Discounting the Long-Distant Future: A Simple Explanation for the Weitzman-Gollier-Puzzle

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Abstract

In this paper, we reconsider the debate on Weitzman's (1998) suggestion to discount the long-run future at the lowest possible rate, referring to Gollier (2004) and Hepburn & Groom (2007). We show that, while Weitzman's use of the present value approach may indeed seem questionable, its outcome, i.e. a discount rate that is declining over time, is nevertheless reasonable, since it can be justified by assuming a plausible degree of risk aversion.

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Keywords: discount rates, uncertainty, risk aversion.

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1 Introduction

In a famous paper Weitzman (1998) has suggested that the lowest possible discount rate should be used for the long–distant future if discount rates are risky and the social planner is risk neutral. Gollier (2004) has challenged this view recommending instead the highest possible discount rate. At first sight, both positions are equally appealing and conform to two familiar approaches to intertemporal evaluation, i.e. to the present value (PV) approach (Weitzman) and to the future value (FV) approach (Gollier). But applying both approaches to cost–benefit–analysis yields results that are radically different. In particular, the time path of discount rates is declining when the PV method is used but increasing with the FV method. So there is a puzzle or even a paradox which has to be solved. Gollier (2004) himself has attributed the divergence between PV and FV to differences in intertemporal risk sharing whereas Hepburn & Groom (2007) have provided an explanation that refers to differences in the evaluation date. Here we first show that both attempts to explain the puzzle can be combined and traced back to the same cause: If productivity is risky the outcome of intertemporal evaluation crucially hinges on the point in time for which a safe payment is assumed and, while so, serves as the point of reference. Our argument, however, should not only give some better understanding of the Weitzman–Gollier puzzle but should also be helpful for a general assessment of Weitzman's and Gollier's approaches. It will be our conclusion that – from a conceptual perspective – Gollier is more right than Weitzman because the PV method is not sensible in the case of risk. But invoking the additional assumption that the social planner is sufficiently risk averse, it becomes possible to derive Weitzman's pattern of declining certainty–equivalent interest rates by making use of the more reasonable FV method. In this way, both approaches can be reconciled, and a new justification for Weitzman's discounting device is found.

2 Comparing the FV and PV approach in case of Gollier Projects

Let us consider a two period model and a "Gollier project": Any Euro that is invested in period $t = 1$ gives, with the same probability $\pi = 0.5$, either a return $R_b = 0$ (in the 'bad' case) or $R_g = M - 1$ (in the 'good' case) in period 2 where $M \geq 1$. So the marginal rates of transformation ("productivities") between consumption in period 1 and period 2 are 1 (or, synonymously, for generation 1 and generation 2) or M, respectively. Each Euro invested in period 1 then gives

$$M_F = \frac{1}{2}(1 + M) \tag{1}$$

as the expected value of payoffs in period 2. A risk neutral planner then prefers a sure project with the safe rate of return R_S to the given risky project if and only if $R_S > R_F$ with $R_F = M_F - 1$. This corresponds to Gollier's FV approach.

Alternatively, one could ask which investment in period 1 would yield an expected return of 1 in period 2. With probability 0.5 (in the 'bad' case), this investment has to be 1 Euro, with the same probability (in the 'good' case) it only has to be $\frac{1}{M}$ Euro. Hence, on average, an investment of $\frac{1}{2}\left(1+\frac{1}{M}\right)$ is required. Then the corresponding marginal rate of transformation between period 1 and period 2 becomes

$$M_P = \frac{1}{\frac{1}{2}(1+\frac{1}{M})} = \frac{2M}{1+M} \tag{2}$$

which reflects Weitzman's PV approach.

For all $M > 1$ we have $M_F > M_P$.[1] Thus M_F and M_P do not coincide and have different implications for intertemporal evaluation. With the PV method it is more likely that a sure project is deemed as superior to the given risky Gollier project than with the FV method. Both M_F and M_P are increasing in M but $\lim\limits_{M\to\infty} M_F = \infty$ and $\lim\limits_{M\to\infty} M_P = 2$. So M_F is growing much stronger in M than M_P and, with M going to infinity, the difference between M_F and M_P becomes infinitely large.

The divergence between the FV and the PV method can be explained in the following way: Assume again that 1 Euro is invested in a Gollier project. Now according to Weitzman's PV approach we determine the investment which makes sure that the payoff $M_F = \frac{1}{2}(1+M)$ is realized in any case for generation 2. To this end, a sum of $\frac{1}{2}(1+M)$ must be invested in the bad case with zero return by generation 1. This 'bad case investment' on its own already contributes $\frac{1}{2} \cdot \frac{1}{2}(1+M) = \frac{1}{4}(1+M)$ to the average value of the overall investment. We have $\frac{1}{4}(1+M) > 1$ if $M > 3$. Then the expected value of the whole investment in period 1, which is $\frac{1}{2}\left(\frac{1}{2}(1+M) + \frac{1}{2}\frac{1+M}{M}\right)$, clearly exceeds 1 Euro, too. The intuition of this explanation is that a large M drives the expected future value of the Gollier project so high that more than the original 1 Euro is on average needed in period 1 to provide sufficient hedging for generation 2.

Let us now consider the standard situation in which productivity grows exponentially with some constant rate $r > 0$ as a special case. Then we have $M(t) = e^{rt}$ where t is a continuous time parameter and $M(t)$ is the discount *factor* at time t. The divergence between the implied expected values $M_F(t)$ and $M_P(t)$ has much effect on the development of the two *certainty–equivalent discount rates* $r_F(t)$ and $r_P(t)$, that are defined by

$$e^{r_F(t)t} = M_F(t) = \frac{1}{2}(1+e^{rt}) \tag{3}$$

and

$$e^{-r_P(t)t} = \frac{1}{M_P(t)} = \frac{1}{2}(1+e^{-r_P(t)}). \tag{4}$$

A short calculation shows that $r_F(t)$ is increasing and $r_P(t)$ is decreasing in t. This result also holds in a far more general setting and clearly reflects the divergent patterns of $M_F(t)$ and $M_P(t)$.

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[1] This follows from

$$(1-M)^2 > 0 \Rightarrow (1+M)^2 = 1 + 2M + M^2 > 4M \Rightarrow M_F = \frac{1+M}{2} > \frac{2M}{1+M} = M_P$$

For a more general treatment see Appendix A1.

3 Interpreting Gollier's and Hepburn & Groom's explanations

Gollier's own attempt at solving the puzzle refers to the different allocation of risk that is implied by each the FV and the PV method. With FV it is the future period that bears all the risk whereas with PV the risk completely falls upon the present period. From this perspective, both cases look completely symmetric, which, however, is not in accordance with the conditions that apply in reality. As in our explanation, Gollier (2004, p. 88) supposes in the FV case, that the "current generation has a fixed budget for investing for the future." The difficulty, however, is that in the PV case there is no complete analogy for that. If productivity is uncertain when the investment decision is made, actually there is no chance to move the risk to period 1. Asymmetry of time inevitably entails asymmetry of risk–bearing. In our model, in which a strictly positive return only occurs with probability 0.5, 1 Euro has to be invested definitely to guarantee 1 Euro as a sure payoff in period 2.

The asymmetry of time also shows up in Hepburn & Groom's (2007) alternative explanation in which different dates for intertemporal evaluation are the crucial element. In order to reformulate their argument in our framework, let, as above, $M(t)$ be an increasing function that describes how the marginal rate of transformation MRT between a payoff at time 0 and a payoff at some time t depends on the continuous time parameter t. $M(t)$ is defined on the finite interval $[0, T]$ with $M(0) = 1$ and $M(T) = M$. Assuming complete interchangeability of payoffs along this MRT–curve the marginal rate of transformation between some arbitrary points in time τ and t out of $[0, T]$ is $\frac{M(t)}{M(\tau)}$, where – this is the essential point – not only $t > \tau$ but also $\tau > t$ is possible. This means that foregoing a payoff of 1 Euro at time τ changes the payoff by $\frac{M(t)}{M(\tau)}$ at point t. Adopting quite formally the FV approach with τ as the evaluation date gives

$$M_F(\tau, t) = \frac{1}{2}\left(1 + \frac{M(t)}{M(\tau)}\right) \tag{5}$$

If $M(t)$ is increasing, $M_F(\tau, t)$ is increasing in t but decreasing in τ as, letting $\tau = 0$ and $t = T$ then (5) is the expected future value of payoffs as described by (1) (see Hepburn & Groom (2007)). Conversely, if $\tau = T$ and $t = 0$ equation (5) gives the expected present value as in (2). To motivate the evaluation approach, a safe payoff is implicitly assumed as a target at evaluation date τ, which indicates the similarity of Gollier's and Hepburn & Groom's approaches (see Hepburn & Groom (2007), especially p. 102).

Even though investment in its literal sense goes from the present to the future, the two cases, $\tau = 0$ and $\tau = T$, nevertheless are equally plausible when productivity is certain. If the payoff accruing in the future is reduced and the payoff in the current period is increased in return, this can well be interpreted as an investment of the future in favor of the present and further elucidates why the FV– and the PV approach are equivalent in this case. In the case of productivity risk this symmetry breaks down: If the payoff in the future is to be increased by 1 Euro with certainty this would mean differentiation of the payoffs in the present before uncertainty is resolved. Neither does this fit precisely to the two–period–model[2] nor is it feasible for real–world decisions on intergenerational allocation. Applying the PV method to risky situations is tantamount to making a consideration in retrospect and corresponds to a purely hypothetical decision.

4 Why the FV approach is warranted and how it may produce Weitzman's results

Both Gollier (2004) and Hepburn & Groom (2007) take a relativistic position: the safe payoff or the vantage point for the intertemporal evaluation can in principle lie everywhere on the time axis. Our considerations, however, have shown that – because time and risk go in only one direction – it is not very useful to adopt a reference point in the future. So in contrast to Gollier's own assertion neither Weitzman nor he himself are both wrong. Rather much more is in favor of Gollier's approach because he puts the risk to the right place, i.e. to the future period. By applying the PV method to situations with productivity risk, Weitzman implicitly seeks to avoid risks for the future period and thus gives the future generation some claim to a safe payoff. This privileged position of the future is clearly reflected in his main result, i.e. in the convergence of the certainty equivalent to the lowest possible value.[3]

If we are interested in the well–being of posterity it is the inevitably uncertain future value of income or utility that has to count. Concerning decisions on intergenerational risk sharing, we are in Gollier's world – like it or not. In the framework of expected utility theory the obvious way to give our descendants more protection is to explicitly introduce some risk aversion. With risk neutrality and Weitzman's PV approach future–friendliness only comes indirectly and has no solid conceptual foundation.

Allowing for risk aversion, the picture changes considerably. Consider the familiar class of isoelastic von Neumann–Morgenstern utility functions which are – for any constant elasticity of marginal utility η – defined by

$$u(x) = \begin{cases} \frac{x^{1-\eta}}{1-\eta} & \text{for } \eta \geq 0,\, \eta \neq 1 \\ ln\, x & \text{for } \eta = 1 \end{cases} \tag{6}$$

where x is the payoff level. Again let $M(t) = e^{rt}$ where r is the exogenously given discount rate. Then, with the FV approach, in our simple model the certainty

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[2] So both Gollier (2004) and Hepburn & Groom (2007) assume that uncertainty is resolved and the true rate of return becomes known before the investment decision is really made. This corresponds to a three stage model which, however, is not made explicit. Hence, it remains unclear what is meant by risk–bearing in the present.

[3] The PV method would only make sense, if the risky project could be repeated very often with uncorrelated risk. Then, with some given target payoff for the future periods, a mixed strategy could be played at each earlier stage in a chain of risky projects. Then also the "present" could bear some risk, and the "future" would on average finish with the desired payoff. Such a repetition clearly is not feasible with global risks, such as climate change.

equivalent discount rates $r_F^\eta(t)$ for some given η are defined by

$$e^{(1-\eta)r_F^\eta(t)t} = \frac{1}{2}\left(1 + e^{(1-\eta)rt}\right) \tag{7}$$

for any point of time $t > 0$. For $\eta = 0$ we are in the case of risk neutrality. Then, clearly, $r_F^0(t) = r_F(t)$, i.e. the interest rates derived from (7) coincide with those in the Gollier approach. If, however, $\eta = 2$ we have $r_F^2(t) = r_P(t)$, i.e. the same discount rates as with Weitzman's PV approach. So Gollier's more sensible conceptual basis can be used to justify Weitzman's solution.

For arbitrary values of η

$$r_F^\eta(t) = \begin{cases} r_F\left((1-\eta)t\right) & \text{for } \eta < 1 \\ r_P\left((\eta-1)t\right) & \text{for } \eta > 1 \end{cases} \tag{8}$$

results, which, as a general result, is demonstrated in Appendix A2. Hence, as in Gollier's approach, the function $r_F^\eta(t)$ is increasing in t if inequality aversion expressed by η is rather low, whereas it is – as in Weitzman's conception – decreasing if η exceeds 1. With $\eta = 1$ we get $r_F^1(t) = \frac{r}{2}$, i.e. a constant discount rate.

Since $\eta \geq 1$ seems to be the more adequate assumption, which is confirmed by experimental studies and regularly invoked in climate change analysis, decreasing discount rates are obtained. In Weitzman's critique of the Stern Review the value $\eta = 2$ is even explicitly suggested as part of a ”trio of twos” (see Weitzman (2007), p. 707).[4] This confirms Weitzman's *result* even by using Gollier's *approach* based on future expected values.

5 Conclusion

Weitzman's (1998) postulate to discount benefit and costs that accrue in the long–distant future at the lowest imaginable discount rate has not found unanimous consent. Our analysis has provided a twofold assessment of this debate: On the one hand, the objections raised by Gollier (2004) seem to be justified insofar as they are directed against the use of Weitzman's present value approach in the case of uncertainty. So Weitzman's approach would imply full risk–bearing by the present generation which – as has been shown in this paper – is impossible because of the asymmetry of time. On the other hand, the result obtained by Weitzman nevertheless seems to be appropriate for long–run decisions, since introducing a plausible degree of risk aversion into Gollier's approach can produce the same pattern of declining interest rates as suggested by Weitzman.

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[4] In the Stern Review on the Economics of Climate Change (Stern (2006)) a value of $\eta = 1$ is used. Other economists as Arrow (2007) also recommend the use of higher η–values. A range for sensible η–values betweem 1 and 2 has been derived axiomatically by Buchholz & Schumacher (2008). For empirical estimates on real–world η–values see e.g. Evans (2005) and Pirttilae & Uusitalo (2007).

Appendix A1

Let $\tilde{M}$ be a random variable which takes on values in an interval $[\underline{M}, \overline{M}]$ where $\underline{M} > 0$ and $\overline{M} < \infty$. As a generalization of (3) and (4) we define

$$M_F = E\tilde{M} \tag{9}$$

and

$$M_P = E\tilde{M}^{-1}. \tag{10}$$

Then, using the Cauchy–Schwarz inequality we obtain

$$\begin{aligned} \frac{M_F}{M_P} = E\tilde{M} \cdot E\tilde{M}^{-1} &\geq E(\tilde{M}^{\frac{1}{2}})^2 \cdot E(\tilde{M}^{-\frac{1}{2}})^2 \\ &\geq \left(E\left(\tilde{M}^{\frac{1}{2}} \cdot \tilde{M}^{-\frac{1}{2}}\right)\right)^2 = 1 \end{aligned} \tag{11}$$

which gives the assertion.

Appendix A2

Let, as in Hepburn & Groom (2007), $\tilde{r}$ be a random variable which takes value in an interval $[\underline{r}, \overline{r}]$ where $\underline{r} \geq 0$ and $\overline{r} < \infty$. Quite analogously to (3) and (4) certainty equivalent discount rates $r_F(t)$ and $r_P(t)$ in this general setting are defined by

$$e^{r_F(t)t} = Ee^{\tilde{r}t} \tag{12}$$

and

$$e^{-r_P(t)t} = Ee^{-\tilde{r}t} \tag{13}$$

for any point in time $t > 0$.

Given some risk aversion parameter $\eta > 0$, $\eta \neq 1$ now define $r_F^\eta(t)$ by

$$\left(e^{r_F^\eta(t)t}\right)^{1-\eta} = E\left(e^{\tilde{r}t}\right)^{1-\eta} \tag{14}$$

First assume $\eta \in]0,1[$. Substituting $t' = (1-\eta)t$ in (12) gives

$$e^{r_F((1-\eta)t)(1-\eta)t} = e^{r_F(t')t'} = Ee^{\tilde{r}t'} = Ee^{\tilde{r}(1-\eta)t} \tag{15}$$

Combining (14) and (15) yields

$$e^{r_F^\eta(t)(1-\eta)t} = e^{r_F((1-\eta)t)(1-\eta)t} \tag{16}$$

which proves the assertion in this case. For $\eta > 1$ the proof is quite analogous. Finally, for $\eta = 1$ we have

$$\ln e^{r_F^1(t)t} = E \ln e^{\tilde{r}t} \tag{17}$$

which yields

$$r_F^1(t) = E\,\tilde{r} = \text{const.} \tag{18}$$

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