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DISCOUNTING DISENTANGLED

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The economic values of investing in long-term public projects are highly sensitive to the social discount rate (SDR). We surveyed over 200 experts to disentangle disagreement on the risk-free SDR into its component parts, including pure time preference, the wealth effect and return to capital. We show that the majority of experts do not follow the simple Ramsey Rule, a widely-used theoretical discounting framework, when recommending SDRs. Despite disagreement on discounting procedures and point values, we obtain a surprising degree of consensus among experts, with more than three-quarters finding the median risk-free SDR of 2 percent acceptable.

Keywords: Social discount rate, project appraisal, expert opinions, simple Ramsey Rule, disagreement.

JEL codes: H43, D61, Q58.

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We report the results of a survey of experts on *"one of the most critical problems in all of economics"* (Weitzman 2001: 260) about which there has been a great deal of disagreement: the long-term social discount rate (SDR). The sample contains over 200 academics who are defined as experts on social discounting by virtue of their publications. A key innovation of our survey is that we elicit information on the fundamental determinants of the SDR, which allows us to disentangle the main sources of disagreement. The experts' acceptable ranges for the SDR are also elicited, which allows an examination of whether there is any space for agreement on discounting. Our findings lead us to the conclusion that current policy guidance on the evaluation of long-term public projects—such as climate change mitigation and long-lived infrastructure—requires substantial revision, in particular, a departure from the simple, deterministic Ramsey Rule.

The appropriate SDR and the procedure for its calculation have long been a source of disagreement among economists. Historically, economists have found themselves either stumbling around in the *"dark jungles of the second best"* in pursuit of an answer or accused of *"stoking the dying embers of the British Empire"* if they claim to find one (Baumol 1968: 789; Nordhaus 2007: 691). Such disagreements resurfaced after the recommendations of the Stern Review on the Economics of Climate Change proved to be extremely sensitive to the choice of the SDR (Nordhaus 2007, 2008; Stern 2007). The extent of disagreement was book-ended by Stern's normative (prescriptive) position which lead to a central SDR of 1.4%, and Nordhaus' positive (descriptive) position, which lead to a long-term SDR of 4.5%. These opposing positions lead to radically different views on the appropriate level of climate change mitigation.

It is for reasons like these that discounting the distant future is viewed as such a *"critical problem"*. Yet, aside from these well publicized cases, we lack a good understanding of the extent and the sources of this disagreement. A survey by Weitzman (2001) provided some indication of the extent of disagreement by asking over 2000 economists for the appropriate *"real interest rate"* for the analysis of climate change mitigation: responses ranged from -3% to 27%. Yet, the Weitzman survey was silent on the reasons for this huge variation in opinion, even on whether respondents were using positive or normative principles to inform their response. Such information is crucial to understanding the basis for SDRs and the principles that guide long-term policy analysis. Our study is motivated by the need for more clarity on this issue.

In order to disentangle the causes of disagreement on the SDR we structure the survey around a well-known framework for inter-temporal welfare evaluations: Time Discounted Utilitarianism and the simple Ramsey Rule. Specifically, we elicit expert responses on two key components of the SDR: the pure rate of time preference and the elasticity of marginal utility. In addition to these *"central normative parameters"* (Nordhaus 2008: 33), we ask experts to estimate growth and the risk-free rate of interest. In this way we obtain information on both positive and normative arguments for the SDR (Arrow et al. 1996, 2012). These concepts are familiar to economists working on discounting, but also have the merit of being policy relevant.[1] Importantly though, we allow sufficient flexibility for experts not to be constrained by the simple Ramsey Rule when making their recommendations on the SDR. This flexibility is particularly crucial as it is to be expected that experts have varied views on how to calculate SDRs. For example, our parsimonious survey was

[1]A number of policy guidelines on cost-benefit analysis across the world are testament to this (HMT 2003; IPCC 2014; Lebegue 2005).

designed such that experts did not have to tackle the thorny issue of project risk, by asking for a SDR with which to discount certainty-equivalent cash flows. Yet allowing for flexibility in responses allowed macroeconomic sources of risk and uncertainty to be factored in by experts when recommending appropriate 'risk-free' SDRs for certainty-equivalents.

The responses make for interesting reading. The median (mean) recommended SDR of our experts is 2 percent (2.3 percent). This is substantially lower than the median (mean) values of 3 percent (4 percent) reported by Weitzman (2001).[2] We also find that there remains substantial disagreement over this value, with individual recommendations ranging between 0 and 10 percent. Despite this, 92 percent of experts report that they would be comfortable with a SDR somewhere in the interval of 1 percent to 3 percent, and over three-quarters find a SDR of 2 percent acceptable.

Looking at the empirical distributions of individual discounting determinants, we find that expert opinion is particularly varied on the rate of pure time preference. The modal value is zero, in line with many prominent opinions. But with a median (mean) of 0.5 percent (1.1 percent), we cannot confirm the IPCC's (2014: 229) conclusion that there is *"a broad consensus for a zero or near-zero pure rate of time preference"*. Also, while we find that experts recommend placing greater weight on normative than positive issues when determining the SDR, most believe that the SDR should be informed by both.

An unambiguous result of our survey is that the prominence of the simple Ramsey Rule in public policy needs to be revisited. When we impute the simple Ramsey Rule for all experts individually, we find wide discrepancies between these values and their recommended SDRs. The rich body of qualita-

[2]Supplementary material A discusses differences between the two surveys.

tive responses provided by our experts explains the need for long-term public decision-making to depart from the confines of this framework. Accounting for a comprehensive set of technical issues, such as the inherent uncertainties and changing relative prices of non-marketed goods, was one set of recommended departures. Stressing the importance of different societal criteria, which embody broader notions of intergenerational equity and sustainability, was another. A third set of recommendations aimed at ensuring that decision-making is participatory and takes a more procedural approach.

Indeed, many argue for a more "*democratic*" approach to informing governmental guidance on social discounting (e.g. Dasgupta 2008: 158). Yet, because the questions raised by long-term cost-benefit analysis are highly complex, there are also arguments for so-called "*genuine specialists*" (Pindyck 2017; Sunstein 2014: 550) to play an active role. The opinions of experts play an important role in public policy. Numerous expert panels held in recent years show that social discounting is no exception.[3] Precisely because discounting policy is so often influenced by such specialists, it is imperative to obtain a more complete picture of the range of opinions they hold. By presenting the responses of a large number of experts on the determinants of the long-term SDR, we contribute to the ongoing academic debate over improving approaches to intergenerational decision-making. We also provide detailed information for the discounting policy revisions taking place in several countries.

[3]Since the Stern Review, expert advice on social discounting has been sought from specialists in the field, among others, by the US Environmental Protection Agency, and the Norwegian, French, UK, and Dutch governments (Groom and Hepburn 2017).

I. Survey Design

A. Conceptual Background

Even a cursory glance at the literature on long-term decision-making reveals a multitude of conceptual approaches which could lead to different recommendations for the SDR. Some disagreement revolves around which rate of return to capital or interest rate best describes the opportunity cost of public investment. On the normative side, approaches such as Time Discounted Utilitarianism (TDU) and Prioritarianism, are consequentialist. Other approaches add procedural rules, such as sustainablility requirements, to a consequentialist framework (see, for example, Asheim and Mitra 2010; Chichilnisky 1996). In each case extensions and variants abound.[4]

Our survey allows respondents to provide qualitative responses which could reveal the fine-grained details of their particular perspectives on intergenerational decision-making. However, the main part of the survey is structured around TDU, as it provides a clear means of disentangling key sources of disagreement on the SDR in terms of widely-understood concepts.

The standard TDU social welfare function, W_0, takes the following form

$$W_0 = \int_{t=0}^{T} \exp(-\delta t) U\left(C_t\right) \mathrm{d}t, \tag{1}$$

where welfare at time 0 depends on all future time-separable utilities of a representative agent whose utility depends on comprehensive real per-capita consumption C_t. Utility is discounted at a constant rate of pure time preference, δ, which determines how much weight is placed on future utilities from

[4]See for instance, Harberger and Jenkins (2015) and Spackman (2017) for recent discussions on (positive) opportunity cost arguments, and Asheim (2010), Botzen and van den Bergh (2014) and Fleurbaey and Zuber (2015) for overviews of alternative normative criteria for long-term decision-making.

today's perspective. A frequently-used simplifying assumption is that utility is isoelastic: $U(C_t) = (1-\eta)^{-1}(C_t^{1-\eta} - 1)$ if $\eta \neq 1$ and $U(C_t) = \ln(C_t)$ if $\eta = 1$. Here, η is the constant elasticity of marginal utility of consumption, which reflects how averse society is to the differences in consumption that arise over time due to growth.[5]

The TDU framework thus captures some key features of the inter-temporal trade-offs that society faces and can lead to a simple social discounting rule known as the Ramsey Rule (Ramsey 1928):

$$r = \delta + \eta\, g, \tag{2}$$

where r is the risk-free return to capital, and g is the real, per-capita, growth rate of consumption. This optimality condition equates the returns to saving/investment in risk-free capital on the production side (r) with the welfare-preserving inter-temporal trade-off on the consumption side ($\delta + \eta\, g$). The latter is the exact solution to the first order condition of the optimal consumption problem with a constant growth rate, $g = g_t = t^{-1}\ln(c_t/c_0)$. Although speaking to optimal saving, the Ramsey Rule also provides a theoretical foundation within TDU for determining the SDR in the absence of uncertainty (Arrow et al. 2012).

Disagreement on long-term discounting often focuses on the two key welfare parameters, δ and η, and their normative-positive content. There is also disagreement about the role of r in social discounting (Arrow et al. 1996; Nordhaus 2007). Two main interpretations of this rule in this context are in common use. First, the opportunity cost of capital approach focuses on the trajectory of the risk-free capital stock, and its rate of return r:

[5]This parameter may also reflect aversion to differences that occur in different states of the world, and so under uncertainty η can also be interpreted as a measure of risk aversion.

$$SDR = r, \tag{3}$$

which anchors the SDR to the yield on relatively risk-free assets, e.g. government bonds. This approach relates to the 'positive' approach to social discounting followed by the US Environmental Protection Agency (US EPA 2010), among others.

The second approach concerns the trajectory of consumption and asks how to optimally distribute the returns of a marginal project over time. In a deterministic world this consumption-side approach leads to the simple Ramsey Rule (SRR):

$$SDR = SRR = \delta + \eta\, g, \tag{4}$$

leading to two reasons why society might discount the future: the rate of societal pure time preference, δ; and a 'wealth effect', $\eta \times g$, which captures the idea that society may place less weight on future net benefits if the future is more wealthy. The SRR is typically considered to be the 'normative' approach, and is the interpretation followed by Her Majesty's Treasury in the UK (HMT 2003) and the German Environmental Agency (UBA 2012), for instance.

While the deterministic structure is helpful to organize ideas on social discounting and to pin down some main sources of disagreement within a parsimoniously structured survey, it is clear that long-term public decision-making has to deal with uncertainty. At the very least, two types of uncertainty matter: one that relates to the growth rate of consumption and another that relates to the payoffs from the marginal project itself. For example, if growth in each year is independently and identically Normally distributed, an extended consumption-side Ramsey Rule (ERR) emerges:

$$SDR = ERR = \delta + \eta\,\bar{g} - 0.5\,\eta\,(\eta+1)\,\sigma^2, \tag{5}$$

with $\bar{g} = \mu + 0.5\,\sigma^2$, where μ is the mean of real, per-capita logarithmic consumption growth and σ^2 is its variance (Gollier 2012). Uncertainty in growth reduces the risk-free SDR for a prudent social planner for precautionary reasons, with the precautionary effect given by $-0.5\,\eta\,(\eta+1)\,\sigma^2$.[6]

While the ERR captures the basic idea of the precautionary effect, equation (5) is based upon a rather limited expression of growth uncertainty. Stronger precautionary effects could emerge if it is expected that large, non-marginal and possibly persistent shifts in growth are possible, such as would be experienced in a major depression. Barro (2006) models a growth process with the prospect of such events and illustrates the reduction in the risk-free rate that this would entail.[7] In the long-term context in which our survey takes place, growth processes like this could play an important part in determining the appropriate risk-free SDR, and may underpin responses from our experts.

Another important element of uncertainty is project specific risk: the risk associated with the project benefits. Because the focus of this study is purely on the components of the risk-free SDR, it is important that the survey is able to abstract from project specific risks so that the risk-free elements of the SDR can be isolated. For instance, in finance it would be typical to deploy a project specific discount rate. This would contain a positive (negative) risk premium

[6] A planner is prudent if the third derivative of the utility function is positive. According to Gollier (2012: Table 3.3), the global average precautionary effect amounts to -1 percent.

[7] Gollier (2012: 75-76) provides a simple example of the point made by Barro (2006). If λ represents the growth shock as an instantaneous percentage loss of GDP, which happens with a probability p, and growth otherwise (with probability $1-p$) follows a Brownian motion, the appropriate risk-free SDR becomes:

$$SDR = \delta - \ln[p(1-\lambda)^{-\eta} + (1-p)\exp(-\eta\bar{g} + 0.5\eta^2\sigma^2)], \tag{6}$$

which is lower than the ERR for positive values of λ, and decreasing in λ.

on top of the risk-free rate to reflect a positive (negative) correlation of the project payoffs with the returns from a market portfolio. The Capital Asset Pricing Model (CAPM) model provides a central theoretical foundation for this approach. In the context of the Ramsey framework, the consumption-based CAPM model recommends a similar adjustment, except that the risk premium would now reflect the correlation of the project's benefits with consumption growth in the macroeconomy. A survey which could elicit project specific risk premiums would require an extensive array of questions on different types of projects. Yet our concern is with the risk-free SDR, which is a common element of the SDR for the appraisal of *all* projects.[8]

In order to focus on disagreement regarding key elements of the risk-free SDR, we frame the survey around certainty-equivalent values. This isolates the risk-free SDR because costs and benefits that are presented in certainty-equivalent terms should be discounted at a risk-free rate.[9] Using certainty equivalence facilitates a parsimonious survey which elicits elements of the risk-free rate without drawing out the additional complexities raised when estimating project-specific discount rate risk-premia.[10]

Beyond the question of uncertainty, a number of other extensions are

[8]In the Discussion section, we further explain that the risk-free component of the SDR is a crucial component even when discounting expected cash-flows at a risk-adjusted rate.

[9]Additional motivation for this approach comes from Zeckhauser and Viscusi (2009: 96), who argue that *"economists generally agree that whoever is the decision maker, the discount rate should not be adjusted for risk. The preferred approach, roughly speaking, is to address risk by converting monetary payoffs to certainty-equivalents, and then do the discounting."* While not all economists would agree with this statement, and while most financial economists would deal with project risk through an adjustment to the discount rate as discussed previously, almost all are familiar with this basis for dealing with uncertainty.

[10]We do not address the question of how to estimate certainty-equivalents, which is considered by many scholars and practitioners to be a highly challenging exercise. Bansal et al. (2016), Lemoine (2017) and Weitzman (2009) are examples of a growing literature discussing the problem of certainty equivalence in the area of climate change, where uncertainties abound.

possible—such as accounting for the changing relative prices of non-market goods (Gollier 2010; Traeger 2011) or declining discount rates (Arrow et al. 2013)—as well as alternative approaches outside of Time Discounted Utilitarianism. Importantly, by eliciting the SDR separately from the individual components of the simple Ramsey Rule, and by including the option for qualitative responses, the survey does not force experts into the Procrustean bed of the simple Ramsey Rule. Flexibility in the way in which experts could respond allows for many different possible rationales to be expressed.

B. The Survey Questions

The survey asked respondents about the SDR and some of its fundamental determinants.[11] The questionnaire began with the following contextual preamble, followed by seven brief quantitative questions and an optional comments section for qualitative responses:

> *Imagine that you are asked for advice by an international governmental organization that needs to determine the appropriate real social discount rate for calculating the present value of certainty-equivalent cash flows of public projects with intergenerational consequences.*
>
> *For its calculations, the organization needs single values for the components of the real social discount rate. While this does not capture all of the important complexities of social discounting, it does reflect most existing policy guidance on the matter. Your answers will therefore help to improve the current state of decision-making for public investments.*

[11] We piloted different versions of the survey with selected experts, economists from different fields, and students to find the best trade-off between completeness and parsimony.

Specifically, you are asked to provide your recommendations on the single number, global average and long-term (>100 years) values of the following determinants of the social discount rate:

1. *Growth rate of real per-capita consumption [X% per year].*
2. *Rate of societal pure time preference (or utility discount rate) [X%].*
3. *Elasticity of the marginal utility of consumption [X].*
4. *Real risk-free interest rate [X% per year]. Remember that this should be a global average and long-term forecast.*
5. *What relative weight (summing up to 100%) should the governmental body place on the following rationales for determining the social discount rate:*
   (a) *Normative issues, involving justice towards future generations [X%], and*
   (b) *Descriptive issues, involving forecasted average future returns to financial assets [X%]?*
6. *What is your recommended real social discount rate for evaluating the certainty-equivalent cash flows of a global public project with intergenerational consequences [X% per year]?*
7. *What minimum and maximum real social discount rate would you be comfortable with recommending [X% to X percent per year]?*
8. *Do you have any additional comments [X]?*

Questions 1–2 elicited responses on the two key normative parameters δ and η. Questions 3-4 asked for forecasts of the long-term global average growth rate of real per-capita consumption, g, and real interest rate, r. Question 6 asked for the point-value of the SDR that should be recommended for evaluating the certainty-equivalent cash flows of a generic global public project

with intergenerational consequences. The open comments section, Question 8, allowed for feedback on the survey, where respondents could, and often did, point towards various deviations from the simple Ramsey rule.

Question 5 elicited information about each respondent's approach to discounting by asking for the relative weight that the governmental body should place on normative versus positive approaches to determining the SDR. Responses were measured on a sliding scale from 0 to 100 percent. This explores the disagreement in rationales that has been evident at least since Arrow et al. (1996): whether normative issues, involving intergenerational ethics and justice, or positive issues, involving forecasted future returns to financial assets, or a mixture of both should determine the SDR. Importantly, the sliding scale admits many interpretations of normative and positive other than those associated with the Ramsey Rule. For instance, responses could reflect the relative weight that respondents place on different consequentialist or deontological ethical frameworks. Finally, in Question 7 we asked for the minimum and maximum values of the SDR that respondents would be comfortable with recommending, in order to elicit an 'agreeable range'.

C. Expert Selection and Survey Dissemination

Because our survey aimed at disentangling the determinants of the long-term SDR, we restricted our sample to scholars who have been involved with these complex issues. For the purposes of this paper, an individual is deemed to be a potential 'expert' if he or she is a (co-)author of at least one pertinent publication in the field of (social) discounting in a leading economics journal. A journal was classified as 'leading' if, according to the ranking of 600 economics journals by Combes and Linnenmer (2010, Table 15), it is rated A

or higher, together with the topical Review of Environmental Economics and Policy. This amounts to 103 peer-reviewed journals. A publication is deemed to be 'pertinent' if it was published between January 2000 and March 2014 and, according to the Google Scholar engine, included at least one of the terms 'social discounting', 'social discount rate' or 'social discount factor'.[12] Correcting for scholars with multiple publications, and discarding papers that did not pass a weak relevancy test, our sample includes 627 potential experts.[13]

There are a number of limitations to this selection strategy. First, by restricting the search to publications since the year 2000 to only capture scholars active in the current debate on social discounting, we potentially miss some relevant earlier contributors. Second, by selecting experts based on their publications, we necessarily include co-authors of relevant papers who are not themselves experts on discounting. Third, due to the rather generous weak relevancy test, we include a number of scholars who might not regard themselves as true experts on the issue. Fourth, we do not pick up relevant publications in the field that have used other terms to discuss discounting. Finally, we miss potentially relevant articles in lower-ranked journals.[14] This may introduce a geographical bias into our sample by under-representing those from developing nations. Despite these possible short-comings, the definition of expert that we deploy here is close to the one frequently used by policy makers, both in general policy contexts and in relation to social discounting.

[12]To obtain a broader set of potential experts, we further performed a search based on abstracts for the term 'discount rate' within the same journals in EconLit. Using EconLit allowed restricting the search to more relevant papers that already discussed discounting in the abstract (a general Google Scholar search for the term 'discount rate' yields more than 300 000 hits, containing a large number of irrelevant papers that would need to be manually evaluated). Of the 627 potential experts, 219 were obtained through the EconLit search.

[13]See Supplementary material B for further details on the selection procedure.

[14]A citation threshold would be an alternative quality signal (see, e.g., Pindyck 2016).

Starting in May 2014, we sent out a link to the online survey (implemented in SurveyMonkey) via e-mail to all potential experts, and used three general rounds of reminders, each time slightly varying the subject line and motivation for answering the survey.[15] In later rounds, we offered the option of completing the survey in a Word document or in the e-mail itself to increase flexibility.

II. Survey Results

Table 1 provides summary statistics for expert responses. By November 2014 we had received responses from 197 experts, including 12 who solely provided qualitative feedback containing important insights. We also received replies from 27 scholars explaining why they did not answer the survey, without warranting inclusion as qualitative responses.[16] Responses were also obtained after the survey closed from 38 previous non-respondents. This group is used to check for non-response bias. Following several standard procedures to test for non-response bias, we find no systematic unidirectional biases for SDR recommendations (see Appendix A.).

Overall, we elicited 262 responses out of a pool of 627 potential experts. The response rate is 30 percent if we only consider the 185 quantitative responses. If we include all responses, the rate rises to 42 percent. Each is in line with comparable online surveys with economists (Necker 2014). Besides this, the sampling strategy was successful in obtaining responses from 'blue ribbon' academic leaders on social discounting, including 12 of the 13 experts of the Arrow et al. (2012) panel who advised the US EPA on this matter.

[15] Supplementary material C provides the initial e-mail text.

[16] The most common reason for non-response was self-reported insufficient expertise, but it also included not having enough time or being unable to respond due to reasons of central bank confidentiality.

Table 1: Descriptive Statistics on Survey Results

Variable	Mean	StdD	Median	Mode	Min	Max	N
Real growth rate per capita	1.70	0.91	1.60	2.00	-2.00	5.00	181
Rate of societal pure time preference	1.10	1.47	0.50	0.00	0.00	8.00	180
Elasticity of marginal utility	1.35	0.85	1.00	1.00	0.00	5.00	173
Real risk-free interest rate	2.38	1.32	2.00	2.00	0.00	6.00	176
Normative weight	61.53	28.56	70	50	0	100	182
Positive weight	38.47	28.56	30	50	0	100	182
Social discount rate (SDR)	2.27	1.62	2.00	2.00	0.00	10.00	181
SDR lower bound	1.12	1.37	1.00	0.00	-3.00	8.00	182
SDR upper bound	4.14	2.80	3.50	3.00	0.00	20.00	183
Quantitative responses							185
Qualitative responses							100
Responses used for analysis							197
Explained non-responses							27
Bias-check responses							38
Total number of responses							262

Note: "StdD" refers to standard deviation and "Min" ("Max") to minimum (maximum) recommendation.

A. Quantitative Responses

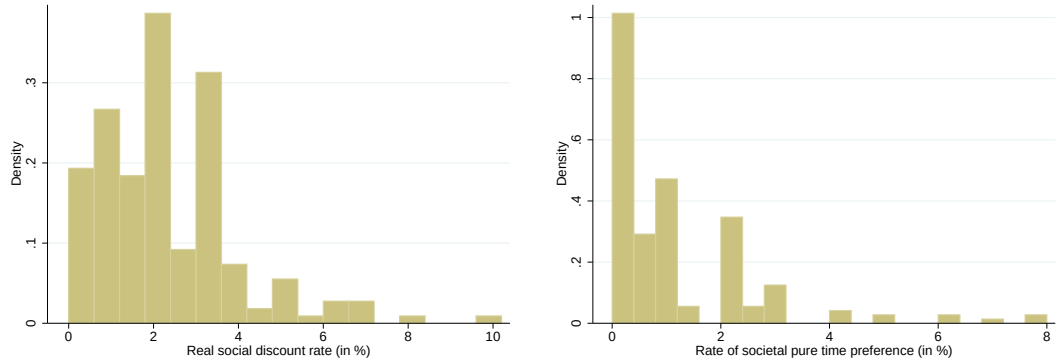
A.1 Recommended Long-Term Social Discount Rate

In recent years, prominent experts such as Gollier (2012), Nordhaus (2008), Stern (2007) and Weitzman (2007) have proposed very different SDRs. Figure 1 (a) illustrates the extent of disagreement on the SDR for discounting real certainty-equivalent cash flows of a global public project with intergenerational consequences. The lowest recommendation is 0 and the highest 10 percent. However, the vast majority of experts provide point recommendations in the range of 0 to 4 percent, while the interval of 1 to 3 percent contains the point

SDR recommendations of 68 percent of experts. The mean (median) value of the recommended SDR are 2.27 percent (2 percent), which are much lower than the corresponding values from Weitzman's (2001) survey of economists of 3.96 percent (3 percent). Yet the most common single value recommended in these two different surveys is 2 percent. These results deviate substantially from the discount rates recommended in important recent guidelines, including the IPCC Fifth Assessment Report (IPCC 2014: 230).

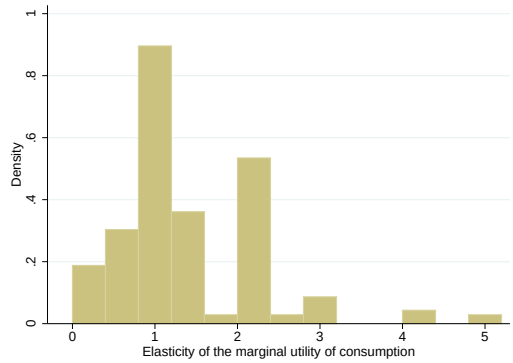
A.2 Rate of Societal Pure Time Preference

Positions on the rate of societal pure time preference, δ, have historically been the subject of intense disagreement. Luminaries of economics, such as Pigou, Ramsey and Harrod, believed that the well-being of each generation ought to be weighted equally, and so pure time preference should be zero. This view stems from their classical impartial Utilitarian philosophy. Disagreement surfaced again more recently with the publication of the Stern Review (Stern 2007), which took a similar stance. Many alternative arguments exist for the use of a positive rate of societal pure time preference (e.g. Arrow 1999; Koopmans 1960; Nordhaus 2007). Figure 1 (b) shows substantial disagreement among experts on their chosen value for this parameter. As the modal value, 0 percent is a focal point, and, if we include those responses that lie in the range of 0 to 0.1 percent, 38 percent take what might be called the Ramsey-Stern view. Yet, the distribution of responses is substantially right-skewed with a median of 0.50 percent, a mean of 1.10 percent and a maximum recommendation of 8 percent. Based on these results, we cannot confirm the IPCC's (2014: 229) conclusion that *"a broad consensus for a zero or near-zero pure rate of time preference"* exists among experts.



(a)

(b)



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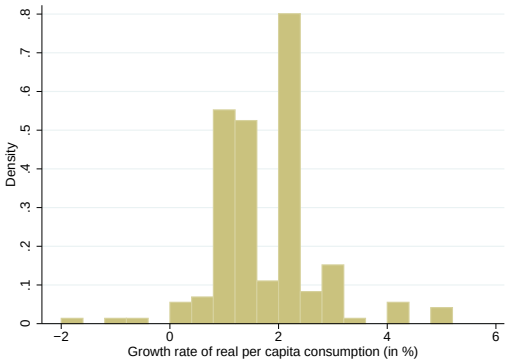
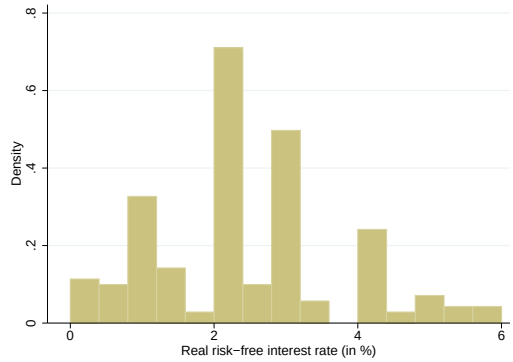
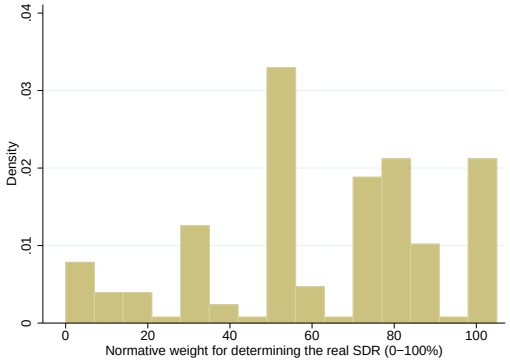


(d)



(e)



(f)

Figure 1: This figure provides histograms of expert recommendations and forecasts on discounting determinants. Figure (a) shows the real long-term SDR (in percent), (b) rate of societal pure time preference (in percent), (c) elasticity of marginal utility of consumption, (d) real growth rate of per capita consumption (in percent), (e) real risk-free interest rate (in percent), and (f) the normative weight for determining the SDR (in percent).

A.3 Elasticity of the Marginal Utility of Consumption

Settling on a value of the elasticity of the marginal utility of consumption, η, is an intricate affair. The reason is that it might capture vastly different concepts and thus lend itself to different interpretations. These are not only divided along the lines of normative (e.g., issues of distribution) and positive (e.g., preferences for consumption smoothing) determinants, but might also capture the inverse of the elasticity of intertemporal substitution or societal preferences for the aversion of consumption inequalities across space, time and also states of nature. All these rationales could have been used by different experts to inform their response, although the survey setting might reasonably have led respondents to primarily consider interpretations relating to an intertemporal consumption smoothing or inequality context, as opposed to representing aversion to risk. Previous discussions in the literature point towards a range of 0.5 to 4 (Cowell and Gardiner 1999; Dasgupta 2008), although Groom and Maddison (2017) argue strongly for a narrower range of between 1.5 and 2 for the UK based on revealed preference approaches. The resulting expert recommendations for the elasticity of the marginal utility of consumption as presented in Figure 1 (c) are indeed widely dispersed, with a mean of 1.35 and a median and mode of 1. These values provide some support to the often made assumption of logarithmic utility.

A.4 Growth Rate of Real Per-Capita Consumption

Figure 1 (d) presents the results of our respondents' forecasts of the growth rate of real per-capita consumption, g. The overwhelming majority forecast a positive growth rate, with a mean of 1.7 percent and a median of 1.6 percent (cf. Table 1). This is close to the 2 percent growth rate of consumption per-capita in the western world for the last two centuries (Gollier 2012) and the 1.6

percent growth rate in GDP per-capita over the period 1900 to 2000 in non-OECD countries (Boltho and Toniolo 1999). Three experts project a negative growth rate, and 55 respondents forecast a lower growth rate than the IPCC's (2000) lower bound projection of 1.3 percent for the period from 1990 to 2100. 28 experts forecast a growth rate larger than 2 percent.

A.5 Real Risk-Free Interest Rate

The mean long-run real risk-free rate of interest among our respondents was 2.38 percent, with a standard deviation of 1.32 percentage points and a median value of 2 percent.[17] The mean response was higher than the observed real rate of return on relatively risk-free assets in many countries at the time of the survey. There are several possible reasons for this apparent discrepancy.

The assets typically (although loosely) described as 'risk-free' are Government bills and bonds, but neither quite meets the theoretical ideal for long-term social discounting.[18] In practice, social discounting policy has tended to regard bonds as the appropriate relatively risk-free asset to benchmark, due to their longer time horizon (see, e.g., Stern 2008; OMB 2016; US EPA 2010). When estimating the schedule of declining discount rates within a positivist framework, researchers have also used bond yields (Newell and Pizer 2003; Groom et al. 2007; Freeman et al. 2015). Within the practice of corporate

[17]While our question explicitly asked for a forecast of a *risk-free* interest rate, we cannot exclude the possibility that some respondents were instead providing a forecast return on production, or even equity, capital. Such returns include the premium associated with investing in risky assets and therefore are not appropriate for discounting certainty-equivalent cash-flows. This may lead to an upward bias in the sample responses.

[18]Bills are virtually risk-free, but their maturity is too short to be relevant for long-term social discounting. Also, while a rolling portfolio of bills can match the maturity of a long-term cost or benefit, we cannot currently observe what rate of return this portfolio will actually provide. Bonds, on the other hand, are long-maturity, but their real realized return is affected by uncertain future inflation. Their yields therefore incorporate an inflation risk premium, meaning they are not strictly 'risk-free'.

finance, there is also a strong preference for using Treasury bond yields as a proxy for the risk-free rate in capital budgeting (Bancel and Mittoo 2014).[19]

Over the period 1900-2016 (since 2000), the global average real return was approximately 0.8 (-0.5) percent for bills and 1.8 (4.8) percent for bonds (Dimson et al. 2017: 10). The mean response of 2.38 percent is therefore not too dissimilar to the mean global bond rates witnessed since 1900.[20] Furthermore, when predicting long-run global rates it is likely that experts were considering different scenarios for the 21^{st} Century, in which the growing economies of Asia, Africa and Latin America have higher rates of return, and hence change the composition of global interest rates.

A.6 Normative versus Positive Approaches

A central point of disagreement on the SDR concerns the question of whether normative issues, involving justice towards future generations, or positive issues, involving forecast average future risk-free rates, or a mix of the two should determine the SDR (Arrow et al. 1996, 2014). Not everyone agrees that Time Discounted Utilitarianism is the correct ethical basis for intergenerational decision-making in the first place. For instance, some prefer deontological ethics which emphasise duties, while others prefer rights-based approaches. In line with this history of disagreement on the SDR, our intention for Question 5 is to establish the extent to which recommendations on the SDR are influenced by *"positive predictions and ethical judgments"* (Ricketts and Shoesmith 1992: 210–211). A clear finding from our data is that a

[19]Freeman (2009) also argues that the theoretical case is stronger for using bonds over bills in this context.

[20]Consider also the lower bound SDR recommended by the US-OMB (2003) for calculating the Social Cost of Carbon based on relatively risk-free savings rates. Greenstone et al. (2013) state: *"Moreover, 3 percent (real) roughly corresponds to the after-tax riskless interest rate"*.

large majority of experts (80 percent) think that both dimensions are relevant (see Figure 1 (f)). However, they generally recommend that governmental institutions should place greater weight on normative issues in determining the SDR; this has a mean (median) weighting of 61.53 percent (70 percent). When considering extremes, 14 percent (5 percent) of experts placed 0 (100 percent) weight on positive considerations, while 42 experts were divided equally between the two rationales; making this the modal response. These findings underscore that setting the SDR requires both forecasts and value judgments.

B. Qualitative Responses

More than half of our respondents provided comments ranging from short remarks, such as *"risk matters"*, to explanations over multiple pages. The qualitative observations provide a rich body of evidence which sheds light on various complexities of the theory and practice of social discounting. We group these comments into four main categories that address (i) individual survey questions Q1-Q5, (ii) technical issues, (iii) methodological issues, and (iv) concerns about limited expertise. Each category has multiple subcategories.

Table B.1 in Appendix B. provides an overview of the most common issues raised, including the number of experts commenting on it and an exemplary quote, sometimes edited for brevity. The five most often raised subcategories are: 'declining discount rates and time-horizon', 'uncertainty', 'substitutability and environmental scarcity', 'heterogeneity and aggregation', and 'comparison to the Ramsey Rule'.

III. Analysis

A. Determinants of the SDR

We now examine the relationship between experts' recommended SDRs and its fundamental determinants.[21] In line with what one would expect from the Ramsey framework, the correlations between the rate of pure time preference, δ, as well as the 'wealth effect', $\eta \times g$, and expert's SDR recommendation are positive. More precisely, a univariate increase in δ of one percentage point increases the SDR recommendation by 0.34 percentage points ($p < 0.01$).[22] The effect of an increase in $\eta \times g$ by one percentage point increases the SDR by 0.15 percentage points ($p < 0.01$).[23] The main driver of the wealth effect is the forecasted growth rate, while η is not significantly associated with higher SDR recommendations in isolation. An increase in r by one percentage point is associated with an increase of the SDR by 0.52 percentage points ($p < 0.01$). A very robust and sizable determinant of the SDR is the weight that experts would put on normative as compared to positive issues ('normative weight') when forming their SDR recommendation. We find that each additional percentage-point of the relative weight put on normative issues reduces the SDR by 0.02 percentage points ($p < 0.01$). This implies that a pure 'positivist' (normative scale = 0) would recommend a SDR that is 2 percentage points higher than a pure 'normativist' (normative scale = 100 percent).

We further examine how other considerations expressed through experts' qualitative comments may determine SDR recommendations. For this, we build on the categorization of qualitative comments as shown in Table B.1

[21] Further analysis is presented in a previous working paper version (Drupp et al. 2015).

[22] All test are based on two-sided t-tests.

[23] When evaluated multivariatelty the partial effects are 0.32 and 0.11 (both $p < 0.01$).

and analyze the relation of the SDR to the three most-mentioned categories. Experts commenting on declining discount rates recommend an SDR that is 0.70 percentage points lower ($p < 0.05$), consistent with arguments provided in the pertinent literature.[24] Furthermore, experts commenting on uncertainty recommend an SDR which is 0.69 percentage points lower ($p < 0.01$), also consistent with the view that prudence in the face of uncertainty tends to lower the appropriate SDR.[25] For those experts commenting on environmental scarcity and relative price effects, we find SDR values that are lower by 0.97 percentage points ($p < 0.01$). Again, this is consistent with the literature on dual discounting and the relative price changes of non-market goods.[26]

While our survey was only designed to capture select fundamental determinants of the SDR for reasons of parsimony, and as the qualitative comments of repondents do not paint a complete picture, it is clear that we only capture some of the determinants of the SDR.[27] Overall, however, this analysis suggests that responses appear to be theoretically motivated.

[24]See, e.g., Arrow et al. (2013), Cropper et al. (2014), Gollier et al. (2008), Groom et al. (2005), Newell and Pizer (2003), Weitzman (2001).

[25]See, e.g., Gollier (2008), Traeger (2009), Weitzman (1998), Weitzman and Gollier (2010).

[26]See, e.g., Baumgärtner et al. (2015), Drupp (2016), Drupp and Hänsel (2018), Gollier (2010), Hoel and Sterner (2007), Sterner and Persson (2008), Traeger (2011).

[27]For example, it seems likely that contained within our normative-positive measure is a variety of unexplained and unobserved normative positions. Variation could also reflect differences within the positive school stemming from, for instance, differences or asymmetries in the information used to provide a global forecast.

B. Experts' SDRs and the Ramsey Rule framework

An important issue for governmental guidance on social discounting is to consider which theoretical framework may form the basis of recommendations on the SDR. The previous analysis of discounting determinants has revealed that experts' SDR responses are indeed informed by some of its fundamental determinants in a way that would be based on theories discussed in Section I. A. We now scrutinize whether and to what extent experts' SDR recommendations may be in line with the simple Ramsey Rule (SRR) or the extended Ramsey Rule (ERR) that feature prominently in policy guidelines.

We first impute the SRR using responses on individual components from each expert. We find that its median (mean) [modal] value is 3 (3.48) [4] percent. The mean SRR is thus 1.21 percentage points higher than the mean SDR. Figure 2 displays a histogram of the differences between individual SDRs and imputed SRRs, excluding five outliers. The SDR coincides with the SRR for only 36 respondents.[28] This strongly suggests that the simple, deterministic Ramsey Rule is not the preferred model for determining the SDR for the majority of experts. Indeed, the qualitative responses of many experts reveal well-motivated reasons for departing from this framework. We now explore potential reasons for the large heterogeneity in differences between the SDR and the SRR depicted in Figure 2.

One prominent alternative to the SRR that many experts might have relied upon is the more general ERR. Indeed, a number of respondents explicitly stated that they considered uncertainty in the economy's baseline growth when forming their SDR recommendation.[29] In the extended Ramsey Rule,

[28]It is important to note that the fact that these responses are equal does not necessarily imply that experts based their SDR response on the SRR.

[29]For example, an expert stated: *"my discount rate is less than implied by the Ramsey*

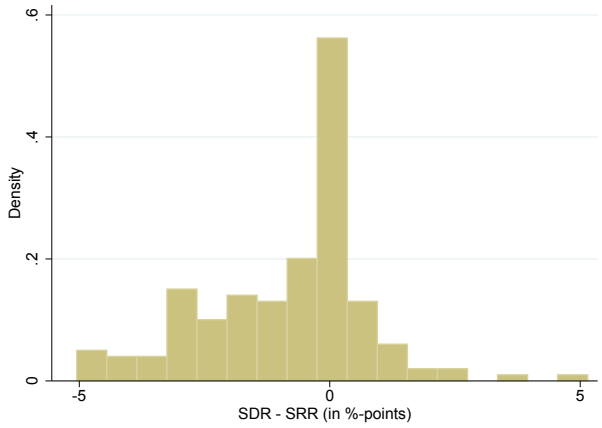


Figure 2: Histogram of the difference between the recommended SDR and the imputed simple Ramsey Rule (SRR $= \delta + \eta \times g$), in the interval [-5.5, 5.5].

a precautionary savings motive results in ERR$-$SRR $= -0.5\eta\,(\eta+1)\,\sigma^2 \leq 0$, where σ^2 is the volatility of real per-capita consumption growth (Gollier 2002, 2011).[30] If respondents use the ERR for determining their SDR, we would expect that SDR $<$ SRR. This seems to be the case for most respondents (see Figure 2). While we do not elicit forecasts of σ, we can indirectly infer the value of this parameter that would make the ERR consistent with the SDR for any given expert. We can reconcile the SDR of only seven respondents with the ERR if their applied estimate of $\sigma \in (0\%, 3.6\%]$. This is the value of σ used by Gollier (2012: Table 3.1). Allowing $\sigma \in (0\%, 9\%]$, the SDR response of 41 experts can be reconciled with the ERR. The mean (median) value of σ that would ensure consistency between the SDR and ERR response for the 97 experts for whom SDR$<$SRR is 11 percent (10 percent), which is considerably higher than standard estimates for this parameter value (Gollier 2011). This implies that even though a number of experts may have relied on the ERR,

rule because I use the extended rule, incorporating uncertainty about long term growth".

[30]Note that the interpretation of η here may differ from that of our survey, as the survey does not explicitly focus on risk aversion and prudence.

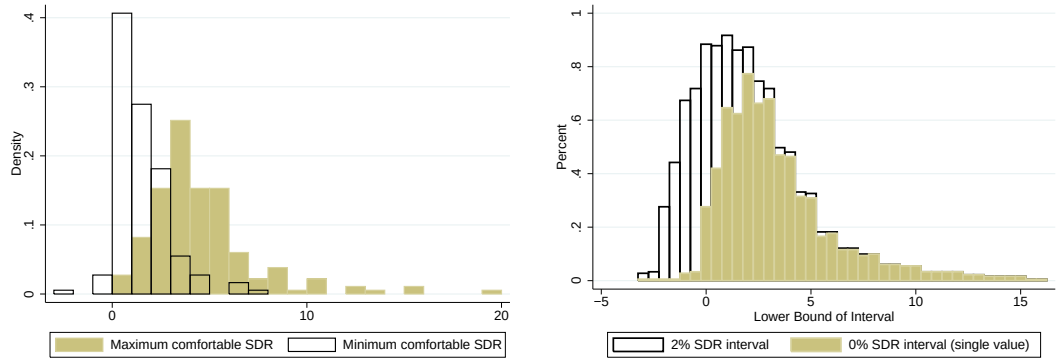
the precautionary savings motive in this framework is unlikely to have been the only determinant driving lower SDRs.

Yet, experts may have factored in more severe forms of uncertainty, such as jump-risks in the spirit of Barro (2006), or considered other issues that drive a wedge between the recommended SDRs and imputed SRRs. Indeed, a range of arguments have been provided by experts for lower SDRs. Among others, these point towards the use of declining discount rates or the consideration of changes in the relative price of non-marketed environmental goods.

Figure 2 also shows a number of experts recommended SDRs that are higher than the imputed SRR and thus cannot be reconciled by precautionary savings. Such positions were often motivated by arguments relating to the opportunity cost of governmental funds, indicating the need to evaluate intergenerational projects using the opportunity cost of capital, rather than the SRR or ERR, together with the idea that the former will typically be higher. Beyond these technical arguments, further criticism focused on the need for alternative approaches to inform intergenerational decision-making.[31]

Overall, the analysis demonstrates that within the expert community there are several distinct schools of thought on how to discount intergenerational projects, which are more nuanced than the standard normative-positive dichotomy. In particular, our analysis reveals quantitatively and qualitatively that many experts are skeptical about the central role of the simple Ramsey Rule in determining policy recommendations on long-term public projects.

[31]Experts recorded doubts about whether *"a representative agent model with a standard Ramsey social welfare function is adequate in either descriptive or normative terms"*. They also point towards *"richer ways of framing questions of intergenerational justice than simply tweaking the discount rate"* by developing alternative criteria for intergenerational decision-making. Such approaches might *"set limits in physical terms to the future development that must not be exceeded for reasons of intra- and intergenerational justice [...]. Then use a discounted utilitarian approach to optimise development only within these limits"*.



(a) (b)

Figure 3: Figure (a) depicts the minimum and maximum SDR values that individual experts are still comfortable with recommending. The x-axis in Figure (b) shows the lower bound of an interval of given size (e.g. 2 percent) and the y-axis the proportion of experts whose acceptable SDR range has some overlap with an interval of a particular size starting at that point.

C. Disagreement on Social Discount Rates

Point recommendations on the SDR range from 0 to 10 percent. It is therefore unsurprising that the minimum acceptable SDRs reported by some experts are above the maximum acceptable SDRs of others (Figure 3 (a)). Yet, a closer inspection of the experts' acceptable ranges shows that there is considerable space for agreement on the SDR.

The colored histogram in Figure 3 (b) shows the proportion of experts whose acceptable SDR range includes any given SDR value. From this colored histogram we can also conclude that, besides being the median and modal point SDR recommendation (cf. Table 1), a SDR of 2 percent is also contained in the acceptable range of more experts than any other value (77 percent). The transparent histogram shows, for any given SDR value, x, the proportion of experts whose acceptable SDR range overlaps the interval $[x, x+2\%]$. Looking

at $x = 1\%$ on this histogram reveals that the interval $[1\%, 3\%]$ is overlapped by the acceptable range of the SDR for 92 percent of experts.

These data on SDR ranges shed light on which of the prominent positions voiced in the academic and public debate—the long-term SDR of 4.5 percent in Nordhaus (2008), or Stern's (2007) central SDR value of 1.4 percent—is more representative of the expert community. Based on the point SDR recommendations, we find that while 30 percent of experts recommend Stern's SDR of 1.4 percent or lower, only 9 percent of experts recommend Nordhaus' value of 4.5 percent or higher, with 61 percent forming the middle ground between these two. The SDRs employed by Nordhaus (2008) and Stern (2007) are included in the acceptable range of 31 percent and 58 percent of experts, respectively. While there is more support for Stern's position, our findings suggest that neither may be deemed robust enough by policy-makers, who might prefer instead to take a position between the two.

IV. Discussion

In this section we discuss advice on determining an appropriate SDR for long-term policy making from the survey evidence. Three immediate questions arise. First, what role should experts play in providing the raw materials for the SDR? Second, how should heterogeneities in expert views be treated when calculating the appropriate SDR? Third, what does this survey tell us about how to discount risky projects?

A. The Role of Experts

The role of experts in public policy has itself been a source of disagreement (Dasgupta 2008; Weitzman 2001). One typical criticism is that guidance on social discounting should be informed via more *"democratic"* means (Dasgupta 2008: 158). It is often claimed that economists do not command any special expertise in matters of ethics. Yet some discussants explicitly advocate an active role for *"genuine specialists"* to steer the process of setting SDRs (Pindyck 2017; Sunstein 2014: 550). This comes as no surprise, as the questions raised by intergenerational discounting are highly complex. Compared to members of the general population, experts will have spent considerably more time considering the intricate issues that arise. We also note that governmental guidance on social discounting is generally influenced by expert opinion, as are other areas of policy as evidenced by, for example, membership of Monetary Policy Committees. There is also a distinction to be drawn within economics between genuine specialists and general economists. Monetary Policy Committee members typically fall into the former category, as do those who have provided recent advice to international governments on social discounting. Therefore, while there are good arguments for more inclusive approaches, it is also imperative that advice is heard from genuine experts on the determinants of the long-term SDR. It is thus also crucial to obtain a more representative account of expert opinions, such as we provide in this paper.

B. Dealing with Heterogeneity

Based on the heterogeneous responses to this survey, a decision-maker might reasonably ask which single rate to use when discounting the certainty-equivalent cash flows from an intergenerational project. Deciding how best to

adjudicate between conflicting opinions, and aggregate different forecasts, is a contentious issue to which there is no single accepted answer.[32] Given the lack of clear theoretical guidance on how to aggregate individual expert responses, what remains may be to rely on a data-driven approach. Fortunately, this points towards a rather clear recommendation: a long term SDR of 2 percent is not only the modal and median recommendation but also the SDR value that is included in the acceptable ranges of most experts (77 percent). Interestingly, this long-run SDR of 2 percent is lower than the equivalent recommendations of the UK, French and US governments.

C. Discounting Expected Cash Flows

The exercise that we have undertaken here has been framed around certainty equivalence. For this reason, the recommended SDRs discussed are risk-free rates, appropriate for calculating present values for risk-free or certainty-equivalent costs and benefits. However, in most circumstances, governments use expected cash-flows directly as if they were already certainty-equivalent values.[33] The problem then is that if there *are* project-specific risks, and these are correlated with consumption risk, then public projects may contribute to,

[32]One proposal is to calculate the discount *factor* for each respondent, and then construct the social discount factor as a weighted average of individual discount factors. This is the approach taken by Weitzman (2001) and leads to a declining term structure of SDRs. The difficulty with this approach is that it is not clear what weights to assign to each of the expert discount factors. While Weitzman (2001) gives each response equal importance, this has been a controversial choice (Freeman and Groom 2015; Heal and Millner 2014; Jouini et al. 2010; Millner and Heal 2017; Weitzman and Gollier 2010; Gollier and Zeckhauser 2005). In particular, Freeman and Groom (2015) show that the appropriate weighting depends on whether responses reflect disagreement on value judgments or uncertainty about forecasts.

[33]This approach has in part been motivated by the Arrow-Lind theorem (Arrow and Lind 1970), which has had considerable influence in policy circles. However, the Arrow-Lind theorem has been subject to increased scrutiny in recent years. Lucas (2014) and Baumstark and Gollier (2014) argue that it is unlikely to hold.

or diminish, macroeconomic risk. The appropriate SDR for evaluating the net benefits in such cases should then vary from one project to another depending on their risk profiles. The SDR for a climate change mitigation project, for example, is likely to differ vastly from that appropriate for health, transport and education projects if the social planner is using expected, not certainty-equivalent, benefits. Any given project should be penalized (rewarded) using a specific risk adjustment depending on whether it increases (reduces) macroeconomic risk (e.g. Gollier 2012: 193). For instance, consider a project j with a project consumption beta, β_j.[34] The consumption-based CAPM model estimates the SDR for project j as the risk-adjusted discount rate:

$$SDR_j = SDR + \pi(\beta_j), \tag{7}$$

where the last term, $\pi(\beta_j)$, represents the risk premium.[35] From equation (7) it is clear that *all* projects require information on the risk-free discount rate even in this expected cash flow setting, and this has been the focus of this paper. Estimating the risk premiums associated with long-term projects is a tricky issue about which there is little general agreement.[36] Further research is required to elicit expert opinions on these matters.

[34]This captures the percentage contribution to societal benefits of a risky project when overall consumption increases by 1 percent.

[35]For instance, Gollier (2012: 191) shows that under the assumptions of Section IA, and jointly normal project and consumption risks with correlation coefficient ρ, the risk premium is given by $\pi(\beta_j) = \eta\beta_j\sigma^2$ where $\beta_j = \rho\sigma_j/\sigma$.

[36]In relation to climate change, see, e.g., Dietz et al. (2017), Daniel et al. (2015), and Sandsmark and Vennemo (2007).

V. Conclusion

We have presented evidence from a survey of over 200 experts on the determinants of the long-term real social discount rate (SDR) for discounting certainty-equivalent cash flows of public projects with intergenerational consequences. The SDR is, perhaps, the single most important driver of any cost-benefit analysis evaluating long-term public projects. We find that the median (mean) recommended SDR of our experts is 2 percent (2.3 percent). While there is considerable disagreement between respondents on point recommendations, which range from 0 to 10 percent, more than three-quarters of those surveyed would find the median and modal SDR of 2 percent acceptable for risk-free projects. More than 90 percent are comfortable with a SDR somewhere in the interval of 1 percent to 3 percent.

A key innovation of our survey is that we not only elicit responses on the appropriate and acceptable SDR itself, but also on individual discounting determinants: recommendations on the rate of pure time preference and the elasticity of marginal utility of consumption, as well as predictions of long-term per-capita consumption growth and the average real risk-free rate of interest. This disentangled data allow us to shed some light on which approaches to social discounting experts use. Importantly, our disentangled data show that the simple deterministic Ramsey Rule, which is still found in governmental guidelines on cost-benefit analysis across the world, cannot explain the responses of the majority of our experts. This finding suggests that more complex models for social discounting are required, a conclusion that is supported by the rich body of qualitative responses we received. Many of our respondents provided comments relating to a number of extensions and alternatives to the simple Ramsey Rule. The issues raised included uncertainty, heterogeneity, relative

prices of non-marketed goods, as well as entirely different (e.g. non-Utilitarian or procedural, rather than consequential) approaches to societal evaluation. Policy guidance on social discounting should consider these alternatives to ensure efficient and equitable decisions on long-term public projects.

Further inspection of the data on individual discounting determinants yields findings that go beyond their value as potential inputs to governmental discounting guidelines. First, we find that the modal value of the pure rate of time preference is zero. Yet, with a median (mean) of 0.5 percent (1.1 percent), our results cannot confirm the IPCC's (2014: 229) conclusion that there is *"a broad consensus for a zero or near-zero pure rate of time preference"*. Second, our data suggest that the IPCC should consider lower growth scenarios in future assessments. Third the median and modal recommended elasticity of marginal utility of consumption of unity provides some support for the frequently made assumption of logarithmic utility. Lastly, we find that there exists considerable disagreement between experts on the relative importance of normative and positive approaches to discounting. Most report that the SDR should reflect both, highlighting that these previously accepted categories overly polarize more nuanced expert views. Engaging with both disagreement about values and uncertainty over forecasts is therefore an essential task for informing decision-making on long-term public projects.

Overall, our findings lead us to the conclusion that the prominence of the simple Ramsey Rule needs to be revisited as it provides an inadequate guide for determining SDRs, and that much of current policy guidance concerning social discounting and the evaluation of long-term public projects requires updating. While not uncontentious, our survey points to a long-term global SDR for certainty-equivalent cash flows of 2 percent. This risk-free SDR is lower than recommended by many governments around the world and prominent experts

(Nordhaus 2008, Weitzman 2001), yet closer to recent revealed evidence on long-term discounting from the housing-market (Giglio et al. 2015).

Our results provide insights into the determinants of the risk-free SDR that form key building-blocks in a range of approaches to evaluating societal decision-making. For instance, our data on the rate of pure time preference and the elasticity of the marginal utility of consumption may inform the calibration of the social welfare functions in integrated assessment models of climate change. Yet, as the future is inherently uncertain, governments should take into account risk and uncertainty when evaluating long-term projects. Building on the results presented in this paper, decision-makers would therefore be well-advised to consider the components of the risk-adjusted SDR, or how certainty-equivalents can be estimated, when evaluating long-term public investments.

Appendix

A. Non-Response Bias and Representativeness

We followed several standard procedures to test for the existence of non-response bias. First, from December 2014 to April 2015 we contacted via e-mail and telephone 60 randomly selected non-respondents. This allowed us to obtain a further 38 responses, with 14 of these experts providing qualitative data and 24 giving reasons for their initial non-responses.[37] Second, our sample includes quantitative responses from 11 of the 13 "blue ribbon" experts on social discounting from the Arrow et al. (2012) panel that advised the US EPA.[38] Third, we divide the sample between early and late responses (Dalecki et al. 1993, Necker 2014), defined by the subsample of 58 experts that directly responded to the first e-mail and those that answered a reminder e-mail. We check for potential non-response bias by comparing mean and median responses of each of these groups (see Table A.1). While there are differences regarding some discounting determinants, we find that there are no statistically significant differences in SDR values across different groups.

A further common measure for potential non-response bias is to consider groups by gender and location (Necker 2014).[39] We find that male experts selected into responding to our survey relative to the non-response group (91 percent versus 81 percent). The proportions of respondents and non-respondents

[37]Reasons include having insufficient time (11 times) as well as insufficient expertise (10 times), which may indicate self-selection of experts into responding to the survey.

[38]A twelfth panel member initially provided qualitative evidence only, but stated after the survey was completed that he would "follow the view of the median panelist."

[39]Personal characteristics were obtained from experts' own web pages. We collected information on continental location, gender, professorial title, and year of Ph.D. graduation as a proxy for (academic) age. We identify 89 respondents from Europe, 80 from the Americas and 14 from the Rest of the World. We have 167 male respondents, while only 16 women gave quantitative answers to our questionnaire. Approximately half our sample are full professors and the mean year of Ph.D. graduation is 1994.

Table A.1: Comparison with Non-Respondents and Arrow et al. Experts

	g	δ	η	**r**	**Normative**	**SDR**	**SDRmin**	**SDRmax**
	Results from the 185 quantitative responses							
Mean	1.70	1.10	1.35	2.38	61.53	2.27	1.12	4.14
Median	1.60	0.50	1.00	2.00	70.00	2.00	1.00	3.50
N	181	180	173	176	182	181	182	183
	Results from the 14 randomly selected previous non-respondent responses							
Mean	1.63	1.46	1.23	1.96	71.36	2.02	1.01	3.09
Median	1.50	1.00	1.00	1.75	75.00	2.00	0.63	3.00
N	12	12	8	12	12	13	14	13
	Results from 11 of the 13 Arrow et al. (2012) panel experts							
Mean	1.80	0.60	1.51	2.66	57.27	2.62	1.30	4.00
Median	2.00	0.50	1.50	3.00	50.00	3.00	1.00	4.00
N	11	11	11	11	11	11	11	11
	Results from the 58 early responses							
Mean	1.49	0.73	1.47	2.26	60.14	1.99	0.92	3.68
Median	1.50	0.38	1.50	2.00	50.00	2.00	0.75	3.00
N	58	58	56	58	58	58	58	58
	Results from the 127 late responses							
Mean	1.80	1.27	1.29	2.44	62.18	2.40	1.21	4.35
Median	1.80	0.90	1.00	2.00	70.00	2.00	1.00	4.00
N	123	122	117	118	124	123	124	125

are balanced in terms of characteristics such as being a full Professor (49 percent versus 48 percent) and average year of Ph.D. completion (1993.6 versus 1993.7). Experts currently based in Europe selected into responding (49 percent of respondents versus 32 percent of non-respondent). This may have led to a slight underestimation of the mean SDR given a slight propensity of Europeans to be more normative than non-Europeans.[40] Overall, our findings do not suggest substantial and systematic unidirectional non-response biases for SDR recommendations.

[40]The 88 experts currently located in Europe had a mean SDR recommendation of 1.91 percent, compared to 2.60 percent for the 91 non-Europeans.

B. Overview of Qualitative Responses

Table B.1: Overview of Qualitative Responses

Issue	N	Exemplary quote
Q1: Growth rate	14	I foresee a very bright economic future with a continued 2 percent growth rate for the coming century.
Q2: Pure time preference	10	I see no reason to treat generations not equally.
Q3: Elasticity of marginal utility	12	The elasticity of marginal utility of consumption is heterogeneous, and using a single value is a crude simplification.
Q4: Real risk-free interest rate	8	There is no interest rate for 100 year horizon (to my knowledge).
Q5: Normative vs. positive	16	The components of the SDR are overwhelmingly normative.
Declining discount rates and time horizon	20	I am more comfortable with declining discount rates [...] due both to declining time preference rates and to uncertainty about future consumption growth.
Heterogeneity and aggregation	19	Ideally, the input for our [social welfare function] would be a utility function that allows for heterogeneous preferences.
Opportunity cost of funds	8	SDRs should reflect the social opportunity cost of funds.
Project risk	6	We would have to consider very carefully the risk structure of the investment to get a correct discount rate.
Relative prices of non-marketed goods	20	If future costs/benefits accrue e.g. to environmental amenities, I would argue for a very low discount rate, based on an expectation of increasing relative prices for these goods.
Uncertainty	20	We need to admit that the current state of the world is full of uncertainties. [Yet] most uncertainties are neglected, and sometimes few remain when these are considered most important, [...] or easiest to accommodate.
Alternatives to discounting	15	Instead of imposing a [social welfare function] and calculate the corresponding optimum, it is 'better' to depict a set of feasible paths of consumption, production, temperature, income distribution, etc. and let the policy maker make a choice.
Comments on the survey	14	The search for THE discount rate, if that is your project, is deeply flawed.
Confidence intervals	8	I would also insist on providing confidence intervals.
Ramsey Rule	17	My discount rate is less than implied by the Ramsey rule because I use the extended rule, incorporating uncertainty.
Role of experts	7	I really think economists have very little special expertise in knowing the 'right' number. These parameters should be chosen in an open, iterative way with an eye toward understanding the consequences of different choices.
Limited confidence	13	Please ignore my response to Q4: I don't have the knowledge to make a meaningful forecast.
Limited expertise	5	I am not a real expert on these issues.

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ONLINE SUPPLEMENTARY MATERIAL

— Not for publication —

A Comparison to Weitzman's (2001) Survey

A natural reference comparison for our results is the seminal survey of Weitzman (2001), who asked more than 2000 Ph.D.-level economists to report a single appropriate *"real discount rate"* or *"rate of interest"* with which to discount projects aimed at mitigating climate change. The key difference between the response data of Weitzman (2001) and our results is that we find a substantially lower mean (median) SDR recommendation, with 2.27 percent (2 percent) compared to 3.96 percent (3 percent). Furthermore, we find a much lower standard deviation of the SDR responses of 1.62 percent compared to the 2.94 percent of Weitzman's (2001) respondents, and the range of point recommendations on the SDR is much more condensed (0 to 10 percent compared to -3 percent to 27 percent).[1] The modal recommended value for the SDR of 2 percent, however, is the same in both surveys.

We can point to at least three potential explanations for these differences. First, experts who have graduated from their Ph.D.s since Weitzman's survey was conducted generally recommend lower SDRs than those who have been in the profession for longer. Second, the literature that has influenced this new generation of academics — for example, on declining discount rates and the arguments articulated in the Stern Review — may have led more established

[1]The standard deviation, minimum and maximum of the imputed SRRs (3.52%, -2% and 26% respectively) are, by contrast, similar to the values reported in Weitzman (2001).

scholars to reduce their SDR recommendations during their careers. Third, Weitzman's pool of potential respondents is a general economics audience, while we select only those scholars who have published directly on discounting and can be considered specialists in this sense.

B Further Detail on the Selection of Experts

Based on full-text analysis in the Google Scholar engine, we searched the 102 leading economics journals (according to the ranking of Combes and Linnenmer 2010) plus the Review of Environmental Economics and Policy for publications since the year 2000 including the terms 'social discounting', 'social discount rate' or 'social discount factor' (in March/April 2014). As a result, we identified 778 potential experts. As not all pertinent contributions to the field use the term 'social discount rate', but often 'real discount rate' or simply 'discount rate', we further performed an EconLit search for the term 'discount rate' (in April 2014). To avoid picking up a large number of papers that only mention 'discount rate' in passing somewhere in the paper, we limited the scope to a within-abstract search. This search yielded an additional 241 potential experts. We thus identified a total of 1019 unique potential experts. We then manually discarded – using a weak relevancy test – publications that are clearly not of direct relevance for our study. The criteria used to judge whether a publication is not relevant are listed below:

- If the search phrases do not appear in the article itself, but only in the reference list.

- If the publication is a book review or another non-original contribution.
- If a value for the SDR is simply applied in an analysis without reference to the literature.
- If one of the phrases is mentioned but not elaborated on.
- If the publication relies on a discount rate that is clearly not relevant to long-term social discounting by governmental bodies, such as discounting of profits or university fees.

A publication is labeled irrelevant if it meets at least one of the listed criteria. If at least one of the publications of a scholar is regarded to be relevant (i.e. passes this weak relevancy test), he or she is considered to be an expert. As a result of the above relevancy test, we exclude 365 scholars from the pool of potential experts, thus being left with 654 potential experts. For 27 of these scholars we could not obtain an e-mail address because, for example, they have left academia or are deceased. Our final population of potential experts thus contains 627 experts.[2]

[2]Although potential experts have published in leading economics journals, a small number of them do not have a Ph.D. in economics but come from diverse fields, including law and the natural sciences.

C E-mail Text

This Appendix provides the text of the initial e-mail introducing experts to the online survey.

Dear [Personal identifier],

We are targeting a select group of academics with expertise in social discounting. The objective is to elicit recommendations on fundamental issues of discounting to inform long-term public investment decision-making.

We would be most grateful if you could find the time to complete the very short survey appended below.

https://www.surveymonkey.com/s/discounting-survey

Your individual response will be held in the strictest confidence.

Many thanks for your time and cooperation,

Ben Groom (LSE), Moritz Drupp (Kiel, LSE),

Frikk Nesje (Oslo, LSE), Mark Freeman (Loughborough)

D Further Checks of Non-Response Bias

We carried out a series of robustness checks to test for potential non-response bias (see Johnson and Wislar (2012) and Necker (2014) for discussions of different testing strategies).

In the main body of the paper, we first compare our 185 quantitative responses with a random sample of 60 potential experts who had not replied by November 2014. Second, we compare our 185 quantitative responses with the sub-sample responses of the Resources for the Future (RFF) Arrow et al. (2012) panel on intergenerational decision-making. Third, we consider differences in observable characteristics – academic age, location and gender – among respondents and non-respondents. A related check is to test for self-selection of environmental economists into responding.[3] Indeed, we observe that they do: 48% of respondents are environmental economists, while only 33% of the non-respondents are environmental economists. Yet, we find that environmental economists' mean and median SDRs are not statistically signficantly different (at the 10 percent level) to non-environmental economists.

Lastly, we consider differences between experts who responded to the initial wave, and those who responded to a reminder. In Table 3 we report the results of a comparison of those who had responded to the first survey and those who had responded to a reminder to obtain a further indirect measure of potentially biasing participation. At the 10 percent level of significance only the mean

[3]We regard an expert to be an environmental economist if the publication that led us to select her or him as a potential expert is in one of: American Journal of Agricultural Economics, Ecological Economics, Energy Journal, Environmental and Resource Economics, Journal of Environmental Economics and Management, Land Economics, Resource and Energy Economics, or Review of Environmental Economics and Policy.

Table D.1: Alternative Comparison of Early and Late Responses

	g	δ	η	r	**Normative**	**SDR**	**SDRmin**	**SDRmax**
Split by time of response in SurveyMonkey								
Results from the 88 early responses								
Mean	1.63	0.93	1.44	2.42	61.72	2.18	1.07	3.89
Median	1.50	0.50	1.25	2.00	70.00	2.00	1.00	3.25
N	88	88	85	88	88	87	88	88
Results from the 88 late responses								
Mean	1.81	1.26	1.27	2.38	61.00	2.34	1.17	4.38
Median	2.00	1.00	1.00	2.00	68.50	2.00	1.00	3.50
N	85	85	83	81	88	87	87	87

forecasted per-capita growth rate and recommended social rate of pure time preference are different between the samples of early and late respondents. The mean forecasted per-capita growth rate and recommended social rate of pure time preference are higher for the sub-sample of respondents that required a reminder. On the other hand, the median recommendation on the elasticity of marginal utility is the only median response significantly different between the subsamples, with the median of those responding immediately being higher. As a robustness check, we also divided early and late respondents into equal sized groups and found that the results were similar. The results of this additional exercise are reported in Table D.1. While we find some effect for those requiring a reminder versus those that responded right away, we do not find significant differences in mean and median recommendations and forecasts when we split the whole sample into equal halves and consider early and late respondents based on this definition.

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