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Article:

Groom, Ben, Drupp, Moritz, Freeman, Mark Charles orcid.org/0000-0003-4521-2720 et al. (1 more author) (2022) The future, now:A review of social discounting. Annual Review of Resource Economics. pp. 467-491.

https://doi.org/10.1146/annurev-resource-111920-020721

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The Future, Now: A Review of Social Discounting

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Xxxx. Xxx. Xxx. Xxx. YYYY. AA:1–21

This article's doi:
10.1146/((please add article doi))

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Keywords

social discount rates, project valuation, governmental guidance, opportunity cost of capital, ramsey rule.

JEL codes: H43, D61, Q58.

Abstract

Governments across the world are coming under increasing pressure to invest heavily in projects that have maturities of decades or even centuries. Key areas of concern include climate change mitigation, environmental and biodiversity protection, nuclear decommissioning, enhancing infrastructure and coastal defenses, and long-term healthcare management. Whether such projects are evaluated as being economically justifiable depends on the social discount rate (SDR) that the government deploys. This variable converts future costs and benefits of public policy into their value today, thereby facilitating the comparison of social investments with different maturities. Critically, the result of such analysis is extremely sensitive to small changes in the choice of the SDR, yet policy guidelines differ widely across countries and international institutions. In this paper, we provide a review of the academic literature on long-term SDRs, with particular emphasis on how these insights have been integrated into governmental guidance.

1. INTRODUCTION

In the appraisal of public policy, programmes and projects, the social discount rate (SDR) converts costs and benefits in the future into commensurate current units of account, known as 'present values'. These reflect how the implicit price of time evolves with the time horizon and thus allows for different courses of action with different time-profiles of benefits and costs to be compared. Social discounting is therefore a crucial part of establishing that government action provides value for money.

When the maturity of a project is long-term, its estimated present value is extremely sensitive to minor alterations to the SDR. This is because small changes to the annualized rate compound to much more significant differences over very long time horizons. Indeed, it is because of the sensitivity of long-run cost-benefit analysis to the choice of the SDR that discounting the distant future has been described as *"one of the most critical problems of all of economics"* (Weitzman 2001, p.260).

In recent decades, disagreement on the SDR was most obviously seen in the aftermath of the Stern Review (Stern 2007) on the Economics of Climate Change, which took a normative stand and advocated for a low real SDR of 1.4 percent. This resulted in policy conclusions that favored strong and immediate action on climate change mitigation. In a positivist response, Nordhaus (2007, p.686) noted that the *"unambiguous conclusions about the need for extreme immediate action [do] not survive the substitution of assumptions that are consistent with today's marketplace real interest rates and savings rates"* and proposed instead a SDR of around 4.5 percent (cf. Nordhaus 2008). This led to a lengthy debate in academic circles over the appropriate value of the SDR. While academic discussions are less polarized now than they were 15 years ago, with the majority of experts forming a 'middle ground' between the positions of Stern and Nordhaus, there is still material disagreement over *how* to determine the discount rate (Drupp et al. 2018). Links between individual academics and policymakers have had a significant influence on how this literature has been applied in government practice (Groom and Hepburn 2017) and this helps explain why policy guidance varies so much internationally (OECD 2018).

The disagreement on approaches relates to the prominence of the 'workhorse' model of the Simple Ramsey Rule (SRR) used by both Stern (2007) and Nordhaus (2007), and on extensions for uncertainty and declining discount rates, risk, inequality, and limited substitutability of non-market goods. Other economists argue instead for basing the SDR on either market based approaches, including the Social Opportunity Cost of Capital, or alternative societal criteria related to intergenerational distribution and efficiency more broadly.

In this paper, we provide a review of the academic literature on social discounting and the way in which different approaches have been incorporated into country and institutional guidelines. We thereby build on and extended previous reviews on the topic (e.g., Golllier and Hammitt 2014). This enables us to provide greater clarity over why policy guidance on this topic is so heterogeneous internationally. Our paper is therefore of particular relevance for policymakers at a time when there are processes in place in a number of countries to review discounting guidelines. We also hope that our paper provides a useful advanced introduction to academics and research students interested in learning more about social discounting.

The paper proceeds as follows. Section 2 provides a broad overview of the purpose of discounting in public appraisal and the different approaches taken. The key distinction is between production side measures reflected by the Social Opportunity Cost of Capital (SOC), and the consumption side reflected by the Social rate of Time Preference (STP). This is followed by a discussion of additional adjustments typically recommended to account for capital market imperfections: the weighted average of SOC and STP approach, the Shadow Price of Capital (SPC), and consideration of the Marginal Cost of public Funds (MCF) respectively. Section 3 provides greater detail on the 'workhorse' theoretical model leading to the SRR, and discusses some notable extensions related to uncertainty and declining discount rates, risk, inequality and limited substitutability of non-market goods. It also offers some insights into how to calibrate these approaches based on expert surveys, or other sources including revealed and stated preferences.

Section 4 provides an overview of the extent to which the literature in the previous two sections forms the basis of governmental guidance across the world. This emphasises the wide variety of approaches that are taken by well-informed policymakers in different jurisdictions. Section 5 reviews some prominent alternative approaches to social discounting not currently accounted for in country and institutional guidelines. It shows how to correct for some of the drawbacks of the SRR and its extensions, thorough sustainability requirements, priority to the worse-off generations and more subtle accountability for intergenerational risks and uncertainties. Section 6 concludes.

2. GENERAL APPROACHES TO SOCIAL DISCOUNTING

2.1. The Purpose of Social Discount Rates

The SDR converts costs and benefits that accrue at different points in time into units that are commensurate at a given evaluation date: usually the evaluation date is the present, hence 'present values'. In this way the efficiency of public interventions, such as investment and regulatory or policy changes, can be appraised (ex ante) or evaluated (ex post) in common units. The SDR will reflect the numeraire (e.g. utility, investment/cash or consumption) and is intrinsically linked to the conception of intertemporal welfare against which efficiency is gauged (Dasgupta 2005). In public appraisal, depending on the approach taken, SDRs reflect the expected state of the world in which net benefits accrue in the future, the risks associated with future income growth (Gollier 2013), societal preferences for the risky inter-temporal trade-offs that investment entails (Groom and Maddison 2019), and the alternative opportunities available in the economy that are displaced by public investment (Burgess 2013). Using some or all of this information, the SDR places a price on costs and benefits that an intervention is expected to induce in the future.

When the object of public appraisal spans generations, the choice of SDR becomes particularly difficult since the outcome of appraisal becomes very sensitive to the SDR (Drupp et al. 2018). Market rates of interest, one source of information for the SDR, may not be appropriate (Beckerman and Hepburn 2007, Arrow et al. 2013, Gollier 2019): observable rates may not exist for extremely long maturities except for special assets (Giglio et al. 2015); they may not reflect the risks associated with public investments, environmental or other externalities, or ethical concepts of fairness, justice and sustainability (Gollier 2019, Dietz and Asheim 2012, Dasgupta 2008). Furthermore, the preferences revealed by individuals and households in the market place may not reflect social preferences: how society might agree to weigh future generations' well-being if they were asked.[1] For long-term appraisal, the debate as to whether normative (prescriptive) versus positive (descriptive) rationales for discounting are appropriate has received considerable attention (Arrow et al. 1996, Nordhaus 2007).

Just as economic fundamentals (e.g, interest rates, growth and risk) vary from country to country, so do the social and individual preferences over them. As a consequence the SDR varies across countries in its level and specific theoretical approach, as seen in Figure 1. The approach to long-run discounting also varies. The remainder of this section explains some of the theoretical underpinnings of these different approaches.

2.2. The Social Opportunity Cost (SOC) and Social Time Preference (STP) Approaches

The Social Opportunity Cost (SOC) approach is primarily a *production-side* approach that measures the social cost of public investment against the social cost of public funding. The SDR stemming from this approach reflects the cost of capital derived from the different sources of government funding and reflects the return on the private or corporate investment that it displaces. The argument is that public investments should have rates of return that compete with returns available elsewhere (e.g., Burgess and Zerbe 2011, 2013). We define the SOC approach as an SDR that reflects this cost of capital, and for simplicity assume that it reflects the returns available in the private sector: r_i. It is approrpriate for discounting costs and benefits when the numeraire is units of investment.

The Social Rate of Time Preference (STP) approach is primarily a *consumption-side* approach in which the STP reflects the rate at which society is willing to trade-off consumption today for consumption tomorrow. The STP reflects society's inter-temporal preferences, and the trade-offs that increase or decrease welfare. Public appraisal using the STP as the SDR require that public interventions compensate deferred consumption at a rate that ensures welfare is increased. The STP can be reflected by the market savings rates, reflecting the consumption rate of interest: r_c, as in the US (US EPA 2010), or otherwise the STP arising from a calibrated Social Welfare Function: e.g. the Simple Ramsey Rule (SRR) as in the UK (HM Treasury 2020). It is approrpriate for discounting costs and benefits when the numeraire is units of consumption.

[1] Theory suggests that SDRs calibrated from market returns do not satisfy the revealed preference criterion (Caplin and Leahy 2004, Millner and Heal 2021). Fairly general conditions have been identified in which it is efficient to give the future more weight than assigned in the altruistic preferences of the present as revealed through saving behavior. If one cares about the distribution of altruistic welfare over time and believes that the future should be given weight beyond what the present gives it through its altruistic preferences, then the weight on the future should be greater. This can also be motivated descriptively: Nesje (2021) shows that saving is generally inefficiently low in equilibrium and does not reflect the efficient discount rate, even without assigning the future more weight than included in the preferences of the present.

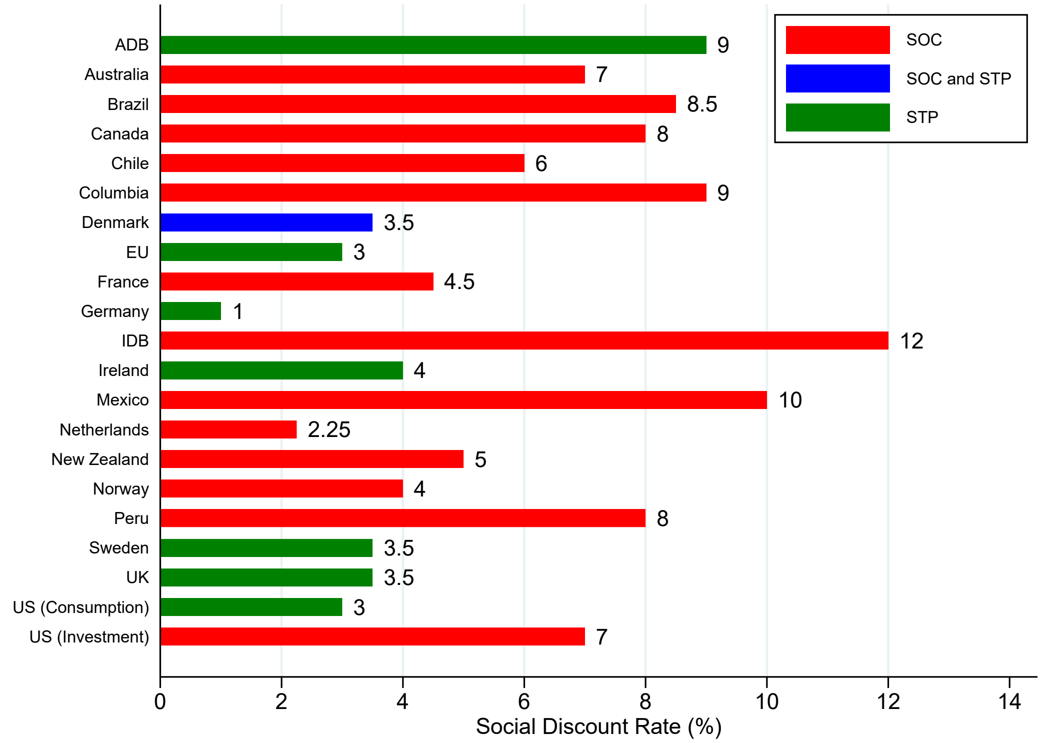

Figure 1: Social Discount Rates (in %) by country and approach.
Source: Own collection based on governmental guidelines; Note: Some countries, e.g. Brazil, Columbia, Mexico and Peru, follow the weighted SOC approach outlined in Harberger (1969); Abbreviations:ADB: Asian Development Bank; IDB: Inter-American Development Bank; SOC: Social Opportunity Cost of capital; STP: Social Time Preference.

With these definitions, the SOC approach considers the production side and ignores the trajectory of consumption, while the STP approach does the reverse (Drupp et al. 2018), and leaves the question of the cost of funding to be handled separately. Yet, in a perfectly competitive economy, where projects have sure costs and benefits, the STP and the SOC approaches coincide as the return to private or corporate investment, r_i, and the consumption rate of interest, r_c, are equalised. Perfectly functioning capital markets reflect the inter-temporal trade-off in market interest rates. In reality, economies are distorted by imperfect capital markets, consumption or profit taxes, and numerous other frictions, meaning that these the market rates of return, r_i and r_c, are no longer equal. A choice is then required on which is the most appropriate SDR for public appraisal in the second best world (Baumol 1986). This choice is highly contested with advocates for the SOC approach recently epitomised by Burgess and Zerbe (2011), Burgess and Zerbe (2013) and Harberger and Jenkins (2015), and for the STP by Bradford (1975) and Moore et al. (2013) and to some extent by Spackman (2020)

As shown by Figure 1, Governments have resolved this question in different ways too, reflecting different perspectives on the theory, including differing assessments of the role of government and its potential to crowd out private capital, or different ideas on what constitutes admissible information (e.g. market or corporate rates (in the US) versus more normative assessments (in the UK)). Some guidance reflects the perspectives of the government advisors and the policy questions being addressed, and the historical framing of cost-benefit analysis (CBA) (Groom and Hepburn 2017). As shown by Figure 1, the SOC usually leads to a much larger single or double digit discount rates, whereas the choice of STP typically leads to lower, single digit numbers.

There are several methods that try and reconcile the potential blindspots of pure SOC or STP approaches to the SDR. One method is to include in the public cost of capital the opportunity cost of both displaced private investment on the production side and displaced savings on the consumption side. Another approach is to use the STP, but deal with the cost of public funding through either; i) estimating a value for the net-benefits arising from the perturbed stream of consumption that displaced private investment induces; or, ii) estimating the marginal cost of raising public funds directly. The following sections elaborate on all of these methods.

2.3. The SOC approach in the second best world

Since Harberger (1969), the second best SOC approach reflects the impact of public investment (or other interventions) on the economy through an adjusted discount rate. Specifically, the cost of public funding is captured in a two-period general equilibrium model of public and private sectors in which the interest rate is endogenous to public investments, thus affecting private sector saving and investment decisions (Sandmo and Dreze 1971). In the second best world, where corporate taxes place a wedge between the rate of return to private investment on the production side, r_i, and the STP as reflected by the return to saving on the consumption side, r_c, the SDR is a weighted average of these two rates: $SDR = \alpha r_c + (1 - \alpha) r_i$. The weights reflect the source of funding for public investment: α is the share of public investment drawn from consumption and $1 - \alpha$ is the share drawn from private investment.[2] The appropriate SDR thus lies between r_c and r_i depending on the structure of public finance and borrowing. This 'Harberger' approach remains an important cornerstone of the SOC approach. Indeed, as Figure 1 illustrates it still directly influences government guidance in many Latin American countries, and indirectly in Canada and Australia. In the US the weighted average is recommended, or sensitivity is organised around the range between r_c and r_i, where typically r_i reflects some weighted average itself of corporate returns (e.g., Li and Pizer 2021).[3] Using the cost of domestic borrowing as the SDR also falls into the SOC category, where the return on Treasury bonds are seen to reflect this margin. Despite these applications, the 'Harberger' approach has been criticised on several fronts: i) the weights α and $1 - \alpha$ are difficult to identify; ii) the assumption that public sector and private sector investment are substitutes and not complements (crowding-out is inevitable); iii) corporate rates of return are not relevant from a risk perspective; iv) corporate rates of return are not welfare significant; and, v) the simple weighted average does not apply in a multi-period context (Spackman 2020). In a multiple-period context, the assumption that all benefits are consumed in the second period becomes problematic, and identifying the time profile of the weights demanding (Dinwiddy and Teal 1995). Nevertheless, the opportunity cost principle of the SOC approach remains a central argument in the SDR literature.

2.4. The STP approach accounting for displaced private investment

The STP approach can be augmented by ensuring that any impact of public investment on private investment (crowding out), and subsequent perturbations to consumption possibilities, are valued and reflected as a shadow price. This resulting price is know as the Shadow Price of Capital (SPC) (e.g., Moore et al. 2013). Another way in which the STP approach can be augmented is via the Marginal Cost of public Funds (MCF). This method adjusts public investment costs in any CBA to reflect the welfare cost of raising public funds using a different shadow price. The adjustment reflects the economic impacts of raising public funds: e.g. the distortionary effect of income tax on labour supply (Dahlby 2008, Spackman 2020).

The SPC approach reflects the welfare cost of public investment by estimating the impact of lost private sector returns in terms of lost future consumption. The shadow price, v_t, is then used to adjust the cost elements in a CBA appraisal where they displace private investment. With costs suitably adjusted, the NPV is calculated using the STP as the SDR. The STP is either calibrated to the observed market savings rate, r_c, or by assuming that consumers are reflected by a dynastic representative agent with a time-discounted Utilitarian social welfare function (SWF), and a (Simple) Ramsey Rule calibrated. We review this latter approach in the next section. The SPC method solves the choice of SDR via pricing/ valuation, rather than via an augmented or weighted average discount rate. To illustrate the mechanics of the SPC method, consider a two period-framework. In terms of consumption a simple investment project will have $NPV = -C_0^v + B_1 (1 + r_c)^{-1}$, where $C_0^v = \alpha + (1 - \alpha) v_0$ is the consumption cost of the marginal public investment reflecting the proportions in which public expenditure displaces consumption (with weight α) and private capital (with weight $(1 - \alpha)$). v_0 is the welfare cost of a marginal unit of displaced private sector capital, reflected by the consumption possibilities in this two period model: $v_0 = (1 + r_i)(1 + r_c)^{-1}$. Finally, B_1 is the consumption benefit in the second period.

Bradford (1975) considered another route through which a public project may affect welfare, and hence the SPC: via the reinvestment of project benefits in the future. In a multi-period context Bradford (1975) assumed

[2] The weights reflect the proportional responsiveness of consumption and private sector investment to changes in the interest rate, i: $\alpha = \partial C / \partial i / (\partial C / \partial i + \partial X / \partial i)$.

[3] In Canada, the weighted average discussed also includes foreign borrowing as discussed in Harberger (1969).

that the benefits of the project are invested and consumed in proportions β and $1-\beta$ respectively. The STP/ SPC decision rule becomes: $NPV = -C_0^v + B^v(1+r_c)^{-1}$, where $B^v = B(\beta v + 1 - \beta)$ is the consumption value of benefits in the second period, taking into account future consumption benefits from investment returns. One of the chief advantages of the STP/ SPC approach is that it separates the issue of valuation of costs and benefits, in the numerator of the NPV criterion, from matters of discounting consumption, using the STP. This allows in principle the cost of public funding to be addressed in a more nuanced way over time than a simple adjustment to the discount rate allows in the SOC approach. Nevertheless, the STP/ SPC decision rule can be represented by an adjusted discount rate so that broad implications can be easily compared to the SOC approach. In cash (rather than consumption) terms the equivalent NPV rule that reflects the STP/ SPC approach is:[4] $NPV^{cash} = -1 + B(1+r_{\alpha\beta})^{-1}$ where $r_{\alpha\beta} = (1+r_c)\frac{(\alpha v+1-\alpha)}{(\beta v+1-\beta)} - 1$. Through this discounting rather than pricing lens, there are several candidates for the SDR depending on v, α and β (as defined above): i) if $\alpha = \beta$, then $SDR = r_c$; ii) if $\alpha = 1, \beta = 0$, then $SDR > r_c$; and iii) if $\alpha = 0, \beta = 1$, then $SDR < r_c$. Importantly, the candidates are *centred* around r_c, not between r_i and r_c, making the typical weighted average approach, or the bounding for sensitivity between r_i and r_c, look questionable (Li and Pizer 2021, p.7).[5]

2.5. An equivalence between STP with SPC, and SOC

Both SOC and STP (with SPC) are attempting to reflect public sector costs in CBA. It is no surprise, then, that in some circumstances there is an equivalence between the STP with SPC and SOC approaches (Li and Pizer 2021). In the simple two period model, for instance, a decision rule equivalent to the STP with SPC approach can be expressed as a cash benefit, B, discounted using a weighted average SDR: $NPV^{cash} = -1 + B(1+r_a)^{-1}$, where $r_\alpha = \alpha r_c + (1-\alpha) r_i$ is the weighted average SOC (Sjaastad and Wisecarver 1977, Li and Pizer 2021). An equivalence holds in a multi-period context in which the project benefits are constant in each period (effectively an annuity) and hence $v = r_i/r_c$ for long time horizons. Here, the equivalent discount rate is again the weighted average r_α (e.g., Marglin 1963). However, the equivalence between the SOC and the STP or STP/ SPC approaches is not guaranteed, and depends on modelling assumptions and parameter values.[6] Indeed, as discussed in Section 3.5, a good practical recommendation is to treat discounting and the SDR separately from valuing/ pricing costs and benefits.

2.6. STP coupled with MCF

An alternative approach to handling the cost of public funds in an STP paradigm is to evaluate the welfare cost of the marginal taxation required to fund public investment via the taxes raised and the distortions it introduces. Income tax typically leads to a deadweight loss of $MCF = 0.5\epsilon wL$, where wL is wage income, and ϵ is the wage elasticity of labour supply (e.g., Dahlby 2008). In CBA the MCF adjusts investment costs to reflect these social costs, thereby converting units of investment into the numeraire of consumption, then uses the STP as the SDR so that the NPV criterion becomes: $NPV = \sum_{t=0}^{\infty}(B_t - MCF * C_t)(1+r_c)^{-t} > 0$. There are multiple theoretical frameworks for the MCF which build upon Pigou (1947), Stiglitz and Dasgupta (1971) and Atkinson and Stern (1974). An accompanying empirical literature shows that the MCF > 1 (e.g., Browning 1976, Snow and Warren 1996, Dahlby 2008), meaning project costs should be proportionately higher and the NPV test becomes more stringent. In practice, while many countries discuss the MCF in light of their use of STP as the SDR in their CBA guidelines, only a handful of countries put it into practice. The Republic of Ireland is a recent exception, where values between 1.2 and 1.4 are recommended. O'Callaghan and Prior (2018, Table 4.2) summarise international experience on the MCF in France (MCF = 1.2–1.25), New Zealand (1.2), the US (1.25), Norway (1.2), the Netherlands (1) and the European Union (1). Other empirical estimates propose values of

[4] Rearrange the expression for NPV above, noting that $C_0^v = \alpha + (1-\alpha)v_0$ and $B^v = B(\beta v + 1 - \beta)$.

[5] Arrow (1966) and Marglin (1963) model the SDR in an optimal growth framework with capital market imperfections as a constant savings rate. General equilibrium effects enter via the effect of public investment on the capital stock and growth, and under the assumption that every period re-investment is $I_t = sK_{t-1}$ in a two period model the SDR reflects the marginal cost of public investment as a weighted average of the STP and the marginal productivity of capital, r_k: $SDR = sr_c + (1-s)r_k$.

[6] As discussed, the weighted average SOC approach does not generalise to multiple periods, for instance. In fact, in a multi-period optimal growth context approach, the SDR converges to the STP when savings rates are constant: $SDR = STP$ (see Dinwiddy and Teal 1995, Chapter 11, p.190-191).

up to 2, suggesting that the welfare cost of raising taxation are twice that of the tax itself (Spackman 2020). Jacobs (2018) notes that the MCF of zero in the Netherlands is justified because of the offsetting welfare effect of progressive taxes on inequality.

Several papers address the equivalence of the SOC approach and the STP with MCF approach to project appraisal in a second best world where $r_c \neq r_i$, with Burgess (2013, p.10) showing that the SOC approach and the STP/ MCF approach are equivalent in the framework of Liu (2003). Burgess (2013) concludes that neither approach has an operational advantage over the other but that care is needed in interpreting claims of theoretical equivalences between STP using MCF and SOC approaches.[7]

The wide range of estimates for the MCF means that it represents another source of potential disagreement and manipulation in project appraisal (Spackman 2020). One practical solution to this particular problem arises if the MCF is common to all projects. In this case projects can be compared not by their NPV but by their Benefit-Cost ratios. Being a common factor, the MCF does not affect the preference order over public projects, just the overall NPV (Spackman 2020).

2.7. The SDR Choice in Practice

The heterogeneity of discounting approaches seen in Figure 1 reflects different practical resolutions to the issues raised. Among the countries in Figure 1, few augment the STP approach with the SPC, often due to the difficulties of estimating the SPC itself (Spackman 2020). Liu (2011), i.a., argues that the difficulty in estimating v, α and β rule out the STP/ SPC and weighted average SOC approaches for practical purposes, preferring instead to recommend the MCF approach. As Figure 1 shows, countries settle on either a pure SOC as a cost of capital usually rooted in private sector returns or the borrowing rate, or choose the pure STP, for reasons relating to the context or political economy of that country. For instance, in the UK, there is a strong tradition of welfare economics, and the STP approach calibrating a SWF is preferred. Here, the borrowing rate is seen as an inappropriate margin to measure welfare effects, also in part reflecting the view that the overall budget envelope is fixed and set politically. Such an approach is seen as a mistake by some, particularly where this leads to a lower SDR than the public cost of capital (e.g., Harrison 2010). The Netherlands use an SOC approach based on the cost of government debt (currently negative). The US is influenced by the weighted average approach of Harberger (1969) and Sandmo and Dreze (1971) in defining the range of sensitivity between 7% based on the SOC and 3% based on the STP measured by the savings rate. Denmark uses both the SOC and STP to calibrate its SDR. Many countries discuss the importance of the MCF, but only a few, e.g. Ireland, routinely use it in appraisal. Furhtermore, many countries use the STP without adjustment for the cost of public funds, or an SOC approach based solely on the return to private corporate investment, r_i. In this context, advocates of the SOC approach note that typically the observed market rates are higher than for the STP, and that:

> *"The real enemies of sound economics are those who press for the use of low discount rates like STP, without due recognition of the costs entailed when foregone investments would have had rates of marginal productivity much higher than STP."* (Harberger and Jenkins 2015, pp.9–10)

One conclusion arising from the observation that STP is less than SOC is that it reflects a broader macro-economic imbalance in savings and consumption, and that greater savings and investment is required in the economy (e.g., Harrison 2010, Chapter 2), and that the optimal policy may be to subsidise capital investment (Barrage 2018). It does not follow that the lower STP rate should be used in the appraisal of marginal projects in pursuing this public investment objective, since this approach could rule out highly productive projects, and rule in less productive ones, leaving the future worse off than it could have been.

Nevertheless, as Spackman (2020) points out, there is some common ground due to the equivalence in many cases of using an SOC approach and using the STP with an MCF > 1 (Harberger and Jenkins 2015, Burgess 2013). Finally, there are at least two cases when the STP is the appropriate SDR, and SOC is not. The first is in the case of Cost Effectiveness Analysis (CEA), where public funds are compared to public funds, rather than to displaced private funds, and hence are equivalent in cost terms. This result was first shown by Feldstein (1970). Second, Li and Pizer (2021) show that the appropriate weighted average SDR in a dynamic framework

[7] Confusingly, for example, in Liu (2011) the MCF reflects the shadow value of relaxing the government resource constraint, rather than the welfare costs of public funding. This approach asks the practitioner to discount costs and indirect revenues at the rate r_i and the project benefits at the STP, r_c, which seems unlikely to be adopted in practice.

is time horizon (H) dependent: $r_\alpha = r_{\alpha\beta} = (1+r_c)\left(\frac{(\alpha v+1-\alpha)}{(\beta v+1-\beta)}\right)^{1/H} - 1$, which converges to r_c as $H \rightarrow \infty$, and narrows the relevant range for sensitivity for medium term horizons. We will therefore consider calibrating the STP approach in more details in the following.

3. THE SOCIAL WELFARE CALIBRATION OF THE STP

We now return to the issue of how the STP can be estimated using a time-discounted Utilitarianism approach rather than by using a market savings rate. As we will show in the next section, this forms the basis for social discounting in a number of international juristictions. In this case, social welfare, $W(C_0, C_1, \ldots)$, is specified as:

$$W(C_0, C_1, \ldots) = \sum_{t=0}^{\infty} \exp(-\delta t) U(C_t). \tag{1}$$

This depends on the existence of a dynastic representative agent whose utility at any time t depends on comprehensive real per-capita consumption, C_t, of a single consumption good. This modelling approach is based on 'monetising' all marketable and non-marketable goods so they are expressible in terms of the single consumption good. This includes biodiversity, human health and other effects that are not normally expressed in straightforward economic terms. It is further assumed that the utility derived from the single consumption good is time-separable and can be discounted at a constant rate of pure time preference, δ.

Consider the social value of any potential project that will create future real benefits B_t at t, where B_t is expressed in terms of the single consumption good. Therefore, if the project is invested in, consumption rises to $C_t + B_t$. The current social value of the project, p, can be interpreted as the social planner's willingness-to-pay and is estimated by policymakers through an equilibrium argument. The expected change in social welfare is the same whether p is spent today to gain the future benefits, or nothing is spent today and no future benefits are reaped. Therefore:

$$U(C_0) - U(C_0 - p) = \sum_{t=1}^{\infty} \exp(-\delta t) E[U(C_t + B_t) - U(C_t)]. \tag{2}$$

If it is then assumed that benefits and prices are marginal in comparison to consumption (see Dietz and Hepburn (2013) for a discussion of this assumption), which allows a first order Taylor's series approximation to be taken:

$$pU'(C_0) = \sum_{t=1}^{\infty} \exp(-\delta t) E[B_t U'(C_t)]. \tag{3}$$

To progress from here, two further assumptions are generally invoked. The first is that utility is isoelastic:

$$U(C_t) = \begin{cases} \dfrac{C_t^{1-\eta} - 1}{1-\eta} & \text{if } \eta \neq 1 \\ \ln(C_t) & \text{if } \eta = 1 \end{cases}. \tag{4}$$

Here, $\eta > 0$ is the constant elasticity of marginal utility of consumption. It reflects how averse society is to differences in consumption both intertemporally and intratemporally and, as we expand upon below, also captures aversion to inequality in consumption across different states of nature in the form of risk aversion. With isoelastic utility, the social value of the marginal governmental project becomes:

$$p = \sum_{t=1}^{\infty} \exp(-\delta t) E[B_t] E[(C_t/C_0)^{-\eta}] + \text{Cov}[B_t, (C_t/C_0)^{-\eta}]. \tag{5}$$

The second commonly invoked simplifying assumption is that per-period logarithmic consumption growth between time 0 and t, y_t, is normally distributed, $y_t = (1/t)\ln(C_t/C_0) \sim N(\mu_t, \sigma_t^2)$,[8] then yielding:

$$p = \sum_{t=1}^{\infty} E[B_t] \exp(-t(\delta + \eta g_t - 0.5\eta(\eta+1)t\sigma_t^2)) + \sum_{t=1}^{\infty} \exp(-\delta t) \text{Cov}[B_t, (C_t/C_0)^{-\eta}], \tag{6}$$

[8]This means that $(C_t/C_0)^{-\eta} = \exp(-\eta t y_t) \sim \exp(N(-\eta t \mu_t, \eta^2 t^2 \sigma_t^2))$ so that $E[(C_t/C_0)^{-\eta}] = \exp(-\eta t \mu_t + 0.5\eta^2 t^2 \sigma_t^2)$.

where $g_t = \mu_t + 0.5t\sigma_t^2$, so that $E[(C_t/C_0)] = \exp(tg_t)$. Equation 6 forms the standard model for normative social discounting and, over the next three subsections, we consider the different elements of this equation.

3.1. The Simple Ramsey Rule (SRR)

The $\delta + \eta g_t$ term within the first summation is the Simple Ramsey Rule (SRR) when $g_t = g$ for all t:

$$\text{SDR} = \delta + \eta g \qquad \text{[Simple Ramsey Rule].} \tag{7}$$

As we will expand on below, this is the 'workhorse' model for normative discounting, applied, for example, by HM Treasury (2020) in its guidance on CBA to public sector bodies across the UK. It is comprised of two terms. The utility discount rate, δ, determines how much weight is placed on future utilities from today's perspective. The 'wealth effect', ηg, captures the fact that, because of decreasing marginal utility, the wealthier the future is expected to be (the higher g), and the more averse society is to consumption inequality across time (the higher η), the less value will be placed on projects that pay off in the future.

Despite its prominent role in policy circles, there are at least two major problems with applying the SRR. First, it is clear that, by ignoring all the other terms in equation 6, the model is theoretically highly simplified. We stressed the significance of this point in our survey of expert academic opinion on very long-term discount rates (Drupp et al. 2018). We asked experts for their preferred values of δ, η and g, which allowed us to calculate an imputed SRR value for each expert. We also asked them directly for their preferred long-term real SDR. We reported that, for many experts, the imputed SRR deviates substantially from their direct SDR recommendation. While the mean (median) imputed SRR is 3.48 (3) percent, the mean (median) SDR recommendation by experts is 2.27 (2) percent, yielding a gap of a full percentage point or more. This strongly implies that most academic experts think that the SRR provides an upward-biased estimate of the true SDR. In addition, even if we were to apply the SRR, there is no agreement between experts on the values with which to calibrate δ, η and g. This makes the SRR difficult to apply in practice despite its theoretical simplicity.

3.2. The Extended Ramsey Rule (ERR) and Declining Discount Rates (DDR)

The $-0.5\eta(\eta+1)t\sigma_t^2$ term in the first summation of equation 6 is a consequence of Jensen's inequality. With isoelastic utility, $U'''(C_t) > 0$ and so $E[U'(C_t)] > U'(E[C_t])$. Uncertainty in C_t thus increases the present value, p, or, equivalently, reduces the SDR. This term contributes to two extensions of the SRR. If all future logarithmic consumption growth is identically normally distributed — $\ln(C_\tau/C_{\tau-1}) \sim N(h, s^2)$ for fixed h, s^2 — then the relationship between $t\sigma_t^2$ and t depends on the autocorrelation, or persistence, of consumption growth. If this autocorrelation is zero, so that logarithmic consumption growth is independently and identically normally distributed, then $-0.5\eta(\eta+1)t\sigma_t^2 = -0.5\eta(\eta+1)s^2$ and this adjustment term is the same for all project maturities. This gives the Extended Ramsey Rule (e.g., Gollier 2013, Chapter 3):

$$\text{SDR} = \delta + \eta g - 0.5\eta(\eta+1)s^2 \qquad \text{[Extended Ramsey Rule].} \tag{8}$$

The strength of this term is driven by the prudence (Kimball 1990) of the social planner, captured by $-U'''/U'' = \eta + 1$. The social planner is concerned that future consumption levels may be below their expected value and therefore is prepared to save out of precaution in projects that pay off in the future. This translates into a lower SDR. However, this term is generally not included in governmental guidance on discounting because the volatility of global real aggregate consumption is too small to make this term of policy relevance (Freeman et al. 2018). For example, if $s = 3$ percent and $\eta = 1$, then the adjustment to the SDR is less than 0.1 percent. Yet, as initially shown by Rietz (1988), in certain models where consumption growth is not lognormally distributed and there is the potential for low probability but high impact negative shocks to consumption, then this can lead to a considerable precautionary savings motive that makes a material difference to the SDR.

The second effect was originally pointed to in a slightly different context by Weitzman (1998). If consumption growth has positive autocorrelation, then $t\sigma_t^2$ will be increasing in t. Therefore the SDR declines with the project maturity. Similar arguments for declining discount rates (DDR) can also be formulated in positivist discounting frameworks either when there is persistency in the short-term interest rate process (e.g., Newell and Pizer 2003) or when aggregating diverse expert opinion (Weitzman 2001). This early work on DDRs has led to a detailed academic literature that has attempted to make this approach relevant to policymakers (see, e.g., Cropper et al. 2014). As with the SRR, though, there are significant difficulties when looking to calibrate the term structure of DDRs. As we have shown in other work, the appropriate term structure is extremely sensitive to whether a normative or positive position is taken on discounting (Freeman and Groom 2015), and that very small changes in econometric assumption have large consequences for the shape of this term structure (Freeman and Groom 2016). Therefore, while DDRs have wide theoretical acceptance, there remains significant disagreement over how they should be applied in a policy context.

3.3. Risk Premiums

The covariance term in the final summation of equation 6 reflects the risk aversion of the social planner as captured by $-U''/U' = \eta$. While a single parameter, η, which is the elasticity of marginal utility of consumption, also determines both the risk aversion and prudence of the social planner, this is a specific characteristic of isoelastic utility that does not hold for all utility functions. This is because prudence and risk aversion reflect two different economic concepts. The former depends only on uncertainty over future consumption levels and is driven by the desire to smooth consumption across time. The latter depends on the systematic risk of a given project and is driven by the desire to smooth consumption across different states of the world at a given point in the future. Isoelastic utility implicitly assumes that these two motivations are related through η, but other utility functions, such as Epstein-Zin (cf. Section 5), allow these to be separated.

There are two broad approaches on how best to deal with this covariance term. Some economists prefer to replace the stochastic B_t with the non-stochastic 'certainty-equivalent' B_t^* in equation 6. B_t^* is set through the relationship $E[U(C_t + B_t^*)] = E[U(C_t + B_t)]$ so that the social planner is indifferent between whether they receive the risky benefit B_t or the certain benefit B_t^*.[9] When B_t^* is used, the covariance term in equation 6 can be ignored although the question then arises as to how B_t^* should best be estimated.[10] Alternatively, the covariance term can be incorporated as a project-specific risk adjustment to the discount rate as might be applied in a Capital Asset Pricing Model (CAPM) or Consumption-Based Asset Pricing Model (CCAPM) approach.

Even if it is accepted that the social planner should adjust the discount rate to account for project risk, it is not clear that the risk premium term is economically significant. The argument here is analogous to that for the Extended Ramsey Rule; aggregate consumption growth is extremely smooth and therefore estimated risk premiums are very small. These normative estimates of the risk premium are very much lower than those demanded by financial market participants as originally pointed out by Mehra and Prescott (1985). Again, low probability but high impact events can considerably increase these normative risk premiums and this is of particular relevance in debates about climate change mitigation, where much of the economic argument revolves around the avoidance of non-marginal tipping points (e.g., Dietz et al. 2021). Nevertheless, as shown below, there is significant disagreement between international policymakers about whether and how the SDR should be adjusted to account for project risk. The relevance of empirically-estimated SOC financial market risk premiums in determining the SDR is a particular point of contention.

Calibrating the covariance term itself is also extremely taxing. While for many projects, particularly those related to long-term transport investment, we can be confident that the covariance term is positive, we still do not even know its sign for climate change mitigation projects. While, Dietz et al. (2018) argue that it is positive, Lemoine (2021) argues instead that it is negative. This means that we cannot say whether climate change mitigation benefits should be discounted at a higher or lower rate than the risk-free SDR.

Finally, as shown by Gollier (2014), the magnitude of the risk premium also varies with the maturity of the benefit, t, if consumption growth has positive autocorrelation. If $B_t = a_t \exp(bty_t)$, where b captures the systematic risk of the project benefit and there is persistency in consumption growth, then the term structure of the discount rate is increasing (decreasing) if $b > 0.5\eta$ ($b < 0.5\eta$). However, even an increasing term structure of discount rates does not necessarily decrease the present value. This is because uncertainty in consumption growth increases the expected benefits B_t and increasing the discount rate through the same Jensen's inequality argument. Freeman and Groom (2021) argue that the present value of the risky project increases with greater

[9] The expectation operator on the left-hand side of $E[U(C_t + B_t^*)] = E[U(C_t + B_t)]$ follows because C_t is stochastic here.

[10] In many policy circles, the traditional Arrow-Lind theorem is applied. This argues that social planners should not be risk-averse and that therefore $B_t^* = B_t$, again separating risk aversion from η in the pricing relationship. More recently, a number of authors (e.g., Lucas (2014)) have pushed back against the theoretical relevance of Arrow-Lind, arguing that its assumptions are too restrictive and that social planners should be concerned about project risk.

consumption growth uncertainty for all values of b unless $b = \eta$ when there is no impact on the present value.

In conclusion, equation 6 sets out the general framework that has informed the normative policy debate on SDRs. Even when restricting the analysis to this equation there are numerous complex questions that must be addressed about how best to calibrate it. As we will see below, many academics also question the assumptions upon which equation 6 is based, including time-discounted Utilitarianism, the existence of a single consumption good and a representative agent, the assumption that projects are marginal, the use of isoelastic utility functions, and lognormality for consumption growth. It is, therefore, perhaps unsurprising that SDR policy varies so widely across the world.

3.4. Intra-temporal Inequality

If a project increases welfare it is efficient. So far the discussion of efficiency relates to the aggregate, usually representative agent conception of welfare, ignoring the underlying distribution of income and consumption. The implicit assumption underlying this welfare assessment is that distributional issues are not welfare significant, and that the existing distribution of consumption represents the optimal outcome of allocation and redistribution according to Pareto welfare weights. However, growing concern about income inequality following high profile reports on the matter (e.g., Stigliz et al. 2010), has led to a reconsideration of the appropriate SDR when there is aversion to intra- as well as inter-generational inequality. How inequality aversion affects the SDR via the SWF is discussed in Fleurbaey and Zuber (2015), Gollier (2015) and Berger and Emmerling (2020). The basic insight is illustrated by Emmerling et al. (2017) in a simple extension of the Ramsey Rule. When the income distribution is lognormal and utility is isoelastic, welfare can be represented by a representative agent with Atkinson's Equally Distributed Equivalent (EDE) consumption, and the SDR becomes:

$$SDR^{EDE} = \delta + \eta g_t^{EDE} \;= \delta + \eta g_t^{mean} + \eta^2 (g_t^{median} - g_t^{mean}). \tag{9}$$

The second term illustrates that when the median consumption is growing faster than the mean consumption (so that inequality is decreasing), the SDR ought to be higher than the Simple Ramsey Rule to reflect both higher growth on average and reduced inequality. Inversely, if inequality is increasing over time, the SDR should be lower since growth has an 'inequality premium'.

Adjustments to the welfare function and SDR to reflect societal inequality aversion are a relatively new phenomenon in the literature, but illustrate how to reflect the secular trends in inequality in project appraisal, essentially by augmenting the measurement of growth to reflect inequality. Emmerling et al. (2017) show that with an inequality aversion of 1 (2), countries like the US and UK whose growth has been historically inequality increasing should reduce their discount rates by 1 percent (2 percent).

This approach is conceptually different to equity weighting in CBA (Adler 2016). Here, the benefits and costs of a particular project are re-weighted to reflect the income levels of the affected parties, whereby the relevant weights are $\lambda_i = (Y^m/Y_i)^\eta$ (OECD 2018, Chapter 11), and are lower (higher) for individual with above (below) average income Y^m, and more so with higher societal inequality aversion, η. Consideration of inequality and the unequal incidence of climate damages also tends to raise the welfare cost of climate change, sometimes doubling the the Social Cost of Carbon (e.g., Anthoff and Emmerling 2019, Kornek et al. 2021).

3.5. Limited Substitutability of Non-market Goods

Our discussion so far has considered consumption goods as all those that provide well-being, including a host of goods that are not traded on markets, such as environmental amenities, health or cultural goods. We have thereby treated C_t as comprehensive consumption equivalents, now denoted as $\tilde{C}_t$. In many applications, however, non-market goods are ignored when computing the SDR. This is only valid in a special case: when non-market goods are perfectly substitutable with market-traded goods. In the general case of imperfect substitutability, non-market goods feature explicitly in the time-discounted Utilitarian SWF (from equation 1):

$$W(C_0, E_0, C_1, E_1, \ldots) = \sum_{t=0}^{\infty} e^{-\delta t} U(\underbrace{C_t, E_t}_{\tilde{C}}), \tag{10}$$

where $U(C_t, E_t)$ is the extended utility function representing preferences over a market-traded consumption good, C_t , and a non-market good, E_t.

There are two approaches to deal with the intertemporal appraisal of projects that impact on market and non-market goods (e.g., Baumgärtner et al. 2015, Gollier 2010, Traeger 2011, Weikard and Zhu 2005). First, we can explicitly consider how the relative price of non-market goods vis-a-vis market-traded consumption goods changes over time to compute comprehensive consumption equivalents, $\tilde{C}_t$, for each point in time and then use a single SDR. Alternatively, we can use good-specific consumption discount rates, one for market consumption, r_{C_t}, one for non-market goods, r_{E_t}.

For the first approach, we compute the value of non-market goods measured in terms of the market good numeraire. This is given by the marginal rate of substitution (U_{E_t}/U_{C_t}), which is the implicit price of non-market goods. This tells us by how much the consumption of market goods would need to increase for a marginal decrease in non-market goods to hold utility constant. The relative price change, RPC_t, measures the change in this valuation of non-market goods over time, and thus the change in their relative scarcity (Hoel and Sterner 2007). Future non-market values can be 'uplifted' using the RPC_t and a single SDR can then be used to discount future flows of private and non-market consumption. This is the approach taken so far in this paper, where a single consumption good captures both market and non-market effects.

For the second approach, we compute good-specific (dual) discount rates, given by:

$$r_{C_t} = \delta + \eta_{CC_t} g_{C_t} + \eta_{CE_t} g_{E_t} \tag{11}$$

$$r_{E_t} = \delta + \eta_{EE_t} g_{E_t} + \eta_{EC_t} g_{C_t} \tag{12}$$

where g_E and g_C are the growth rates, η_{CC_t} (η_{EE_t}) the elasticity of marginal utility of market good (non-market good) consumption with respect to itself, and η_{CE_t} (η_{EC_t}) denotes the elasticity of marginal utility of market good (non-market good) consumption with respect to the other (see, e.g., Baumgärtner et al. 2015). These dual rates can also be used in cases where non-market goods are not evaluated in monetary units, such as in satellite accounts for national accounting or for biophysical impact assessments.

To make this more concrete, consider a standard constant-elasticity-of-substitution (CES) utility function:

$$U(C_t, E_t) = \left(\alpha C_t^{\frac{\theta-1}{\theta}} + (1-\alpha) E_t^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}} , \tag{13}$$

where $0 < \theta < \infty$, is the constant elasticity of substitution between the two goods, and $0 < \alpha < 1$ is the utility share parameter for private consumption. With this CES utility function, we get the following straightforward equivalence between the two alternative approaches (cf. Weikard and Zhu 2005):

$$RPC_t = \Delta r_t = \; r_{C_t} - r_{E_t} \; = \; \frac{1}{\theta} \left[g_{C_t} - g_{E_t} \right] . \tag{14}$$

Accordingly, adjusting relative prices using RPC_t or applying dual discounting through the use of two separate discount rates r_{C_t}, c_{E_t}, are theoretically equivalent.

Calibrating either approach is empirically challenging. While there is some evidence on same-good elasticities, η_{CC_t} (see, e.g., Groom and Maddison 2019) and η_{EE_t} (Venmans and Groom 2021), there is very little on the two cross-good elasticity parameters that are required to calibrate dual discount rates. For computing relative price changes, evidence on the degree of substitutability, θ, is derived indirectly via an inverse relationship to the income elasticity of willigness to pay elicited in non-market valuation studies (Baumgärtner et al. 2015, Drupp 2018, Drupp and Hänsel 2021). These studies suggests that non-market and private goods are weak substitutes, with mean elasticities of substitution ranging from 1.30 (Drupp and Hänsel 2021) to 2.63 (Baumgärtner et al. 2015). Drupp and Hänsel (2021) contrast these empirical estimates with values used by experts (Gollier 2010, Kopp et al. 2012, Sterner and Persson 2008), with a mean value of 0.75. Similarly, while Baumgärtner et al. (2015) have assembled estimates of growth rates of ecosystem services, which suggest that ecosystem services have declined by 0.52 percent per year on average in the past 50 years, no comprehensive forecasts are available on non-market goods comparable with those of private consumption. Taking these estimates together yields values for the RPC_t, or equivalently for the difference in good-specific discount rates, Δr_t, of between 0.8 and 3.5 percent, suggesting sizable impacts for intertemporal project evaluation.

4. GOVERNMENTAL GUIDANCE

Previous sections have outlined different theoretical approaches to setting SDRs, which we now confront with governmental practice. Table 1 provides a selective overview of discounting guidance across a number of countries and inter- and supra-national institutions. Within most recent guidance, we have collected information on the headline SDR, the general approach to setting the SDR, components of the SRR and information on extensions discussed in Section 3: DDRs, project risk premiums, equity weights and non-market effects.

Table 1 showcases considerable heterogeneity across countries in setting the SDR. For instance, headline SDRs vary substantially. Overall, we see that somewhat more countries follow the SOC approach (N=14) as compared to the STP approach (N=8), while two countries feature both approaches. SDRs set according to the STP are, on average, 3.7 percentage points lower than those based on SOC approaches. While we observe a qualitatively similar pattern within Europe, where SOC informed SDRs are still 0.5 percentage points higher than the average of STPs (3.6 versus 3.1 percent), cross-continental differences dominate. SOC informed SDRs range from 2.25 percent in the Netherlands to 10 percent as used by the Inter-American Development Bank (IDB), while those informed by the STP range from 1 percent in Germany to 9 percent as used by the Asian Development Bank (ADB). Some countries exhibit mixed approaches, such as the simultaneous use of the SOC and STP approaches in the USA to derive the 7 percent and 3 percent SDRs, and the Danish approach that can be interpreted as being based on both approaches condensed into a single SDR. Discount rates used by other countries or institutions reflected additional rationales, such as the 10 to 12 percent rate commonly used by the World Bank, which is best thought of as a 'rationing device' instead of reflecting the SOC (Belli et al. 1998). SDRs in most Latin American countries follow approach by Harberger (1969).

4.1. Uncertainty

Almost all guidelines deal with uncertainty—either through DDRs, project risk premiums, both of these or yet in other ways. We have identified five main approaches in the selected guidelines: First, a few guidelines employ sensitivity analysis with alternative SDRs (e.g., Australia, Netherlands, USA). The Australian guidelines explicitly argue that this *"reflect[s] the uncertainty about the 'true' discount rate."*

Second, the guidelines in Denmark, Netherlands, and Norway capture systematic risk via a general risk premium on top of a risk-free rate, where the latter is sometimes negative in most recent guidances (e.g., in the Netherlands). Risk premiums vary from 1.5 percent in Denmark to 3.25 percent in the Netherlands and even 7 percent equity risk premium in New Zealand. The French guidance is particularly interesting as it aims at varying the risk premium between different projects based on their individual systematic risk, rather than the average risk across public projects. This has not yet been applied in practice, though, and for an interim period the SDR is effectively flat at 4.5 percent. Based on the work of Golllier and Hammitt (2014), a general risk premium increases rather than decreases over time, from 2 percent to 3 percent after 2070, exactly offsetting a declining risk-free component of the discount rate from 2.5 percent to 1.5 percent at the same point in time.

Third, we observe the use of declining discount rates (DDR) across a number of governmental guidelines. For instance, in Australia, the initial headline SDR of 7 percent declines to 3.7 percent after 300 years, with a value of 4.8 percent for the years 76 to 125. Similarly, the SDR in the UK declines from 3.5 percent to 2.14 percent after 75 years. In the USA, the suggestion for sensitivity analysis with lower SDRs for longer time horizons also appeals to theoretical underpinnings of DDRs. Across all guidelines that we have considered, we find that the longer-term SDR a century from now is a full percentage point lower on average as compared to the instantaneous headline SDR.[11]

Fourth, guidelines in Sweden and the UK capture catastrophic extinction risk as an additive component to the rate of pure time preference, effectively increasing δ by 1 percent, although the UK component captures a number of different uncertainty-related effects. Finally, a number of guidelines treat risk and uncertainty separately from setting SDRs, such as via Monte Carlo analyses (e.g., ADB and Canada) or by computing certainty-equivalents (e.g., Germany).

[11] This includes effects of DDRs and of lower SDRs for benefits with longer time horizons (e.g., in Peru).

Table 1: Selected overview of discounting guidance across countries

Country	Year	SDR	SOC or STP	δ	η	Uncertainty	Inequality	Non-market effects
ADB	2017	9%	STP	1%	1.5			6% SDR for env. or soc. benefits
Australia	2020	7%	SOC			Sensitivity with 3% & 10%, DDR to 3.7% (>300yrs), lower risk premium for non-market benefits		4% SDR for non-market benefits
Brazil	2020	8.5%	SOC					
Canada	2007	8%	SOC					3% SDR may be used for health & env. goods
Chile	2021	6%	SOC					
Columbia	2019	9%	SOC					
Denmark	2021	3.5%	Both	0.1% to 3%	1.25	1.5% systematic risk premium, falling to 0% (>70yrs). DDR to 1.5% (>70yrs)		
EU	2021	3%	STP			DDR for >50yrs		
France	2013	4.5%	SOC			Risk-free SDR from 2.5% to 1.5% & risk premium from 2% to 3% (>2070)		RPA for env. goods
Germany	2018	1%	STP	0%	1		Equity weights for SCC	
IDB	2021	12%	SOC					
Ireland	2019	4%	STP			DDR to 1.5% >275yrs		
Mexico	2014	10%	SOC					
Netherlands	2020	2.25%	SOC			3.25% risk premium; SDR sensitivity with 1.85% to 2.65%		1% RPA for env. goods
New Zealand	2020	5%	SOC			7% risk-premium		
Norway	2021	4%	SOC			DDR from 4% to 2% (>75yrs). 1.5% risk premium		
Peru	2021	8%	SOC			DDR from 8% to 1% (>200yrs)		
Sweden	2014	3.5%	STP	0.5%	1	1% catastrophic risk premium		
UK	2018	3.5%	STP	0.5%	1	1% catastrophic risk premium; DDR to 2.14% (>75yrs)	Separate equity weights	1.5% SDR for health; 2% RPA for air pollution damages
USA	2003	7% & 3%	Both			Lower SDRs may be used for important intergen. effects		

Source: Own collection based on governmental guidelines. Abbreviations: ADB: Asian Development Bank; IDB: Inter-American Development Bank; SOC: Social opportunity cost of capital; STP: Social Time Preference; DDR: Declining discount rate; SCC: Social cost of carbon; RPA: Relative price adjustment. Brazil, Columbia, Mexico and Peru follow the SOC approach outlined in Harberger (1969).

4.2. Intra-temporal Inequality

None of the guidelines perform a direct SDR adjustment to account for intra-temporal inequality, as suggested by Emmerling et al. (2017). Many guidelines relegate a treatment of inequality to separate analyses or refer to inequality in sections on stakeholder involvement, thus taking a more procedural approach. The Canadian guidelines, for instance, deem a quantitative treatment of equity impacts as "too controversial", while the UK guidelines have an explicit section on equity weights, including a clear recommendation on the degree of inequality aversion that ought to be employed. The guidelines of the German Umweltbundesamt (Matthey and Bünger 2020) employ equity weights for instance for computing the Social Cost of Carbon (SCC).

4.3. Limited Substitutability of Non-market Goods

A few countries already account for the limited substitutability of non-market goods, but relative price adjustment (RPA) or dual discounting has not seen widespread adoption yet.

The Netherlands, for instance, consider RPA of environmental goods of 1 percent per year (Groom and Hepburn 2017, Koetse et al. 2017). The general RPA of 1 percent can be re-adjusted depending on the specific project under evaluation. The guidance from 2020 (own translation) states that *"for project effects on easily substitutable ecosystem services and/or ecosystem services whose growth does not lag behind the growth rate of consumption, no relative price increase needs to be used"*. As an exemplary case they suggest agricultural production. Similarly, a RPA of more than 1 percent can be considered *"if there are hardly any substitution possibilities and/or the growth rate lags far behind consumption growth"*. They consider local recreational opportunities as an exemplary case.

The UK Treasury has set up a working group in 2021 to investigate whether a lower discount rate should be used for environmental effects, similar to the discount rate used for health effects that is 2 percentage points below the headline SDR of 3.5 percent. They concluded not to change the discount rate to be used for environmental effects but to rely on RPA, which will be further specified soon (HM Treasury 2021). Meanwhile, UK Defra (2021) already suggests to 'uplift' damage costs of air pollution by 2 percent per year, akin to using RPA. France considers RPA but does not provide any headline value for it. Other guidelines that consider dual discounting of sorts are less clearly rooted in the theoretical underpinnings outlined in Section 3.5, but apply sector-specific discount rates for some sectors but not for others. Along these lines, Canada and the ADB consider a lower SDR for environmental goods, health or social sector social benefits. The differences in good-specific discount rates, Δr, vary from 5 percent in Canada to 3 percent, as employed by the ADB.

5. ALTERNATIVE APPROACHES

We have so far discussed the SOC and STP, including time-discounted Utilitarianism approaches, that dominate international guidance on SDRs. The latter underlies the SRR and a number of its extensions but this is far from being the only plausible prescriptive theory when it comes to informing intergenerational decision making. Several alternative ethical approaches and SWFs have been proposed in the literature (Asheim 2010, Botzen and Bergh 2014, Fleurbaey and Zuber 2015). The relevance of these proposals depends on the particular context in which they are applied, as well as the consequences of their adoption. Generally, alternative welfare specifications tend to put higher priority to the worse-off in terms of intergenerational distribution or those subject to risk and uncertainty. In the context of climate change, we typically see a weakly higher SCC for central parameter values under these approaches as compared to time-discounted Utilitarianism. Lessons for the SDR are less straightforward, but could be implied by the higher weight on the future under each proposal.

5.1. Intergenerational Distribution

Time-discounted Utilitarianism is criticised for not properly accounting for the interests of future generations. The Chichilnisky criterion (Chichilnisky 1996, 1997) explicitly puts weight on the infinite future as defined by its level of instantaneous utility:

$$W(C_0, C_1, \dots) = \phi\Big(\underbrace{\sum_{t=0}^{\infty} e^{-\delta t} U(C_t)}_{W(\cdot) \text{ from equation } 1} \Big) + (1-\phi) \lim_{t\to\infty} U(C_t)\,, \tag{15}$$

where ϕ, with $0 < \phi < 1$, gives the relative weight on the time-discounted Utilitarian component, while $1 - \phi$ gives the weight on the limit of utility as time goes to infinity, thus putting a welfare weight on the infinite future. Yet, how to calibrate $1 - \phi$ remains an open issue. (Chichilnisky 2009, p.5) argues for a high value in the context of climate change, and thus a higher SCC, relating it to the marginal utility at *"the point of extinction"*. Several other papers consider this approach (e.g., Tol 1999, Botzen et al. 2018), although the precise consumption plan and implications for the SDR remain sensitive to parameter choices.

Time-discounted Utilitarianism is also criticised for not appropriately giving priority to the worse-off generations. Rank-Discounted Utilitarianism (Zuber and Asheim 2012) is one approach to rectify this. The criterion combines two notions of priority of the worse-off, namely a generation's absolute level of consumption and relative rank in consumption (Fleurbaey 2015). Social welfare can be expressed in terms of equation 1, but with consumption reordered according to ascending rank order $(C_{[1]}, C_{[2]}, \ldots)$:

$$W(C_{[1]}, C_{[2]}, \ldots) = \sum_{r=1}^{\infty} e^{-\delta(r-1)} U(C_{[r]}), \tag{16}$$

where δ can be interpreted as an additional parameter of intergenerational inequality aversion. This SWF reduces to equation 1 when consumption increases uniformly over time, as most guidelines assume.

Prioritarianism (e.g., Adler 2012, Fleurbaey 2015) also belongs to this strand of the literature. Setting $\delta = 0$ and considering a finite time horizon T, one can formulate the following SWF based on priority to a generation's absolute level of consumption:

$$W(C_0, C_1, \ldots, C_T) = \sum_{t=0}^{T} f(U(C_t)), \tag{17}$$

where f is strictly increasing and strictly concave, and captures the priority. Adler (2012) and Adler and Treich (2015) work with a power function: $f(U(C_t)) = U(C_t)^{1-\gamma}/(1-\gamma)$, which simplifies to time-discounted Utilitarianism when $\gamma = 0$. Adler et al. (2017) show that δ and γ are not equivalent in the context of climate change. The effect of a higher γ is non-trivial, as it does not always lower the SCC. For central parameter values, however, non-discounted prioritarian SWF imply a higher SCC than time-discounted Utilitarianism.

5.2. Intergenerational Risk and Uncertainty

Further extensions make additional adjustments for intergenerational risk and uncertainty (cf., Traeger 2009, Gollier 2013, Chapter 11). For example, when future consumption and/or project benefits are uncertain, Epstein-Zin preferences (Epstein and Zin 1989, 1991) have been proposed to disentangle plausible interpretations of η in equation 4. The SWF can be expressed recursively as (cf., Ackerman et al. 2013):

$$W(C_t, C_{t+1}, \ldots) = \left[(1 - e^{-\delta}) C_t^{\chi} + e^{-\delta} \{\mu_t(W(C_{t+1}, C_{t+2}, \ldots))\}^{\chi}\right]^{1/\chi}, \tag{18}$$

where $\chi < 1$ captures preferences for substitution across time, and the elasticity of intertemporal substitution is given by $1/(1-\chi)$. Certainty-equivalent future utilities are given by $\mu_t(W(C_{t+1}, C_{t+2}, \ldots)) = (E_t([W(C_{t+1}, C_{t+2}, \ldots)]^{\psi}))^{1/\psi}$, where $\psi < 1$ captures the preferences for substitution across states of nature, with the coefficient of relative risk aversion given by $1 - \psi$. This allows for different preferences for substitution across states of nature and time. In the special case that $\chi = \psi$, the criterion reduces to time-discounted Utilitarianism with isoelastic utility with $\eta = 1 - \chi = 1 - \psi$. Daniel et al. (2019) have studied how $\chi \neq \psi$ results in 'insurance values' which differ from time-discounted Utilitarianism, and in turn endorses difference consumption plans and discount rates. They find that the introduction of Epstein-Zin preferences puts *"the focus on near-term action and on the large costs of delay"* (Daniel et al. 2019, p.20889).

6. CONCLUSION

We have reviewed how social discounting is typically motivated and calibrated in both academic and policy-making circles. Over the past two decades this has become an increasingly pressing issue given the attention given to governmental action to help mitigate against climate change, protect biodiversity, enhance national infrastructure, and protect long-term health outcomes. As these issues span such very long maturities, the perceived social values of policy interventions are highly sensitive to the SDR. Yet, despite this, there is wide disparity of practice across different governments and supra-national organisations. We also note that, while the appraisal of public investment itself—the Net Present Value (NPV) calculation—may be sensitive to the SDR, and care is needed in selecting it, appraisal is 'rarely the last word' (Spackman 2020). In practice many other factors determine the final public investment *decisions*, as evidenced by the UK National Auditing Commission who note that there were 14 projects, worth £819m, with negative NPVs that were nevertheless funded (National Audit Office 2012, p.30).

While there are many ways to determine the SDR, in practice governments tend to rely either on the Social Opportunity Cost of Capital approach, which uses the social cost of public funding to determine the appropriate discount rate, often rooted in rates of return to displaced private capital, or the Social Rate of Time Preference. Over the last two decades, there has been a general shift towards using lower SDRs under both of these two approaches. This has been motivated by a range of new theory and empirical evidence (e.g., Weitzman 1998, Newell and Pizer 2003, Millner 2020, Lemoine 2021), lower market interest rates (Giglio et al. 2015, Bauer and Rudebusch 2020, 2021), and expert recommendations using both normative and positive considerations (Drupp et al. 2018). These lower SDRs contribute to more weight being placed on future well-being in the appraisal of public policy, programmes and projects. In the climate context, for instance, lower SDRs have substantial effects on the optimal stringency of climate policy (Hänsel et al. 2020, Traeger 2021).

Policymakers have actively engaged with a wide range of complex theoretical and empirical issues in their social discounting guidelines, implying that this is a very academically sophisticated policy audience. Widespread explicit consideration is given to declining discount rates, project risk, limited substitutability between market and non-market goods, and intratemporal inequality (although, for the last of these issues, the equivalence between equity weighting and adjustments to the SDR needs to be clarified). However, to date, governments have tended not to engage with normative debates about the SDR that lie outside standard time-discounted Utilitarianism. We have briefly outlined some alternatives to this, which governments may wish to consider in the future. Questions related to the long-run fundamentally deal with issues of intergenerational distribution and efficiency. This is likely to require more participatory and inclusive approaches than are currently incorporated in governmental guidance.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

We are grateful to the editor and a reviewer for constructive comments and to Noah Mensink, Marie Janssen and Simon Disque for excellent research assistance. We are also extremely grateful to Michael Spackman for extensive and excellent comments on an early draft. BG holds the Dragon Capital Chair of Biodiversity Economics, funded by Dragon Capital. MD gratefully acknowledges support from the BMBF ValuGaps project (01UT2103B) and from the DFG under Germany's Excellence Strategy (EXC 2037 and CLICCS) project no. 390683824, contribution to CEN of Universität Hamburg.

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