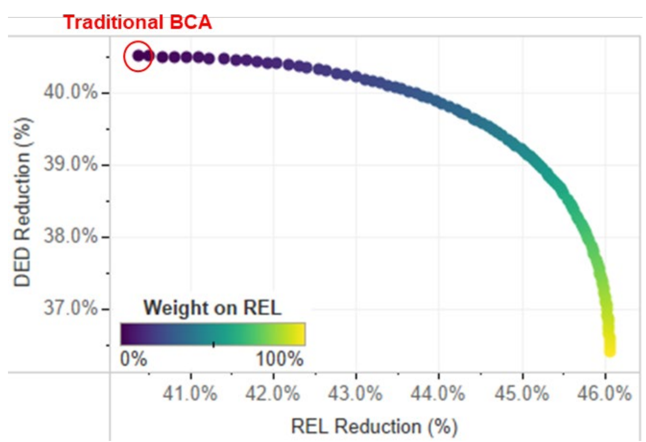


*Figure 1. Pareto frontier of benefits from non-dominated \$3.64 billion policies, with DED and REL reductions expressed as a percentage of the Future Without Action baseline risk.*

Not surprisingly, households with a PIR greater than 2 (i.e., income at least twice their poverty threshold) bear a disproportionate share of baseline risk when expressed as DED: 66.3% of the population compared to 70% of DED. In general, the distribution of REL in the baseline scenario is more proportionally equitable across income strata.

*Table 1. Population by poverty-income ratio in block groups where home elevation(s) occur in at least one policy.*

| Poverty-Income Ratio | Population (#) | Population (%) | DED (Baseline) (Baseline) | REL (Baseline) |
|---|---|---|---|---|
| Less than 0.5 | 73,706 | 7.1% | 5.7% | 6.1% |
| 0.5 to 1.0 | 90,801 | 8.7% | 8.3% | 9.2% |
| 1.0 to 2.0 | 186,717 | 17.9% | 16.0% | 17.1% |
| Greater than 2.0 | 689,822 | 66.3% | 70.0% | 67.6% |
| **Grand Total** | **1,041,046** | **100.0%** | **100.0%** | **100.0%** |

*Table 2. Population by race in block groups where home elevation(s) occur in at least one policy.*

| Race | Population (#) | Population (%) | DED (Baseline) | REL (Baseline) |
|---|---|---|---|---|
| White | 730,780 | 70.2% | 79.3% | 77.3% |
| Black | 236,517 | 22.7% | 14.0% | 15.8% |
| Multi-Racial / Other | 40,368 | 3.9% | 3.3% | 3.5% |
| Asian | 21,693 | 2.1% | 1.4% | 1.4% |
| Indigenous | 11,688 | 1.1% | 1.9% | 2.0% |
| **Grand Total** | **1,041,046** | **100.0%** | **100.0%** | **100.0%** |

Breaking out the policies' achievable DED and REL reduction by income strata, we find that the policy maximizing REL (bright yellow in Figure 2) actually represents a Pareto improvement for all three low-income groups with PIR less than 2. When optimizing budget allocations in an income-blind way (Figure 1), the tradeoff is almost entirely associated with the highest income group. This indicates that with respect to income, an REL-focused strategy satisfies prioritarian preferences while the metric is rooted in egalitarian equality.

Next, we examine equity in baseline risk (Table 2) and outcomes for five racial groups

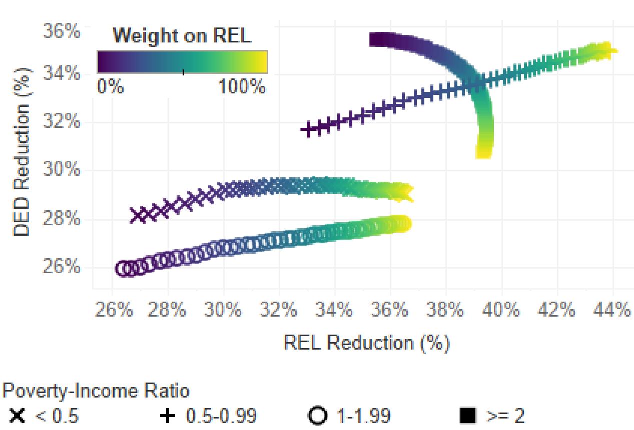


*Figure 2. DED and REL reduction associated with Pareto-efficient risk mitigation policies, by income strata.*

reported by the US Census: White, Black, Native American (Indigenous), Asian and Pacific Islander (Asian), and Multi-Racial / Other. White households bear a disproportionate share of risk in the baseline scenario: 79.3% of DED and 77.3% of REL compared to 70.2% of the population. Again, the distribution of REL is more proportionally equitable across groups than the distribution of DED. This finding about baseline risk may not generalize to the entire coastal zone, due to the much larger proportion of Black residents in New Orleans (58.1%), which is at much lower baseline risk due to protection provided by the greater New Orleans Hurricane & Storm Damage Risk Reduction System (HSDRRS). As a result, the racial makeup and baseline DED/REL values are systematically different in block groups where home elevations and buyouts are not recommended by the policies identified in this analysis.

The breakdown is less clear with respect to how individuals from different racial groups benefit from policies with varying preferences for REL versus DED reduction. Asian households experience the greatest levels of risk reduction in general, but for them, policies focusing primarily on REL reduction are dominated by policies that focus predominantly on DED reduction (Figure 3). For Black, Indigenous, and Multi-Racial/Other households, policies with balanced preferences (i.e., not 100% weight on REL or 100% weight on DED) can improve aggregate outcomes for DED, but a purely REL-focused policy produces the best outcomes with respect to REL reduction. For each group, though, the difference between the maximum achievable DED reduction and the DED reduction from a purely REL-focused policy is less than two percentage points, with generally a larger amount of REL reduction to be had in exchange. Meanwhile, policies that are Pareto-efficient in aggregate when optimized in a race-blind manner appear not to yield any dominated strategies with respect to outcomes for White households.

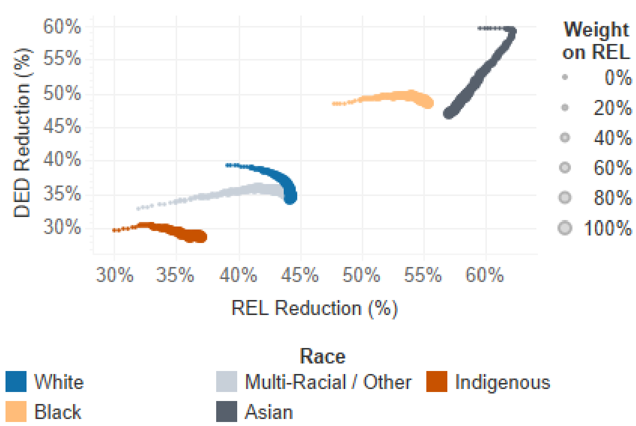


*Figure 3. DED and REL reduction associated with Pareto-efficient risk mitigation policies, by race.*

Finally, we also note that differential risk reduction may be achievable across urban and rural divides (Figure 4). This is important to explore because of possible differences in cost of living and home values between urban and rural areas; if average replacement costs are systematically different, this gives theoretical support for incorporating a value-neutral risk measure like REL into the policy design. With respect to risk reduction, we also see systematic differences in Figure 4 for both overall DED and REL reduction. Urban areas are more likely to be located in areas with lower baseline hazard, or to already have some degree of structural protection, meaning that interventions like home elevations are more likely to be effective in mitigating the residual risk. Put another way, rural areas are more likely to be located in areas where home elevations are less cost-effective due to the larger underlying hazard, requiring a higher and more costly elevation to appreciably reduce damage. Further research would be required to tease out the impact of each of these potential effects, in Louisiana and elsewhere. A more detailed analysis could also examine intersectional effects associated with correlations between income, race, and urbanicity.

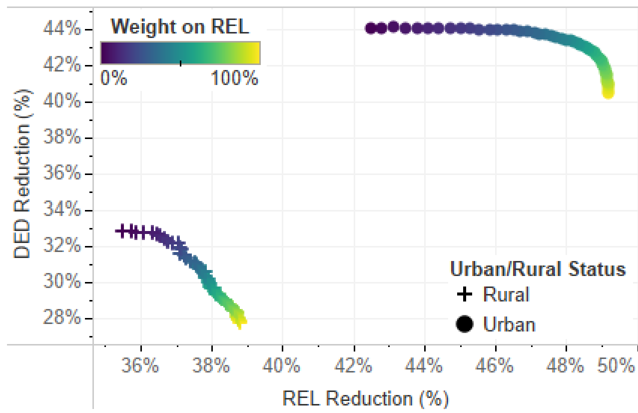


*Figure 4. DED and REL reduction associated with Pareto-efficient risk mitigation policies, by urban/rural status.*

## 4. DISCUSSION

Considering commonality and differences between these policies, we find that only about half of homes are selected for mitigation in all strategies. Because the policies are designed to optimize a weighted average of performance with respect to DED and REL reduction, this is roughly equivalent to saying that about half of homes are included in policies that focus purely on DED reduction and purely on REL reduction; if a building is not in both, it generally is included/excluded in all policies up to a certain weighting factor, then excluded/included from all policies thereafter. For homes that are included in at least one policy, 23% are included in less than half of the policies. If budget availability is uncertain, the homes included in all policies may be viewed as good candidates for higher priority mitigation, in the sense of being robust to decision-maker preferences. Conversely, policy makers may view the 23% as being considered for implementation if funds become available, or they may merit greater scrutiny as to the risk reduction impacts and community characteristics associated with them.

This exploratory analysis suggests that incorporating REL into the evaluation of flood risk mitigation projects can identify prioritarian strategies that are Pareto-improving for lower-income households with relatively smaller impact on the economic benefits to higher-income households. Due to correlations between income and race in some regions, this also has potential to improve historic inequities in the provision of risk mitigation across racial groups while allocating funds in a race-blind manner. This is not guaranteed, however, and may require closer examination due to the patterns observed for some racial groups in Figure 3. Policy makers will need to weigh the baseline distribution of risks, the magnitude of potential risk reductions across demographic groups, and the degree to which weighting REL results in varying economic performance with respect to DED reduction (i.e., aggregate benefit-cost ratios for the overall budget allocation).

In our experience, decision makers often want to incorporate equity and social vulnerability considerations into their planning processes, but they either do not know how or they worry about pushback if plans appear to explicitly favor one group over another. By incorporating alternative risk metrics into a cost effectiveness analysis of flood protection projects, our results indicate that more equitable outcomes can be achieved without explicitly optimizing for it and with minimal loss in economic efficiency. The residence-equivalent losses metric may be appealing to policy makers wishing to consider the distributional impacts of project evaluation that are often obscured by a traditional benefit-cost analysis.

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