Discount Rate Selection for Investments in Climate Change Adaptation and Flood Risk Reduction Projects

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Abstract

The selection of an appropriate discount rate is a critical yet often neglected aspect of valuing flood protection and climate adaptation projects. We examine current discounting practices in flood risk management and climate adaptation literature and compare these practices with a proposed fair market value (FMV) discounting approach, in which we discount project cash flows based on their levels of systematic market risk, consistent with practice in the private sector. Using publicly available data from the National Flood Insurance Program (NFIP), we demonstrate minimal correlation between flood risk-related cash flows and overall market returns, suggesting flooding-related cash flows are most appropriately discounted near the risk-free rate. We consider the example of a proposed storm surge barrier in Boston Harbor and compare prevailing public sector discounting approaches to this FMV approach. Our results suggest prevailing discounting approaches systematically undervalue flood risk reduction benefits and climate adaptation investments relative to the private sector valuation implied via the FMV approach.

Introduction

Valuation is a critical component of the decision-making process for any project or investment. The selection of a discount rate is an important step in valuation, as it can greatly influence the perceived profitability of an investment or project. This is particularly true when valuing infrastructure investments, as they often entail large upfront costs and future benefits that accrue over the lifespan of the asset (Chen & Bartle, 2022). In such situations, the present value of future benefits is highly sensitive to changes in the discount rate. As the discount rate increases, larger future benefits are required to offset initial project costs and justify investment in a given project. Climate change adaptation projects represent a rapidly expanding class of infrastructure and are especially sensitive to discount rate selection, as the expected benefits tend to increase with time, proportional to increases in the frequency and/or intensity of climate-related hazards (i.e., coastal flooding associated with storm surge and sea level rise; Strauss et al., 2021; IPCC, 2022). Despite this notable sensitivity and the prevalence of a varied range of discounting practices, discount rate selection is often neglected or misunderstood within the climate adaptation and coastal flood risk management literature. The existing literature also lacks substantial guidance on discount rate selection relevant to the private sector, despite the growing need for investments in adaptation across industries within the private sector and rapidly increasing property and casualty insurance premiums (ECAWG, 2009; Kousky et al., 2021).

In order to address this gap in the literature, we first examine relevant discounting rationales employed in the literature for valuation of public sector adaptation investments, inclusive of relevant U.S. federal policy guidance. Next, relying on basic modern financial principles, we outline a private sector oriented fair market value (FMV) approach to discount rate selection for adaptation investments, wherein discount rates for project cash flows are informed by their underlying systematic risk and correlation to the broader market. This stands in contrast to prevailing public sector discounting rationales applied to adaptation investments, which routinely neglect such systematic market risks. Operationalizing the proposed FMV approach, we first estimate the systematic (i.e., market correlated risk) for flood risk-related cash flows, examining the correlation between U.S. flood insurance claims and broader market returns via a copula-based approach. Informed by these results, we apply the FMV approach to value a real-world climate adaptation case study, a proposed Boston Harbor Barrier, and underscore the general implications of the proposed FMV approach for climate adaptation projects. We conclude with actionable policy and best practice recommendations for appropriate discounting practices specific to coastal flood protection and climate adaptation projects.

Prevailing Discounting Practices Presented in Climate Adaptation Literature

In adaptation planning literature and practice, discount rate selection is often treated in a summary fashion, using a rate provided or extracted from policy guidance with little justification (e.g., Kirshen et al., 2020; Melo et al., 2020, DHS, 2020; Ha et al., 2021; Stewart & Rosowsky, 2022). The rather cavalier and straightforward discount rate selection process can be considered pragmatic, as alignment of economic analyses with public policy guidance lends a nominal degree of legitimacy to the findings and conclusions associated with a given study, particularly if conclusions are intended to support (in)action within prevailing institutional frameworks or federal funding programs (e.g., justification of funding under the Federal Emergency Management; FEMA Building Resilient Infrastructure and Communities; BRIC program; DHS, 2020). Furthermore, since public policy within most western countries specifies the use of a single discount rate for public sector investments (Bastidas-Arteaga & Stewart, 2019; Gollier, 2021), the selection of any alternative rate implies a direct challenge to the assumptions underlying prevailing public policy, though such contradictions are not necessarily irreconcilable in practice. Relevant case law in the United States suggests federal agencies in fact have some latitude in the selection of discount rate, insofar as they provide substantive justification for a selected discount rate (Viscusi, 2022).

Rather than select and justify a single discount rate, some authors instead apply a more agnostic approach and present results based on a range of rates, choosing to conduct sensitivity analyses that illustrate the impact of discount rate on the present value of an adaptation investment or study recommendations (e.g., Lincke & Hinkel, 2018; Oddo et al., 2020). Nominally aligning with OMB (1992) best practice recommendations, such analyses can be useful, particularly when the resulting investment decision is insensitive to changes in the discount rate (i.e., if the results are robust to changes in discount rate). Rather than consider a range of discount rates, other authors sidestep the selection of discount rate and investment valuation entirely, by presenting undiscounted future values (e.g., Hallegatte et al., 2013; Neumann et al., 2021) intending for these to serve as the basis of policy and investment recommendations. Still others formulate adaptation planning frameworks that avoid financial analysis and discount rates entirely (e.g., Buchanan, et al., 2016; Rasmussen et al., 2020). While studies that avoid the selection of a discount rate can provide useful information for decision making, they ultimately fall short of valuing adaptation investments, thereby disallowing direct economic comparisons of adaptation projects to other alternative public investments, all of which are ultimately competing for a limited availability of funds.

Another approach is to apply a discount rate equivalent to the cost of borrowing for government institutions, in effect recommending use of the risk-free rate for valuation of projects. For instance, NIBS (2019) recommends discounting adaptation investments using the real yield of a 3-month U.S. Treasury bond. The current US Army Corps of Engineers (USACE) discount rate selection policy takes a similar approach (notwithstanding the archaic peculiarities specific to their discount rate selection formula) specifying that the discount rate for water resources projects shall be informed by the nominal yield of long-term (i.e., >10 years to maturity) U.S. Treasury bonds (Water Resources Development Act, 1974; USACE, 2019; Discount Rate Rule WRC, 2020). Other authors (most notably Arrow & Lind, 1970) provide justification for discounting public sector investments at the risk-free rate, insofar as it is suggested that the (federal) government is capable of diversifying away the contributions towards aggregate (i.e., systematic or market) risk associated with a given investment (Arrow & Lind, 1970; Gollier, 2021).

A separate contingent of authors suggest that adaptation projects represent intergenerational wealth transfers over exceptionally long-lived horizons (similar to climate change mitigation efforts) and hence, advocate for low or negative discount rates (Markanday et al., 2019; Keenan, 2019) despite the presence of substantial near-term benefits associated with the majority of such projects, and the lack of consensus on the expectations of relative wealth inequality between generations or the subsequent implications for intergenerational discounting (Viscusi, 2022). A larger subset of authors consider a social time preference (discount) rate (STPR), applying Ramsey-style discount rate (Ramsey, 1928) that is informed by a time preference (typically inclusive of an allowance for catastrophic systemic risk) and a wealth effect informed by expectations of future consumption growth (HM Treasury, 2020; Vousdoukas et al., 2020; Lee & Ellingwood, 2015; Rennert et al., 2022). A tangential discounting rationale, rooted in implementation of the consumption capital asset pricing model (CCAPM) suggests the discount rate for public sector investments follows a declining term structure (Lowe, 2008; Gollier, 2014; Lee & Ellingwood, 2015), particularly in the valuation of projects with lifespans surpassing a certain threshold (e.g., 30-50 years; Bastidas-Arteaga & Stewart, 2019). As noted by Gollier & Hammitt (2014), this declining term structure is valid for investments whose associated risk premium under the CCAPM is less than a certain value (the relative inequality aversion constant), whereas if its risk premium is greater than this value, then discount rates would instead increase with time, reflecting greater uncertainty in systematic risk.

Methodology: A fair-value approach to discount rate selection

Rather than rely on any given policy or public sector-oriented discounting philosophy at face value, we instead aim to estimate the systematic (i.e., market-correlated) risk and resultant discount rates for flood risk related cash flows and adaptation investment costs, given available data. Taking a market driven approach, we assume the discount rate for any given (public or private sector) investment should reflect its inherent level of systematic risk, as such risk is in practice non-diversifiable, irrespective of the investor (Lucas, 2014a; Gollier, 2021). While this contrasts with the majority of previously outlined discounting practices, such a fair market value (FMV) approach to discount rate selection is consistent with basic principles of corporate finance and best practices in the private sector. Fundamentally, such a valuation approach aims to determine the value of a (public or private) investment on the open market, rather than its taxpayer subsidized value (an issue which is particularly relevant during the negotiations between a public agency and a private consortium prior to the establishment of a Public-Private Partnership, PPP; Lucas & Montesinos, 2020). Such discounting approaches minimize the possibility of "budgetary arbitrage" wherein government investments in risky assets (e.g., high-risk mortgages) only appear profitable if discounted at the cost of government borrowing, and inherent market risk is neglected (Lucas, 2014b). Further, discounting at the cost of borrowing would violate the Modigliani-Miller theorem, a basic principle of modern finance, in effect subsidizing riskier investments at the taxpayers' (i.e., equity-holders') expense (Lucas, 2014b).

As such, from a FMV perspective, market prices are the best available proxy for social value, and the discount rate, or more precisely, the cost of capital (COC), should therefore reflect the expected return an investor would make from a typical asset with similar level of systematic risk and return as the asset (or cash flow) of interest (Geltner & de Neufville, 2018). Rephrased, the discount rate is the minimum acceptable rate of return an investor or management is willing to accept for a given project or cash flow (Martland, 2012). Such discount rates incorporate the effects of both time preference and risk aversion on value.

Here, we determine the appropriate discount rate for adaptation project costs and benefits (i.e., flood-related cash flows) via the Capital Asset Pricing Model (CAPM). We choose to employ the CAPM rather than the consumption-based capital asset pricing model (CCAPM) as in practice, the CCAPM has not well-characterized observed market risk premia (Mankiw & Shapiro, 1984; Gollier & Hammitt, 2014). The CAPM is widely recognized and often employed by institutional investors when assessing expected returns of assets when constructing investment portfolios (Brealey et al., 2011). The CAPM defines the expected return of an asset or cash flow ($E[R_a]$) based on the present risk-free rate (R_f, i.e., the rate of return on a risk-less asset) the expected return of the broader market, $E[R_m]$, and the level (or correlation) of risk relative to the market, the asset beta, β_a, (Brealey et al., 2011):

$$\mathrm{E}|\mathrm{R_a}| = \mathrm{R_f} + \beta_\mathrm{a}(\mathrm{E}|\mathrm{R_m}| - \mathrm{R_f}) \tag{1}$$

Estimates of the level of systematic risk relative to the market (i.e., the risk premium and related asset beta) are typically found by compiling historical data on the unlevered returns of the asset of interest or economic sector relative to the market (e.g., the correlation of stock performance to the overall stock market) or through correlations of comparable assets or industries to the market, when information on the specific asset or cash flow of interest is unavailable or incomplete (e.g., see Damodaran, 2021). Mathematically, the asset beta is defined as the covariance of asset returns (R_a) and market returns (R_m), divided by the variance of the market returns:

$$\beta_a = \frac{cov(R_a, R_m)}{var(R_m)} \tag{2}$$

Market Rate of Return and Risk-Free Rate

Selection of an appropriate expected market rate of return and risk-free rate is an often-overlooked aspect of operationalizing the CAPM yet is central to the determination of expected returns and the appropriate opportunity cost of capital. A recent survey of financial analysts, managers, and professors across 88 countries suggests that the market rate or return, market risk premium, and risk-free rate are highly dependent on geographical market, and can vary widely with a given market (Fernandez et al., 2021). In the U.S., the survey found an average expected market return of 7.3%, reflecting investor sentiment on the expected future returns of the broader U.S. stock market, rather than historical, required, or implied market returns (Fernandez et al., 2021). (For reference, relying on data collected by Shiller (2022), we estimate the S&P500 returned 7.34% over the 50 years prior to October 2022.) Here, we adjust this value for inflation, (which based on the CPI has averaged 2.5% over the past 10 years as of the time of writing; Shiller, 2022) and consider the real expected market return to be 4.8%.

Fernandez et al. (2021) find the average risk-free rate across participants in the US was 1.8%, (i.e., less than the US dollar long-term inflation rate) and was largely informed by nominal short- and medium-term US treasury yields. Alternatively, the yield of a duration-matched US treasury bond can also be employed as an appropriate risk-free rate, consistent with USACE policy (USACE, 2021). Here, we apply a risk-free rate equal to the 5-year average of the real yield of long-term (i.e., >10 years to maturity) U.S. Treasury bonds (U.S. Treasury, 2022), calculated to be 0.43% as of October, 2022.

Risk Premium of Adaptation Costs

Recognizing the different levels of systematic risk associated with climate adaptation investment costs and benefits, we apply separate discount rates to project costs and benefits. In contrast to flood-risk related cash flows (which we explore further in the following subsection), the costs associated with construction of flood protection measures and related infrastructure (e.g., costs of elevating critical infrastructure assets) are correlated with the market (i.e., subject to systematic market risk) and therefore carry an associated risk premium under the CAPM pricing framework. As such, the appropriate discount rate for adaptation costs varies by industry (Lucas & Montesinos, 2020). For example, an adaptation project undertaken by a transit agency could reasonably discount project costs (and other benefits associated with regular operations and maintenance) using the expected rate of return for the transportation sector as determined by equation (1) and the appropriate asset beta. **Table 1** provides unlevered asset betas (Damodaran, 2021) and associated discount rates (using the inflation-adjusted expected market return and real risk-free rate established in the prior subsection) for various U.S. industries likely to undertake climate adaptation investments.

Table 1. Asset betas and CAPM derived (real) discount rates associated with industries likely to undertake climate adaptation or flood risk reduction investments

Industry Name	β_{α}*	r_{real}
Transportation	0.91	4.4%
Air Transport	0.78	3.8%
Utility (General)	0.28	1.6%
Utility (Energy)	0.38	2.1%
Utility (Water)	0.42	2.3%
Telecom. Services	0.63	3.2%
Green & Renewable Energy	0.68	3.4%
Environmental & Waste Services	0.83	4.1%
Insurance (Prop/Cas.)	0.67	3.3%
Reinsurance	0.80	3.9%
Real Estate (Development)	0.72	3.6%
Real Estate (Operations & Services)	0.80	3.9%
Engineering/Construction	1.05	5.0%
Hospitals/Healthcare	0.56	2.9%

*average unlevered asset beta corrected for cash (2016-2021); Damodaran (2021)

Risk Premium of Flood Risk-Related Cash Flows

Despite a lack of empirical evidence in the literature, it is generally accepted that localized catastrophes (e.g., floods) have a negligible influence on the overall economy (Merton, 1976). Related literature focused on catastrophe bond pricing rests on the resulting premise that insured catastrophe events (and resultant cash flows) are uncorrelated with the market (Lee & Yu, 2002; Froot & Posner, 2003; Ma & Ma, 2013; Nowak & Romaniuk, 2013). Attempting to provide an empirical basis for this assumption, we investigate the level of systematic market risk inherent in flood risk-related cash flows, as characterized by the FEMA National Flood Insurance Program (NFIP) redacted claims dataset (FEMA, 2021), which provides detailed record of insured flood damage policy payouts within the United States since the inception of the program. Although NFIP claims do not represent the sum total of flood-related damage costs in the U.S. (given NFIP policies only offer limited coverage and only represent a subset of insured losses; Smith & Katz, 2013), they are nonetheless a robust flood risk-related cash flow with sufficient data available to perform a reliable longitudinal analysis.

The NFIP redacted claims dataset contains over 2,500,000 flood insurance policy claims from the inception of the program in 1970 and is updated regularly (Dombrowski et al., 2020). The dataset is directly available from FEMA, either as raw data or via the OpenFEMA API (FEMA, 2021). Using the OpenFEMA API and a data scraping algorithm (written in JavaScript), we aggregate monthly NFIP claims based on the date of claim (for both structures and contents claims) paid to policyholders. Adjusting monthly claims data for inflation using the U.S. Bureau of Labor and Statistics (BLS) consumer price index (CPI; Shiller, 2022) we determine the real value of monthly claims from 1970 to July 2021 (expressed in USD at 2021 Q2 price levels). Here, we choose to adjust for inflation using the CPI, as this index considers price changes in both contents (i.e., consumer goods) and structure (i.e., shelter) from the perspective of a policyholder (i.e., consumer). Further, this data is readily and publicly available over the time period of interest, thereby increasing the transparency and replicability of the proposed methodology. Alternatively, a construction cost index (e.g., the paywalled Engineering News Record; ENR; construction cost index) could be applied instead, though such an index is best applied to structures damages only.

Here, we investigate the relationship between the monthly change in cumulative NFIP claims and S&P 500 returns (as a proxy for overall market returns) for the period of January 1980 to July 2021, modelling the relationship between these two assets via a Frank copula. Copulas are multivariate joint probability distributions that relate the probability of two marginal distributions given a (typically univariate) measure of dependence between the marginals (Joe, 2014). While there are a variety of potential bivariate Archimedean copulas that could be used to relate the returns of these two assets, we employ a Frank copula as it allows for characterization of negative dependence between marginal distributions (Joe, 2014). Creating the copula first requires the specification of a marginal (probability) distribution for each variable (i.e., asset) of interest. Here, we fit a general form beta distribution to the sample data for each asset (Guthrie, 2020). Next, we characterize the correlation between these two assets using the historical sample data, first via the asset beta (as defined above), and via the Kendall rank correlation (i.e., the relative concordance of data pair rankings between the sets). Next, we use this Kendall rank correlation, τ_{sample}, to directly estimate the dependence parameter, θ, for the Frank copula via the following closed form solution (Joe, 2014; Weber, 2015):

$$\tau_{sample} = 1 + \frac{4}{\theta}\left(D_1(\theta) - 1\right) \tag{3}$$

where $D_1(\theta)$ denotes the 1st order Debye function.

Given this dependence variable, the marginal cumulative distribution functions characterizing monthly changes in cumulative NFIP claims, $F_1(u)$, and S&P 500 returns, $F_2(v)$, we can characterize the observed dependence between the two marginal distributions via a Frank copula (Joe, 2014):

$$C(u,v,\theta) = \frac{-1}{\theta}\ln\left(\frac{1-e^{-\theta}-(1-e^{-\theta u})(1-e^{-\theta v})}{1-e^{-\theta}}\right) \tag{4}$$

$$c(u,v,\theta) = \frac{\theta(1-e^{-\theta})e^{-\theta(u+v)}}{[1-e^{-\theta}-(1-e^{-\theta u})(1-e^{-\theta v})]^2} \tag{5}$$

where $C(u,v,\theta)$ denotes the joint cumulative distribution function (CDF) and $c(u,v,\theta)$ denotes the joint probability distribution function (PDF).

Given this copula, we develop a full range of possible market risk premia (i.e., CAPM beta values using equation 1) via Monte Carlo Simulation (MCS), simulating the sample period (i.e., 1980-2021; t = 41 years) for n=10,000 trials. Some research suggests there is empirical evidence that certain market sectors (i.e., insurance) cannot fully diversify natural disaster risks (inclusive of flood risk), leading to statistically significant increases (or decreases) in post-disaster returns (Wang & Kutan, 2013; Bourdeau-Brien & Kryzanowski, 2017). Considering this possibility of increasing (or decreasing) dependence, we further interrogate the influence of correlation on CAPM beta values, and investigate how the market risk premium varies with increasing correlation to market returns (as measured by Kendall's Tau), by repeating this MCS for a range of Kendall's Tau values (-0.5, 0.5) for n = 1,000 trials.

Results

Compiling NFIP redacted claims across the U.S. on a monthly basis, we see monthly claims over the study period ranged from \$1M to \$1B, with the exception of three notable outliers concurrent with the arrivals of Hurricanes Katrina (August, 2005), Sandy (October, 2012), and

Harvey (August, 2017), as shown in

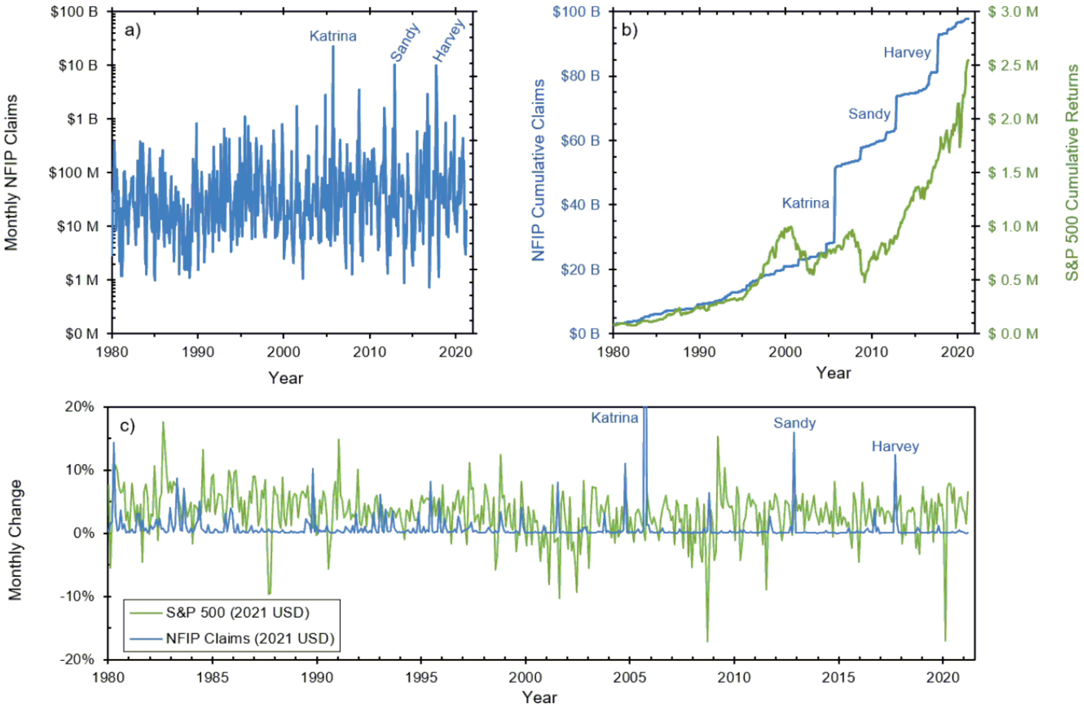


Fig. **1**a. Cumulative NFIP claims and S&P 500 cumulative returns are shown in

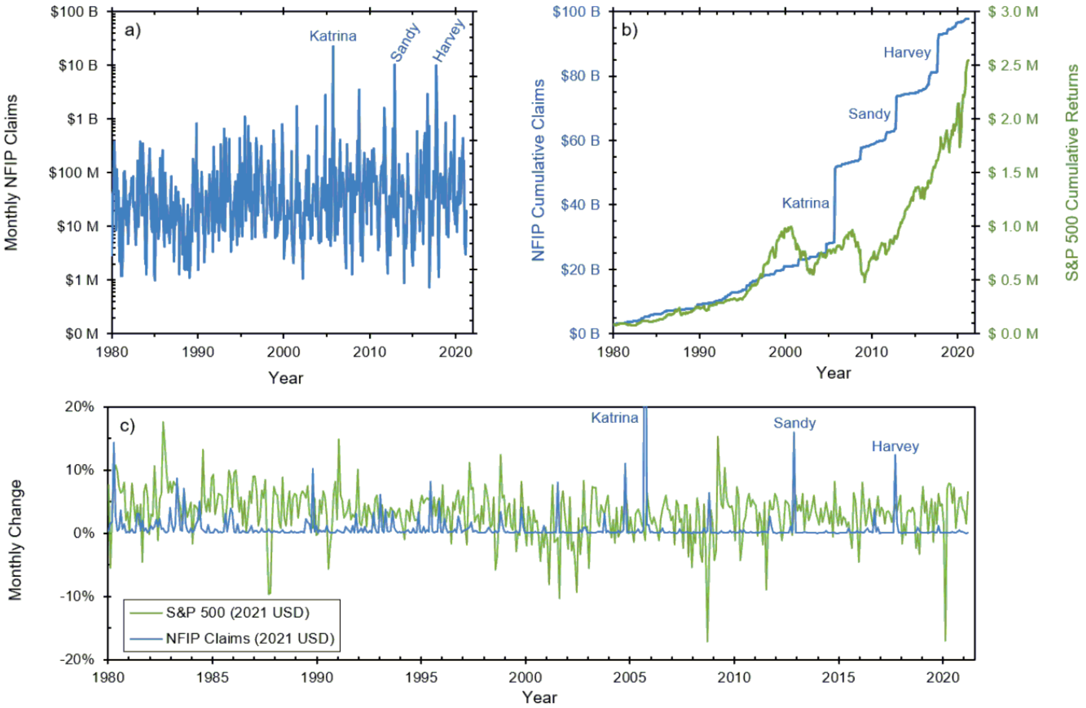
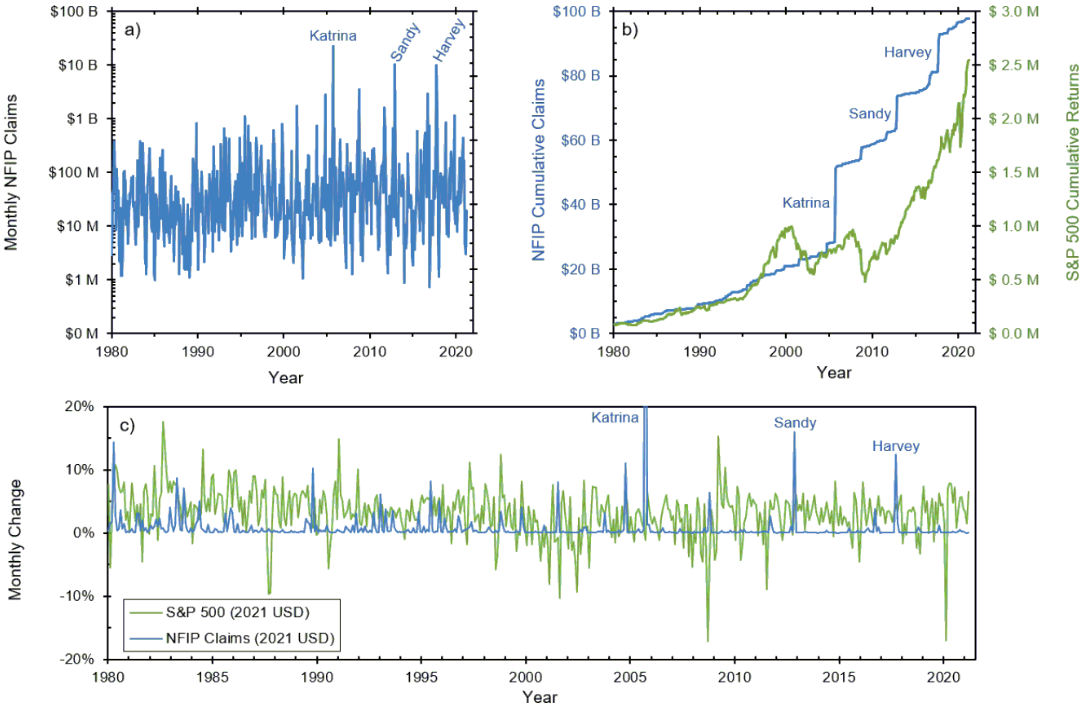


Fig. **1**b, and monthly changes in cumulative NFIP claims and S&P 500 returns are shown in Fig. **1**c, with the arrivals of Hurricanes Katrina, Sandy, and Harvey labeled appropriately. Given this sample data, we estimate a market risk premium, $\beta_{sample} = -0.027$, and a Kendall rank correlation coefficient, $\tau_{sample} = 0.0977$.



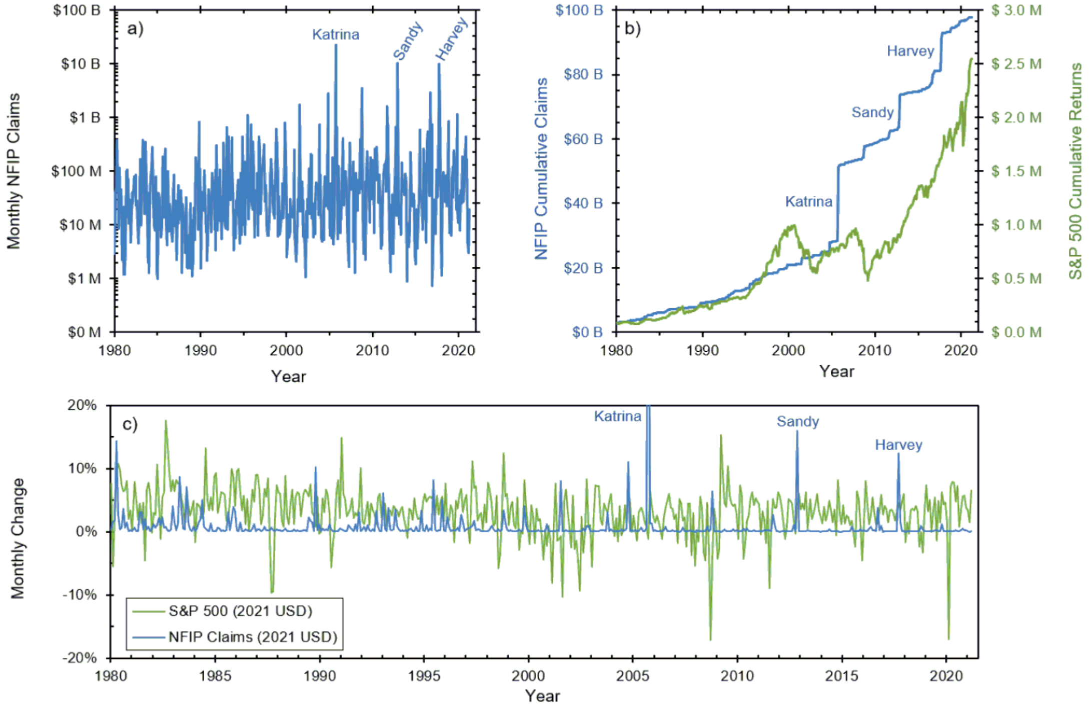


Fig. 1. FEMA National Flood Insurance Program (NFIP) a) monthly claims over time; b) cumulative claims over time and S&P 500 cumulative returns; c) monthly change in cumulative NFIP claims and S&P 500 monthly returns over time. All values shown adjusted to 2021 Q2 price levels. (NFIP data from FEMA, 2021; S&P 500 data from Shiller, 2022).

Relying on equation 3, we estimate a Frank copula dependence parameter, $\theta = 0.93$, indicative of minimal dependence between the two variables. Using this dependence parameter and the fitted marginal (general form beta; β) distributions ($\beta(\alpha, \beta, min, max)$: $\mathrm{d(S\&P\ 500)} = \beta(11.43,\ 8.00,\ -0.17,\ 0.36)$; $d(NFIP) = \beta(0.032,\ 3.12,\ 0,\ 0.77)$,), we construct the Frank copula shown in Fig. 2 to characterize the joint probability distribution of monthly changes in S&P 500 returns and cumulative NFIP claims.

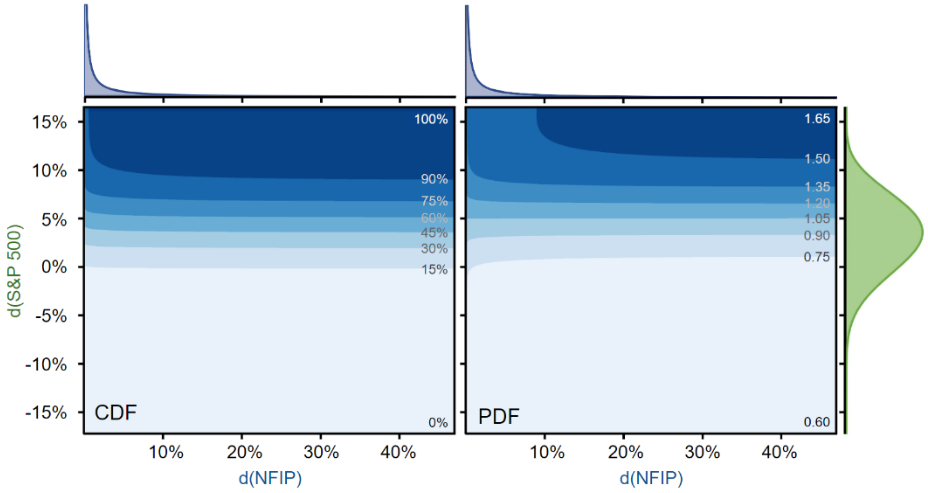


Fig. 2. Joint Cumulative Distribution Function (CDF) and Joint Probability Density Function (PDF) of monthly S&P 500 returns and monthly change in cumulative NFIP claims as characterized by a Frank copula (θ = 0.93).

Given this characterization of joint probability, simulating the 41-year study period (1980-2021) for n=10,000 trials, we develop a wider range of estimates for the Kendall rank correlation coefficient and market risk premium (CAPM beta). As shown in Fig. 3a, given these marginal distributions and copula construction, we estimate a Kendall rank correlation coefficient, $\tau = 0.10 \pm 0.11$.

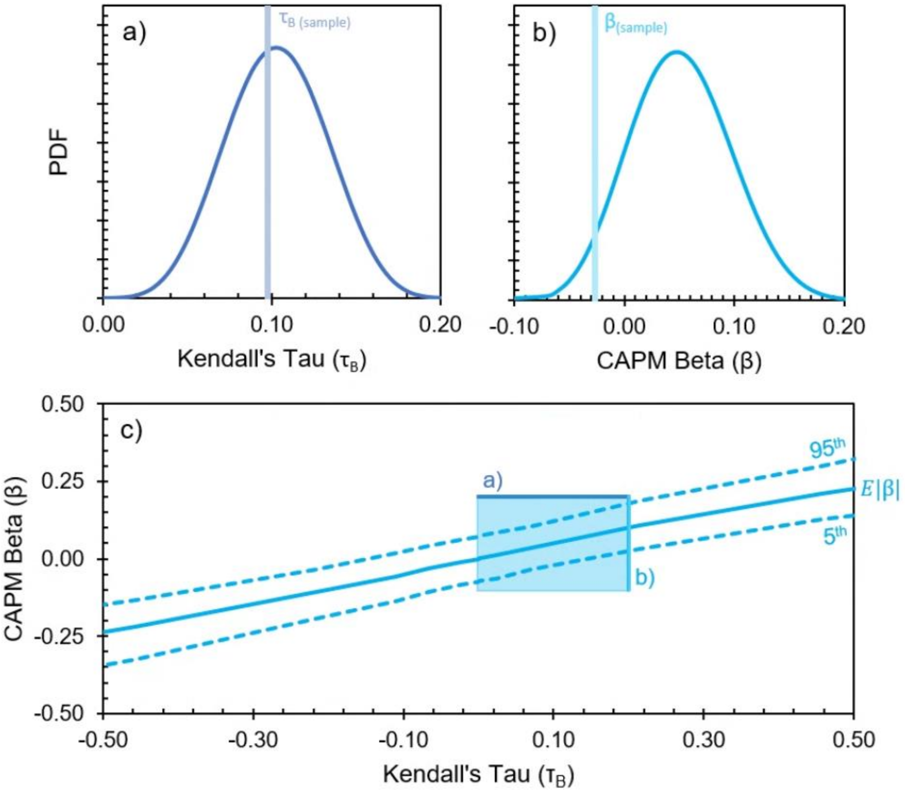


Fig. 3. Estimated a) Kendall's Tau, and b) market risk premium (CAPM Beta) for flood risk-related cash flows, given observed dependence for n= 10,000 trials; c) market risk premium (CAPM Beta) estimates for flood risk-related cash flows at varying levels of correlation to the market, as measured by Kendall's Tau

As a result, we estimate a market risk premium (as defined by the CAPM beta), $\beta = 0.052 \pm 0.20$, indicative of minimal positive (or negative) correlation with broader market performance. Further investigating the potential systematic market risk premium across a wider range of potential dependence levels via MCS (recalibrating the Frank copula for a range of Kendall's rank correlation values), we observe a linear relationship between market risk premia and correlation, as measured by Kendall's rank correlation. We note that given prevailing correlations between global mean sea level (GMSL) and market returns, there is at present little evidence to suggest the market risk premium of flood risk-related cash flows will change over time. Changes in cumulative NFIP claims exhibit little correlation with monthly changes in GMSL over the period for which data is available (1993-2021; NOAA, 2021), $r = -0.02$; $\tau = 0.096$, and monthly changes in GMSL are similarly uncorrelated with monthly S&P500 returns, $r = 0.06$; $\tau = 0.053$.

These results demonstrate the risk associated with NFIP claims, and by proxy flood risk-related cash flows is nearly fully diversifiable under a CAPM pricing framework, and therefore commands a very small market risk premium, $\beta = 0.052$, suggesting an appropriate discount rate of 0.7%, when specified in real terms, given prevailing interest rates at the time of writing. These results largely support the established consensus in the catastrophe bond market (i.e., that catastrophe-related cash flows are uncorrelated with the market), yet the implications for FMV discounting and valuation of climate adaptation projects contrast sharply with prevailing discounting practices presented in the literature, including current U.S. federal policy.

Case Study: Boston Harbor Barrier

To further illustrate this contrast between a FMV approach and prevailing discounting approaches, we investigate the valuation implications for a real-world coastal adaptation case study, a Boston Harbor barrier design proposed by Kirshen et al. (2018). While Kirshen et al. (2018) outline and assess several different potential harbor barrier configurations, construction timelines, and performance assumptions, here we focus on a single example, the 'inner harbor barrier' configuration (Scenario 2B, Kirshen et al., 2018) as shown in Fig. 4a. Under this particular scenario, the proposed inner harbor barrier would be constructed over a 20-year period, reaching completion in 2070 at a present value cost of $10.0B (2021 Q2 USD), after which operations and maintenance costs are expected to be $30M annually. After completion in 2070, the barrier is anticipated to provide flood risk reduction benefits for coastal flood events exceeding an elevation El. +4.3 m (El. +14 ft) NAVD88 (it is assumed shore-based measures will be built up to this elevation by 2070, regardless of whether the barrier is constructed). These benefits are estimated to increase linearly from 2070 to 2100, reaching an expected annualized value of $888M, plateauing thereafter until the end of the analysis period in 2130. Fig. 4c summarizes these undiscounted cash flows.

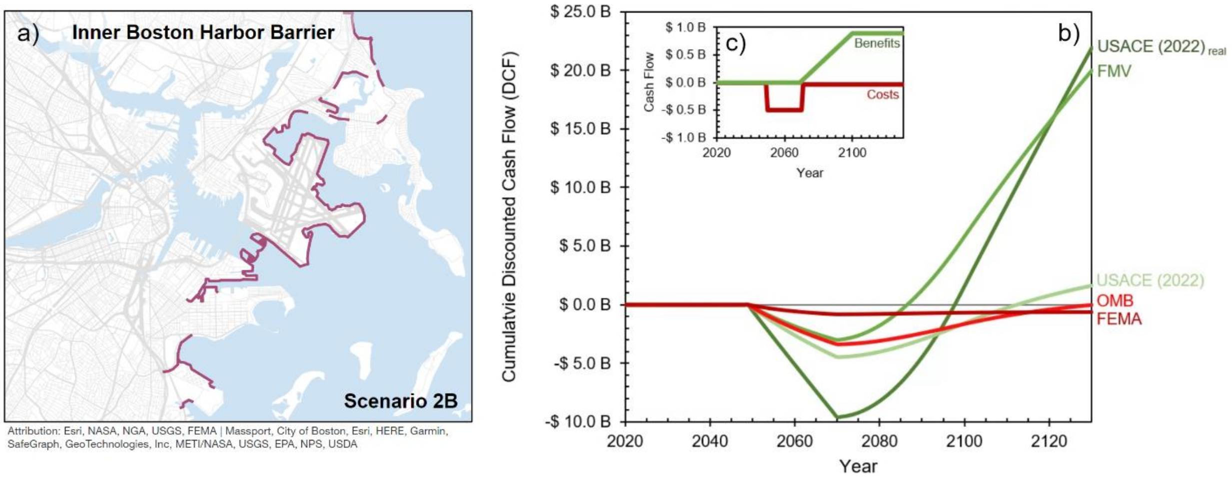


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Fig. 4. a) Inner Boston Harbor barrier configuration (Scenario 2B proposed in Kirshen et al., 2018; Esri, 2023); b) cumulative discounted cash flow (DCF) over time for the Boston Harbor Barrier example, under several discounting approaches; and c) the undiscounted stream of direct adaptation costs and flood protection benefits.

We assess the value of this Boston Harbor barrier configuration under several relevant discounting approaches embedded within U.S. federal policy, contrasting these with a FMV approach and a modified version of current USACE policy, adjusted for inflation. Here, we adjust the nominal discount rate specified by WRDA (1974) by 2% to account for inflation (i.e., to determine the equivalent real discount rate) as to properly discount the future costs and benefits which are specified in real terms. (We note that current USACE valuation guidance nonetheless specifies that real future cash flows be discounted using the nominal cost of borrowing; USACE, 2019.) Under the FMV approach, we discount the benefits of this adaptation project (i.e., flood risk reduction) at the 0.7% rate outlined previously and apply a discount rate of 3.3% to project costs, reflecting the expected market risk associated with property and casualty insurance industry investments. Fig. 4b provides the cumulative discounted cash flow (DCF) over the study period for the harbor barrier under these discounting approaches, and **Table 2** summarizes performance across discounting approaches.

Table 2. Applied discounting approaches and associated financial performance of the Boston Harbor Barrier case study

Discounting Approach	Discount Rate, r	NPV [$B]	BCR
USACE (2021) real	0.25%	21.9	2.99
Fair Market Valuation (FMV)	0.7%, 3.3%	20.0	7.26
USACE (2021)	2.25%	1.6	1.34
OMB (2003)	3.0%	-0.04	0.999
FEMA (2021)	7.0%	-0.63	0.25

We observe significant valuation discrepancies arising from the varied discounting methods, with an inflation-adjusted USACE discounting approach (most consistent with Arrow & Lind, 1970) yielding the highest NPV. The FMV approach yields the next highest NPV, though a higher benefit-cost ratio (BCR) as adaptation investment costs are discounted more heavily, given their higher levels of systematic market risk. Current USACE discounting policy for FY 2022 (USACE, 2021) specifies a 2.25% discount rate (based on the nominal yield of long-term U.S. Treasury bonds) and yields a much smaller, though still positive NPV. By contrast, a 3% discount rate (a STPR presented by OMB, 2003; primarily intended for analysis of proposed regulations) yields a negative NPV, though suggests the investment would be very close to breaking even by the end of the analysis period. Relying on the more general 7% discount rate (intended to reflect the expected market rate of return for private capital; OMB, 1992), which is applicable for FEMA funded projects (DHS, 2021), the project has a negative NPV and BCR = 0.25.

Should the City of Boston choose to advance this particular harbor barrier beyond preliminary analysis, these valuation discrepancies have significant practical implications, as these results suggest FEMA is unlikely to view this adaptation investment as worthy of funding. However, USACE would likely consider the project as a worthwhile investment. Our FMV results suggest that a private sector investor would place even greater value on the adaptation investment opportunity, implying that there may be latent demand for PPP delivery, if an agreement on sufficient payment structure could be reached between the municipality and a private consortium.

Discussion and Conclusion

As demonstrated by the case study, relative to a FMV approach, prevailing federal policy and underlying discounting approaches significantly over-discount and subsequently undervalue future adaptation benefits (i.e., avoided climate-related damage costs). By neglecting the (lack of) systematic risk inherent in flood risk-related cash flows, prevailing discounting approaches consider future flood damages to be less important (or less “painful”) than a FMV approach would otherwise suggest. Consequently, the avoidance of future flood damages is comparatively less valuable. Further, these results suggest the prevailing discounting approaches currently employed by US federal agencies best positioned to finance climate change adaptation projects systematically undervalue flood risk reduction benefits, relative to the private sector.

Such a systematic undervaluation of adaptation benefits is liable to result in a misallocation of capital away from a subset of adaptation projects with a positive fair market value but nominally negative net present value, potentially imposing a “deadweight loss” onto society (Gollier, 2021). The resulting systematic bias towards underinvestment in climate change adaptation projects favors ***reactive*** spending in response to climate-related disasters, rather than ***proactive*** investments aimed at minimizing future climate-related damage costs. This bias towards underinvestment extends beyond the U.S., insofar as prevailing discounting policies in other countries are founded on similar philosophies and approaches that neglect systematic market risk associated with project cash flows. Though unlikely, adoption of a FMV discounting approach at the federal level would empower key federal agencies to properly consider systematic market risk when valuing climate adaptation projects, while simultaneously restructuring broader federal discounting practices to better align with the philosophy underlying prevailing OMB guidance (OMB, 1992).

While relevant portions of federal policy codified in public law are unlikely to change in the near-term, current case law suggests federal agencies have the authority and latitude to diverge from OMB guidance with sufficient justification (Viscusi, 2022), suggesting that there is already enough latitude to implement a FMV discounting approach in certain situations within a U.S. context. Further, nonfederal U.S. public agencies are likely to have even greater latitude in determination of internal discounting policy. Even in instances where non-federal public agencies are required to follow prevailing federal discounting policy to satisfy federal funding requirements, a FMV approach can nonetheless still be employed to develop separate valuations for internal purposes and decision-making processes. Public agencies typically have the latitude formulate their own capital investment criteria (Chen & Bartle, 2022) and therefore have the capacity to adopt a fair market valuation approach when planning, prioritizing, and budgeting for future capital investments. Valuing projects in a manner that adequately reflects the associated systematic risks (or lack thereof) enables public agencies to better estimate the societal value of a project and make more informed capital allocation decisions, thereby more effectively utilizing public funds.

In principle, the application of the proposed FMV discounting approach can be readily extended beyond the context of adaptation investments, provided sufficient data is available to estimate the systematic (i.e., market-correlated) risk of underlying project cash flows (e.g., climate mitigation projects, should stakeholders reach agreement on the ‘climate beta’; Dietz et al., 2018). However, given that the current valuation framework as presented relies on traditional discounted cash flow analysis to arrive at an NPV, the current valuation framework is unable to consider inter-annual variability in systematic risk levels, or embedded project optionality (In et al., 2022). The valuation framework presented could be extended to allow for certainty-equivalent discounting, wherein future cash flows are first discounted to account for systematic risk (or probabilistically adjusted to account for embedded optionality), then subsequently discounted at the risk free rate (Brealey et al., 2011). Such extensions would allow for consideration of adaptation projects with more complex cash flows and temporally dependent market correlations.

Beyond these limitations, we further note that operationalizing the proposed FMV approach is sensitive to changes in both the expected market rate of return and the risk-free rate. Consequently, as broader market conditions change and influence these factors over time, any resulting discount rates will also change, implying sensitivity to the base year of analysis. More generally, the sensitivity of the discount rate to these key input parameters suggests that reliable and timely estimation of the expected market rate of return and risk-free rate is imperative for accurately capturing prevailing market conditions and effectively operationalizing the proposed FMV approach.

Extending beyond the public sector, the proposed FMV approach outlined in this paper is notably directly applicable to private sector investments, and is to the authors' knowledge, the first such approach proposed within the climate change adaptation literature. Ultimately, as Li et al. (2014) note, clear communication and transparency surrounding discounting assumptions in cost-benefit analyses is a key aspect of legitimizing the business case for a climate adaptation project, irrespective of which discount rate(s) are applied for valuation of (public or private) climate change adaptation investments.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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