The pricing of environmental risks with non-pecuniary benefits

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Abstract. Investors may accept financial returns from environmental assets that are lower than those justified by their risk, if additional benefits are present. We show this using a novel consumption-based asset pricing model that allows for risk-free assets and equities along with environmental assets. We assume that the later produce non-pecuniary utility dividends in addition to financial returns. Under realistic parameter assumptions, our model predicts discount rates for the environmental assets that are close those of the risk-free asset although their risk profile resembles that of equities. The results lend support to the much debated practice of adopting low discount rates in the cost-benefit analysis of long-term environmental damages.

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1. Introduction

What is the discount rate we should adopt in determining the present value of future payoffs related to the use or misuse of environmental projects, activities and goods? This single number lies at the heart of heated debates and high-level decision making in policy, business and society. Unfortunately, our standard academic model, the Ramsey approach, is not very helpful as it is consistent with a wide range of discount rates (see Arrow et al., 2013). On the one hand, the adoption of ethical principles, that favours generation fairness, leads to discount rates that are very low, close to the so-called risk-free rates. On the other hand, efficiency considerations, that stress the risk-adjusted opportunity cost of capital, suggest high levels of discount rates. The discount rate lies also at the core of longstanding disputes in environmental economics (e.g., Dasgupta, 2008) as it has critical implications for policy evaluations and recommendations (Weitzman, 2007; Tol, 2009). Characteristically, Portney and Weyant (1999, p. 4) point out that "[t]*hose looking for guidance on the choice of discount rate could find justification* [in the literature] *for a rate at or near zero, as high as 20 percent, and any and all values in between*". But how are discount rates used and what is their actual effect in practice? Since present decisions have difficult-to-reverse impacts, a balance is sought between the costs of action and the damages of inaction. In the tradition of cost-benefit analysis, future payoffs are discounted into present values. However, the relevant time period for assessing costs and benefits may spread over decades or even centuries from now. This places a heavy burden on the choice of the discount rate. For example, as shown by Braat and ten Brink (2008), using a

1% discount rate, the present value of the loss of ecosystem services from forest biomes over the next 50 years is estimated at €3.1 trillion, or, 7% of world GDP in 2000. However, with a 4% discount rate this loss estimate becomes just €1.35 trillion, or, 3% of world GDP in 2000.

We contribute to the academic literature and policy debate by proposing a new framework for determining the appropriate rate for discounting future payoffs related to environmental projects, activities and assets. The approach draws from the financial literature and is based on an extended version of the consumption-based capital asset pricing model (CCAPM; Lucas, 1978). Our model allows for conventional investment opportunities, such as risk-free assets and equities, along with opportunities for investments in environmental assets. All three classes of opportunities have a financial return and investors are motivated by the desire to smooth consumption. However, environmental assets have additional non-use benefits that are non-pecuniary and are priced in the total return of the asset. These "utility dividends" are recognized as a special feature of environmental assets that is increasing in the value of the environment. They capture the additional satisfaction that people experience when the value of environmental goods is high. We make the additional assumption that environmental investments are assets with a high consumption covariance. In other words, they tend to have high returns when consumption is large, that is, when the marginal utility of consumption is high. This assumption is in line with Gollier (2012) who shows that any credible calibration of the standard integrated assessment models implies that the payoffs from environmental protection are large when production and aggregate consumption are large. For example, when economic growth is high, more greenhouse gases are emitted and the benefits of mitigation are large.

We calibrate our consumption-based pricing model to predict appropriate discount rates for environmental assets. The simulation is based on a three-state specification of the consumption growth process: high-growth, low-growth, crash (as in, for example, Rietz, 1988). In this way it can capture the effects of a catastrophic climate outcome with an unlikely but dramatic decline in economic growth (e.g., see Weitzman, 2009; Barro, 2015). In our model the choice of the discount rate for investments comes down to the extent to which their payoffs co-vary with aggregate consumption. A major conclusion drawn from our model, is that it justifies low discount rates for environmental assets to the extent that investors are compensated by non-use benefits. These benefits are drawn from enjoying environmental goods of high value. While the cyclicality of environmental asset returns is by construction similar to those of equity, this premise does not justify equating discount rates for the two asset classes. This is because the typically positive risk premium for the pro-cyclical environmental asset is offset by the utility dividend which endogenously moderates the levels of environmental returns. Technically, the marginal utility of consumption is shifted upwards when the value of the environment is high. Although we are not trying to defend a particular value for the discount rate, our model suggests that the non-use benefits of environmental assets can be a strong factor in lowering discount rates. Indeed, reasonable model calibrations predict a discount rate close to the risk-free rate.

Non-use benefits are recognized as an additional complication for valuing environmental assets (Farber et al., 2002). However, they have not been used explicitly, as in or model, for valuation purposes. Our approach accepts the principle that environmental discount rates should reflect observed financial market returns (e.g., Nordhaus, 2007). However, this does not mean that these rates should be equated to the market returns of risky private assets. Our rationale originates from the observation that individuals derive utility from environmental assets in many other ways than through direct consumption. For example, the tropical forest in the Amazon basin is not only valuable in terms of its potential as timber. It also has aesthetic and intrinsic values that do not involve direct or indirect uses. In particular, Horton et al. (2003)

estimate that non-user households in the UK and Italy are willing to pay annually $46 per hectare for protected areas in the Brazilian Amazon. The possibility that people are willing to pay to conserve an environmental good, even though they may never use it, has been studied extensively since the seminal work of Krutilla (1967). Non-use benefits, in particular, are discussed as a major source of utility of environmental assets (e.g., Braden and Kolstad, 1991). The non-use benefit may arise from the knowledge that the good exists or from the mere existence of the good (Hanley et al., 1997). Moreover, it may originate from some form of altruism or concern for the interest of future generations (McConnell, 1997; for discussion of the different underlying concepts see Davidson, 2013). Suppose we are considering, for example, the value of coastal wetlands. People derive utility from the direct and indirect use of the coastal wetland, such as: fishery, recreation, pollution assimilation and flood control. To the extent that wetlands have non-use benefits, they derive additional satisfaction from just knowing that this ecosystem continues to exist and that other people have or will have access to it. Empirical estimates suggest the non-use benefits can be very important, with fractions of total value reported as high as between 50 and 97 percent (Pearce and Barbier, 2000, p. 59). People get utility and transfer consumption for an environmental good because it has value. Non-use benefits or psychological motives are also discussed in the theory of consumer behavior for other classes of goods such as fine art (e.g. Ng, 1987; Mandel, 2009). Kalman (1968) endorsed the view that the value of such goods affects utility directly. Thus, utility functions are formulized which contain the quantity of consumables and their value. In this vein, we proceed by assuming that the value of environmental goods directly factors into utility. It is essential to put this special feature of environmental goods into the picture.

2. Related work

The controversy about the appropriate discount rate originates primarily from environmental issues related to climate change. Although finance theory can shed light on this problem, it primarily addresses the short-term pricing of assets and risk. Therefore, it remains a challenge to expand the theory to explore consequences over long term horizons (Gollier and Hammitt, 2014). Gollier (2002, 2008) and Weitzman (2007) use standard consumption-based asset pricing theory to conclude that the large uncertainty associated to the distant future should induce the use of lower discount rates for more distant payoffs. Gollier bases his arguments on the precautionary effect, which refers to the willingness of consumers to sacrifice present income in the face of uncertainty about future growth. Weitzman first notes that the discount rate used to evaluate risky environmental projects depends on how their payoffs co-vary with changes in aggregate consumption, a stylized feature of the CCAPM. A final approach involves accommodating risk by converting payoffs into certainty equivalents (e.g. IPCC, 1995). This certainty-equivalent method is indeed theoretically equivalent to the CCAPM method. This latter approach has emerged as the workhorse model of risk-adjusted discounting (Gollier and Hammitt, 2014).

With the notable exception of Hoel and Sterner (2007) and Sandsmark and Vennemo (2007), approaches to date employ one-good models (e.g., Heal, 2009). Hoel and Sterner analyze an economy where one conventional sector grows indefinitely while the environmental services sector is constant or even declining due to climate change damages. The scarcity in the environmental sector leads to rising relative prices for the environmental good which has direct effects on the discount rate itself. The model shows that the discount factor including the price effect is always lower than the conventional discount rate. Sandsmark and Vennemo treat environmental investments as a specific asset class with payoffs that are negatively correlated with income, which implies a negative beta (see also Howarth, 2003; Murphy and Topel, 2013). In this manner, environmental investments provide self-insurance returns in unfavorable states of the economy which justifies low discount rates.

However, the consumption covariance of environmental assets is subject to disagreement in the literature. Lind (1982) in his influential work states that unless there is substantial evidence to the contrary, the returns of environmental projects should be assumed to be highly positively correlated with returns to the economy as a whole (see also Bailey and Jensen, 1972; Nordhaus, 1994). More importantly, in the context of climate change, the standard integrated assessment frameworks, as in Nordhaus (1994, 2011), tell exactly the opposite story of Sandsmark and Vennemo. In particular, Nordhaus (2011) uses Monte-Carlo simulation of his canonical model to obtain a positive beta and conclude: "*Those states in which the global temperature increase is particularly high are also ones in which we are on average richer in the future*." In a similar vein, Gollier (2012) suggests that the relative uncertainty affecting long-term economic growth is much larger than the uncertainty affecting climate sensitivity. This would yield a positive beta along with a high discount rate. Gollier indeed shows that any credible calibration of the integrated assessment models implies that the benefits from investments in environmental protection are large when production and aggregate consumption are large. In case we assume that the only source of uncertainty is about economic growth, any project whose benefits are to reduce emissions has a constant beta equaling unity. Empirical work on the consumption covariance of environmental investments is hampered, inter alia, by the difficulty of finding comparable assets traded on markets with very long horizons. Giglio et al. (2015) use real estate data over a horizon of hundreds of years to document that this important long-term investment class is indeed risky. It has returns that are positively correlated with consumption growth and it performs badly during consumption disasters and crises. They also find that the term structure is downward-sloping, leading to a long-run discount rate of 2.6%. Arguments in favor of using a decreasing term structure of discount rates are, inter alia, also provided in Weitzman (1998, 2001).

In our paper we obtain results similar to Sandsmark and Vennemo (2007). This is possible despite making the assumptions that the benefits of enhanced environmental quality are high in good states of the economy. Our rationale is that the value of environmental quality is an inherent aspect of human welfare. As in the prescriptive strand of the literature (Cline, 1991; Howarth and Norgaard, 1993; Stern, 2007), our model predicts low discount rates. However, a key difference is that we do not resort to making ethical assumptions which have been strongly criticized due to inconsistencies with the revealed time and risk preferences of individuals (e.g., Dasgupta, 2007; Nordhaus, 2007; Weitzman, 2007). In this respect, the practical importance of a distinction between two discount rates to separate normative evaluation and positive description, as proposed in Goulder and Williams (2012) and Kaplow et al. (2010), remains to be worked out.

3. Model and Calibration

3.1. Consumption asset pricing model

Consider the popular Lucas (1978) fruit-tree economy with a single representative agent and a single homogenous consumption good c_t produced by one productive unit or "tree". The evolution of the production level y_t and, thus, the consumption level c_t through time t is described by

$$y_{t+1} = g_{t+1}y_t = c_{t+1}, \tag{1}$$

where g_t is the growth rate which follows an Markov process as in Mehra and Prescott (1985)

$$Prob\left(g_{t+1} = \lambda_j | g_t = \lambda_i\right) = \phi_{ij}. \tag{2}$$

Each period, the agent in the economy chooses how much to consume and how much to invest. Investments are motivated by the desire to smooth consumption both over time and across states at a point in time. There are three different investment possibilities: a risk-free asset, a risky equity asset and a risky environmental assets, all of which are abstractions of reality.

The risk-free asset f guarantees that the current consumption will also be paid in the next period. Equity s is modelled as a claim on the stochastic process $\{y_t\}$, i.e., the produced output in period t is the period dividend in endowment economy. The representative agent can also invest in the environmental asset e in the same manner as in other assets.

We proceed by assuming that the supply of environmental assets is fixed and that the agent is endowed with one unit of the environmental asset. As Krutilla (1967) notes: "*...while the supply of fabricated goods and commercial services may be capable of continuous expansion from a given resource base by reason of scientific discovery and mastery of technique, the supply of natural phenomena is virtually inelastic..*". Unlike equity, the environmental asset offers no claim on the endowment process of the consumption good. Consequently, demand factors fully determine equilibrium environmental returns.

Due to the existence of non-use benefits, we propose that the the value of environmental goods directly enters the preferences of the agent. Utility is modeled as increasing and concave in the value of the environmental asset. Specifically, preferences of agents are specified by a utility function of the constant relative risk aversion class

$$U(c_t, e_t p_t^e) = \frac{c_t^{1-\propto}}{1-\propto} + \frac{(e_t p_t^e)^{1-\propto}}{1-\propto}, \tag{3}$$

where $e_t p_t^e$ is the value of the environmental asset and $\propto$ is the coefficient of relative risk aversion. For simplicity, we specify environmental assets as entering into utility in an additively separate manner, i.e., environmental goods leave the consumption quantities of other goods unaffected.

The agent maximizes the expected discounted value of her stream of utilities

$$E_0\left(\sum_{t=0}^{\infty} \beta^t U(c_t, e_t p_t^e)\right), \tag{4}$$

subject to her budget constraint

$$c_t + f_t p_t^f + s_t p_t^s + e_t p_t^e \leq f_{t-1} + s_{t-1}(p_t^s + y_t) + e_{t-1} p_t^e, \tag{5}$$

where β is the subjective time discount factor, which describes how impatient the agent is to consume; f_t, s_t and e_t are the risk-free, equity and environmental asset holdings in period t, respectively; and, $p_t^i (i \in \{f, s, e\})$ are the corresponding asset prices in period t.

The first-order conditions for this problem are

$$Risk - free: \quad p_t^f U'(c_t, e_t p_t^e) = \beta E_t[U'(c_{t+1}, e_{t+1} p_{t+1}^e)], \tag{6}$$

$$Equity: \quad p_t^s U'(c_t, e_t p_t^e) = \beta E_t[U'(c_{t+1}, e_{t+1} p_{t+1}^e)(y_{t+1} + p_{t+1}^s)], \tag{7}$$

$$Environment: \quad p_t^e U'(c_t, e_t p_t^e) = \beta E_t\left[{e_{t+1}}^{-\propto} {p_{t+1}^e}^{1-\propto} + U'(c_{t+1}, e_{t+1} p_{t+1}^e) p_{t+1}^e\right]. \tag{8}$$

Equations (6) and (7) are the standard results from the theory of intertemporal choice. Risk-free assets and equity are priced such that the loss in marginal utility incurred by sacrificing current consumption and buying the asset is equal to the expected gain in marginal utility that is conditional on the expected increase in consumption when the asset pays off in the future. Equation (8), in contrast, is original to the present analysis of environmental investments. It illustrates that the representative agent in the case of the environment faces a trade-off between contemporaneous marginal utility of consumption and two different sources of incremental utility next period: (i) the expected future value of environmental asset holdings, and, (ii) the expected increase in consumption from the capital gain in the future (as in the case of pure financial investments). Thus, two motivations determine the price of environmental assets: the expected "utility dividends" and the expected capital gains.

Considering a frictionless economy, market clearing implies $\{c_t = y_t;\ f_t = 0;\ s_t = 1;\ e_t = 1\}\ \forall\ t$. Given that y_t and g_t are sufficient for forecasting y_{t+1} and g_{t+1}, we can redefine the state as the pair (c, i), if $y_t = c$ and $g_t = \lambda_i$. Making the assumption that both equity and environmental prices are homogeneous of degree one in c (i.e., $p^s(c, i) = \varphi_i c; p^e(c, i) = \omega_i c$) and using (1), we can rewrite (7) and (8) as

$$\varphi_i = \beta \sum_{j=1}^n \phi_{ij} {\lambda_j}^{1-\propto}\left(1 + \varphi_j\right), \tag{9}$$

$$\omega_i = \beta \sum_{j=1}^n \phi_{ij} {\lambda_j}^{1-\propto} \omega_j\left(1 + {\omega_j}^{-\propto}\right), \tag{10}$$

where φ_i and ω_i are undetermined coefficients. Note that this homogeneity assumption and the particular form of utility impose a strong positive correlation between equity and environmental assets. A utility function setting in which environmental assets have a different risk aversion parameter than the consumption good may yield lower correlation of asset prices. Although appealing, the investigation of this task is beyond the scope of this paper.

The equilibrium asset pricing equations that guarantee market clearing in the financial and goods market are given by (6), (9) and (10). Next, we take these necessary conditions to predict the rate of return for each asset for reasonable preference ($\propto$ and β) and technology parameters (ϕ_{ij} and λ_i), respectively.

If the current state is (c, i) and the next state is $(\lambda_j c, j)$, the equity return and environmental return become

$$r_{ij}^s = \frac{\lambda_j(\varphi_j + 1)}{\varphi_i} - 1, \tag{11}$$

$$r_{ij}^e = \frac{\lambda_j(\omega_j + 1)}{\omega_i} - 1. \tag{12}$$

Consequently, when the current state is (c, i), the expected returns to equity and environment are, respectively

$$R_i^s = \sum_{j=1}^{n} \phi_{ij} \, r_{ij}^s, \tag{13}$$

$$R_i^e = \sum_{j=1}^{n} \phi_{ij} \, r_{ij}^e. \tag{14}$$

Analogously, the return on the risk-free asset can be written as

$$R_i^f = \frac{1}{p^f(c,i)} - 1. \tag{15}$$

3.2. Calibration

We now turn to predicting appropriate environmental returns, or, in other words, discount rates that should be applied to the expected payoffs of environmental policies. To this end, we numerically calibrate our model based on a set of stylized facts and realistic assumptions that reflect long-term trends in financial markets.

As in Rietz (1988), we assume that consumption growth follows a three-state Markov chain (i.e., $g_t \in \{\lambda_1, \lambda_2, \lambda_3\}$) constructed in such a way that the moments of the growth rate of per capita consumption match the sample values for the United States economy. We build on this framework because it provides an elegant solution to model an empirically plausible equity risk premium and risk-free rate in combination with reasonable degrees of time preference and risk aversion. Moreover, it rests on the incorporation of a low-probability crash state which may capture the effects of a catastrophic climate outcome with an unlikely but dramatic decline in economic growth (e.g., Weitzman, 2009).

The three-state specification incorporates (i) a high-growth state λ_1, (ii) a low-growth state λ_2, and, (iii) a crash state λ_3

$$\begin{aligned} \lambda_1 &= 1 + \mu + \delta, \\ \lambda_2 &= 1 + \mu - \delta, \\ \lambda_3 &= \psi(1 + \mu), \end{aligned} \tag{16}$$

where ψ is a fraction or combination of the other parameters such that $\lambda_3 < \lambda_2 < \lambda_1$. The corresponding transition probability matrix is

$$\phi = \begin{bmatrix} \phi & 1 - \phi - \eta & \eta \\ 1 - \phi - \eta & \phi & \eta \\ 1/2 & 1/2 & 0 \end{bmatrix} \tag{17}$$

Note the symmetry of the high and low states (first rows) as well as the nature of the crash state (third row). A crash follows only the high or low states and never occurs twice in a row. States 1 and 2 follow a crash with equal probability. While the probability of a crash η is low, its negative impact on consumption is dramatic, which is reflected by a low value for λ_3.

Making assumptions about the two crash state variables, probability η and strength ψ, we determine the parameters of the consumption growth process (μ, δ, ϕ). This is done following Mehra and Prescott (1985) by equating its mean, standard deviation and first-order autocorrelation with sample values for United States data between 1889-1978 (0.018, 0.036 and -0.14, respectively).

We present our return simulations for crash scenarios with an unlikely, but severe market crash. More specifically, we set the crash strength variable to $\psi = 0.5$, which implies that output falls to one-half of its normal expected value during a crash. In other words, output falls about as much in one crash year as it did in the first three years of the Great Depression (Rietz, 1988, p. 125). The probability of entering this crash state is constrained to $\eta \in [0.0001, 0.004]$.

To ensure plausible environmental return predictions, we calibrate the model to observable financial data. More specifically, we look for reasonable preference parameter configurations ($\propto$ and β) that yield results conforming to stylized facts in actual financial markets, that is, an equity risk premium between 5 percent and 7 percent and a risk-free return under 3 percent. Based on the parameters that match the empirical facts, we then use equations (9) to (15) to solve for the unconditional expected returns of risk-free assets, equity and environmental assets, respectively.

4. Results

Table 1 presents the resulting asset returns for different parameter configurations. In row I, we start with a simulation of the model that yields a return on equity and a risk-free return very close to the values obtained from the 120 years long sample studied by Mehra (2012). That is, an annual return on a relatively riskless security of 1.1% and a return on equity of 7.5%, yielding an equity risk premium of 6.4%. Given a 1-in-1,000 chance of a crash (η = 0.001), we find that a risk aversion parameter of 6.75 and a time preference parameter of 0.99 can lead to reasonable values of 1.08% and 6.38% for the risk free rate and equity premium, respectively. More importantly, this empirically plausible scenario generates an expected environmental return of 1.99%.

[Table 1 about here]

Environmental returns are much closer to the risk-free rates than the equity returns which is particularly interesting. This is because the simulated standard deviations suggest that the risk of environmental assets is comparable to that of equities. Moreover, the simulated covariance implies that environment assets and equity are highly correlated, i.e., environmental assets have a beta of one. Given that the variance and cyclicality, environmental returns should be similar to those of equity. However, the positive risk premium for environmental assets is offset by the utility dividend which endogenously moderates the levels of environmental returns. The agent is willing to accept the low financial return from environmental investments given that she benefits from an augmenting utility when the value of environmental goods is high. Technically, the marginal utility of consumption is shifted upwards when the environmental value is high.

[Figure 1 about here]

To illustrate the dependency of environmental returns on the state of the economy, Figure 1 depicts the simulated returns in connection with the three states of endowment growth (upper blue line). While the risk-free rate is clearly countercyclical, equity and environmental returns exhibit strong and pro-cyclical co-movements. The rate of return difference between the latter reflects the non-pecuniary benefit associated with holding environmental assets. Only when consumption growth crashes, in period 9, equity and environmental returns are very similar, even though the ordering of returns remains unchanged. Putting it all together, we suggest that it is not the crash state per se that generates the relatively low environmental returns. To examine the impact of the technology (η) and preference ($\propto$ and β) parameters, we subsequently investigate alternative simulations of the model (row II-VII). For the sake of brevity, we only present results that are consistent with an equity risk premium between 5% and 7%, and, a risk-free return under 3%.

As a first comparative analysis, row II and III of Table 1 present model simulations under alternate assumptions about the time discount factor β, which is a subject of disagreement in the literature. Although there are many subtleties, advocates of the descriptive approach favor a β less than one, i.e., a positive pure rate of time preference. This is based on the belief that agents faced with a constant consumption stream prefer early consumption compared to later consumption (e.g. Nordhaus, 1994). In contrast, proponents of the prescriptive approach advocate a pure rate of time preference closer to zero. This ensures the ethical principle of treating all generations equally (e.g., see Cline, 1991; Stern, 2007). In the light of this disagreement, we also simulate asset returns for the cases of $\beta = 0.999$ (row II) and $\beta = 0.98$ (row III). Again, reasonable risk-free returns and equity premiums arise with fairly stable environmental returns of about 2%. This finding can be attributed to the fact that the price enters directly in the utility of agents. The low theoretical returns to environmental assets in our model do not rely on a particular time preference parameter value.

Row IV and V of Table 1 show the simulated asset returns under alternate assumptions about risk aversion. Row IV (V) illustrates the effect of higher (lower) risk aversion in the model. As expected, both equity and risk-free returns decrease (increase) because the agent is less (more) willing to shift consumption over time. In contrast, returns to environmental assets are increasing in the coefficient of relative risk aversion. This is because the utility dividend of environmental assets decreases for higher risk aversion, which slightly increases the environmental returns to 2%. Yet, it is not possible in the model to simulate environmental return levels significantly above 2% by increasing the level of risk aversion while maintaining a reasonable risk premium and risk-free return. This is not problematic as most economists would argue that a high degree of risk aversion is inconsistent with micro-econometric data and introspection. In fact, there is some rough agreement that degrees of risk aversion above five imply implausible individual behavior (Kocherlakota, 1996).

In the light of the above, in row VI and VII we show that an alternative way of generating a reasonable risk-free rate/equity premium with a lower risk-aversion parameter is to increase the probability of a crash. The predictions highlight that the risk aversion parameter needed to explain observed market rates decreases as the crash probability increases. For example, with a 4-in-1000 chance of a crash (row VII), a risk-aversion parameter as low as 4.66 can lead to risk-free returns and equity returns near the sample value of the economy. As previously, the simulated environmental return in this specification of the model is about 2%. The stability of environmental returns is further corroborated by the results presented in row VI.

Finally, in Figure 2 we plot environmental returns as a function of the crash probability η for various degrees of risk aversion $\propto$. In contrast to the simulations in Table 1, we now also consider parameter configurations that are not consistent with observed market rates (i.e., do not solve the equity premium puzzle). The figure highlights that the low theoretical environmental return, ranging between 1.9 percent and, 2.2 percent, is a robust finding even under implausible parameterizations. More specifically, it shows that environmental returns are increasing in the probability of a crash and the increase is most pronounced for higher degrees of risk aversion. The economic intuition is straightforward: if agents are very averse to large falls in consumption, even if such crashes are highly unlikely, they demand a higher return to compensate for the extreme losses they may incur during a severe crash.

[Figure 2 about here]

5. Conclusions

This paper puts the concept of non-pecuniary benefits into a simple model of environmental assets as investment vehicles. We show that financial returns expected from environmental investments are low since they are only one element of compensation. Total returns reflect not only the desire to smooth consumption over time, as for any investment vehicle, but also the utility derived from its non-use benefits. The latter endogenously moderate the level of environmental returns. While the cyclicality of environmental returns is by construction similar to those of risky private assets, environmental investors require less compensation in financial terms for their risk exposure. This finding has substantial implications for the normative debate about the appropriate discount rate in environmental cost-benefit analysis. Even if one takes the position that the social discount rate should reflect actual returns in financial markets, this premise does not justify equating the discount rate for environmental projects with the market returns to risky private assets. Indeed, empirically plausible model calibrations rather predict a discount rate close to the risk-free rate.

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Figure 1: Simulated endowment growth process and asset returns

The figure shows 20 of 1,000,000 simulated periods, which are selected to illustrate a crash state (period 9). The average asset returns of the model can be found in Table 1, row I. Endowment growth (blue line = 1+growth rate) follows a three-state Markov chain with a 1-in-1000 chance of entering a crash state in which output falls to one-half of its normal expected value.

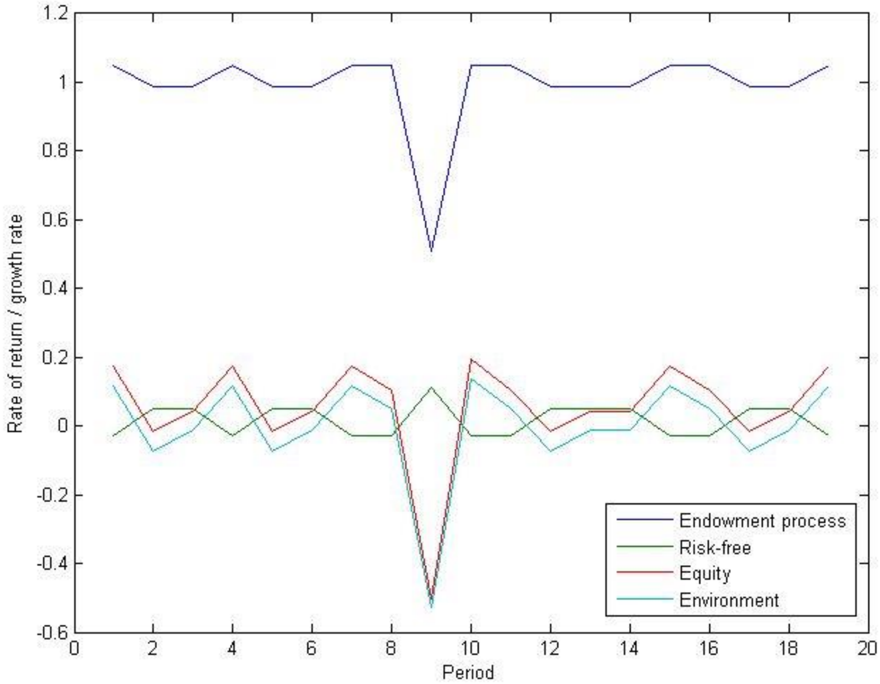

Figure 2: Simulated environmental returns vs. crash probability

The figure shows environmental returns as a function of the probability of entering a crash state for various degrees of risk aversion ∝. The graphs set β=0.99.

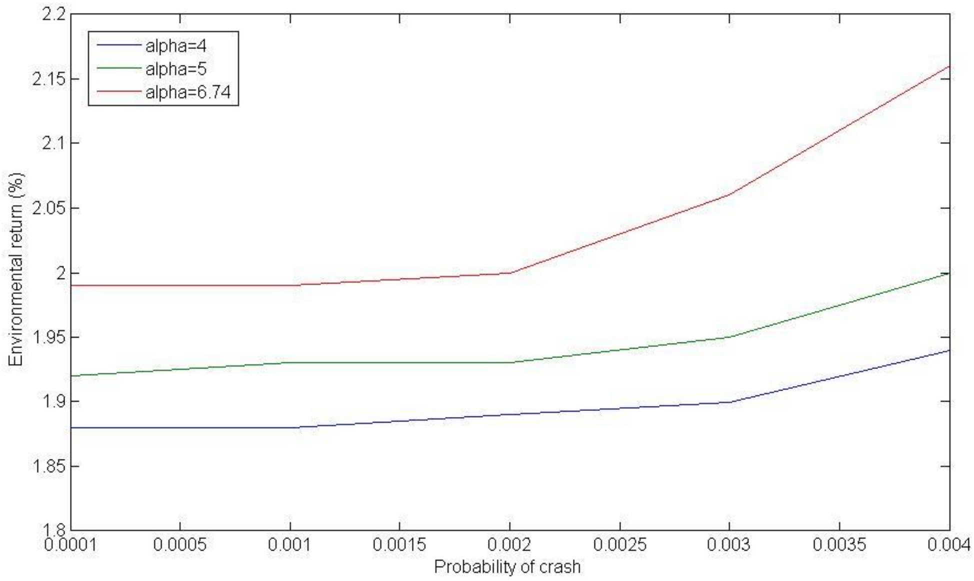

Table 1: Predicted returns for environment, equity and risk-free assets

The model is calibrated for different parameter configurations [crash probabilities (η), risk aversion (α) and time preference (β)] that yield an equity risk premium between 5 percent and 7 percent and a risk-free return under 3 percent. During a crash state output falls to one-half of its normal expected value. The standard deviation of asset returns is given below the expected returns in italics (based on 1,000,000 model simulations).

	Crash probability (η)	Risk aversion (α)	Time preference (β)	Risk-free (% p.a.)	Equity (% p.a.)	Equity premium (% p.a.)	Environ-ment (% p.a.)	Covariance (environment, equity)
(I)	0.001	6.74	0.99	1.08	7.46	6.38	1.99	0.0053
				3.38	*7.30*		*7.20*	
(II)	0.001	6.74	0.999	0.16	6.50	6.32	1.99	0.0052
				3.35	*7.26*		*7.18*	
(III)	0.001	6.74	0.98	2.11	8.55	6.43	2.00	0.0053
				3.41	*7.37*		*7.25*	
(IV)	0.001	6.90	0.99	0.16	7.13	6.96	2.00	0.0054
				3.39	*7.37*		*7.28*	
(V)	0.001	6.33	0.99	2.98	8.07	5.08	1.98	0.0049
				3.31	*7.09*		*6.96*	
(VI)	0.002	5.46	0.99	1.95	6.98	5.02	1.96	0.0044
				3.25	*6.70*		*6.60*	
(VII)	0.004	4.66	0.99	0.92	5.94	5.02	1.97	0.0049
				4.62	*6.96*		*6.98*	