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ABSTRACT

We develop a demographically-based approach for estimating the utility discount rate (UDR) portion of the Ramsey rule. We show how age-specific mortality rates and life expectancies imply a natural UDR for individuals at each age in a population, and these can be aggregated into a population-level social UDR. We then provide empirical estimates for nearly all countries and for the world as a whole. A striking part of the analysis is how the estimated UDRs fall within the range of those currently employed in the macroeconomics and climate change literatures. We use our results to derive heterogenous social discount rates across countries and explore the consequences for an integrated assessment model of climate change. We find that introducing regional heterogeneity of UDRs into the RICE model has little impact on the business-as-usual trajectory of global emissions. It does, however, change the trajectory of optimal emissions, the corresponding optimal carbon tax, and the distribution of emission reductions across countries.

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1 Introduction

Few topics in economics are as fundamental and generate as much controversy as discounting. Benefit-cost analyses of long-lived public projects—such as those related to environmental protection, infrastructure, education, and health—rely heavily on social discounting. While most regulatory agencies and sub-fields within economics have established procedures for discounting future benefits and costs, economists continue to debate what constitutes an appropriate discount rate and, even more fundamentally, how discounting should be applied. That the potential consequences of the debate are significant is well-known: because small changes in the discount rate and procedures can have so much influence on present value calculations of long-lived projects, questions about discounting play a critical role in policy evaluation.

Within the last decade, economic analysis of climate change has brought many of the important issues about long-term discounting to the fore, showing that whether more or less aggressive climate policy passes a benefit-cost test depends critically on the social discount rate. This is the central insight of the highly influential and contrasting contributions of Nicholas Stern (2007) and William Nordhaus (2007).[1] Both employ the Ramsey-Cass-Koopmans framework for discounting within integrated assessment models (IAMs) of climate change, yet they differ in an important way on their underlying assumptions about the utility discount rate (UDR). In this context, the UDR represents a social planner's rate of pure time preference between generations irrespective of differences in consumption.[2] While Stern uses a very low rate that supports more aggressive climate policy compared to Nordhaus, the differences in how they justify their assumptions are central the motivation of the present paper. Stern follows classical economists and argues that the choice should be based on ethical considerations, whereas Nordhaus argues that discounting should be consistent with behavior reflected in observable market interest rates.

[1] Stern and Nordhaus have written several papers on the topic, but here we reference the original two where the distinction and focus on the discount rate first arose.

[2] The UDR is a parameter of the Ramsey discounting equation that is sometimes referred to as the social rate of pure time preference, in addition to other variants in the literature.

The Stern-Nordhaus exchange rekindled a long-standing debate about "prescriptive" versus "descriptive" approaches to discounting (see, for example, Arrow *et al.* 1996), and subsequent papers have sought to further clarify the role of normative and positive assumptions implicit in the economics of climate change and discounting more generally.[3] While the existing literature furthers the understanding of conceptual issues surrounding the choice of social discount rates, there remains relatively little empirical guidance on how to choose the underlying parameters, especially with regard to the UDR in the standard Ramsey equation.[4] As a result, researchers and policymakers are typically left to choose parameters based on one of two approaches. The first is a reliance on some ethical or normative criteria, many of which push in opposite directions. The second is to back out values after calibrating to observable parameters, including *a priori* assumptions about what the overall social discount rate should be.

In this paper, we develop an alternative, demographic approach for estimating the UDR that serves as a useful benchmark. Rather than make a judgment about how a social planner is to compare utilities across future generations, we exploit the fact that multiple generations are extant in a population at any point in time, and the UDR can reflect an aggregation over how these generations care about their own future utility. We begin with the assumption that individuals care about the future only to the extent that they live to enjoy it; that is, individuals discount future utility according to their own mortality risk.[5] We then derive estimates of a mean and median social UDR based on the age structure of a population and life expectancy at each age. Given actual life expectancies, the estimates inform periods considered long-term for many policies (e.g., 50 to 80 years), and they can apply even further into the future to the extent that population structures are stable.

While our approach over-simplifies how individuals may, or may not, have preferences for the distant future, arguments can be made in support of either over- or under-estimation.

[3] Examples include Weitzman (2007), Dasgupta (2008), Goulder and Williams (2012), Arrow *et al.* (2012), Schneider, Traeger, and Winkler (2012), and Gollier (2012).

[4] The other parameters implicit in Ramsey discounting, which we will discuss in more detail later in the paper, are the elasticity of the marginal utility of consumption and the rate of growth in consumption.

[5] Note that this differs from the risk of catastrophe at the population level, which has been discussed in the literature as it relates to the UDR (e.g., Weitzman 2009; Dasgupta 2007; Goulder and Williams 2012).

One's own concern for future generations would tend to lower the UDR, whereas general impatience would tend to increase it. Unlike other approaches, however, the methodology that we describe has an empirical and observable basis, thereby making it a useful point of comparison for existing assumptions about the UDR in the literature. Indeed, our approach shares the same basic structure as the macroeconomic literature on life-cycle models that weight future utility based on survival probabilities.[6] In effect, the demographic basis of our approach is "descriptive" at the individual level, and "prescriptive" in the population aggregation, which is necessary to arrive at an overall *social* discount rate. We estimate and discuss the two alternatives that we consider based on the mean or median of a population. Hence an advantage of our approach, as we will discuss, is that many normative judgments about the discount rate can be anchored with an empirical basis and focus on trade-offs among generations of the current population rather than assumptions about future generations not yet born.

We use the approach to empirically estimate UDRs for nearly all countries of the world with detailed demographic data from the World Health Organization. A striking feature of our results across countries is that they fall within the range economists generally employ and consider reasonable. Overall, the approach yields global estimates of the UDR at 1.3 and 2.1 percent for the median and mean aggregation, respectively. When comparing the results across countries, we emphasize the offsetting role of two demographic effects: age and life expectancy. A younger age structure and longer life expectancy tends to decrease a country's UDR, because more years to live will cause individuals to discount the future less. But, of course, a country's age structure and life expectancies are closely related. Countries that are younger tend to have shorter life expectancies (i.e., many developing countries), whereas countries that are older tend to have longer life expectancies (i.e., many developed countries). The result, as we will show, is that countries with very different demographic profiles can have similar estimates of the UDR.

[6] Yaari (1964) provides a seminal example, and recent papers use the same approach to explain patterns of economic growth and observed interest rates (Carvalho, Ferrero, and Nechio 2016; Gagnon, Johannsen, and Lopez-Salido 2016; Eggertsson, Mohrotra, and Robbins 2017).

Our primary contribution is the demographically-based approach for estimating UDRs, but we also place our empirical results in the context of deriving the overall social discount rate, sometimes referred to as the consumption discount rate. Specifically, we combine our estimates of the UDR with estimates of the other parameters in the Ramsey equation. The analysis is primarily illustrative, and we use a combination of expert opinion and country specific forecasts of economic growth. For example, based on Drupp *et al.*'s (2015) survey of experts on their views about consumption growth per capita (1.7 percent) and the elasticity of marginal utility (1.35), our estimates of the world's UDR imply social discount rates of 3.6 and 4.4 percent for the median and mean aggregation, respectively.[7] In what follows, we also estimate heterogenous social discount rates for each country based country-level UDRs and forecasts of economic growth.

Our approach provides a new methodology for deriving regionally-specific UDRs, with potential application to IAMs of climate change. We provide one such application using the Regional Integrated Climate-Economy (RICE) model (Nordhaus and Yang 1996; Nordhaus 2010). We compare the results of two alternative calibrations: one where all 12 regions of the model have the same global estimate of the UDR, and one where each region has its own estimate of the UDR. We find that introducing the heterogeneity has little affect on the *business-as-usual* trajectory of emissions. It does, however, have a meaningful effect on the *efficient* trajectory of emissions. We find that adding the UDR heterogeneity results in an efficient carbon tax that is 28 percent greater by the end of the century. Underlying the aggregate effects is a shift among countries such that those with lower UDRs reduce emissions more. Not only does a lower UDR impose greater concern for future climate damages, as is often noted in the literature, it also increases a country's emissions trajectory as a result of greater savings, capital accumulation, and output.

The remainder of the paper proceeds as follows. The next section develops our conceptual framework for deriving UDRs and contrasts it to previous approaches in the literature. This includes papers by Eckstein (1961) and Kula (1985), in addition to the recent macore-

[7] As we will discuss later, Drupp *et al.* (2015) also find that the average estimate of the UDR among economists is 1.1.

conomics literature previously referenced. Section 3 describes our data and reports the main estimates: country-specific and global results, along with an analysis of how demographic trends over the last two decades affect the estimates. Section 4 places our results in the context of overall social (consumption) discount rates. Section 5 reports the results of our RICE analysis. Finally, Section 6 concludes with a summary of our main results and a discussion of broader implications.

2 Conceptual Framework

We begin with the standard motivation for long-term discounting of social welfare in the Ramsey-Cass-Koopmans framework. There is an additively separable, utilitarian social welfare function of the form

$$W = \sum_{t=0}^{\infty} \left(\frac{1}{1+\delta} \right)^{t} U\left(C_t\right), \tag{1}$$

where δ is the UDR, and $U(\cdot)$ is assumed to be time invariant. The convention in this literature is to assume a utility function that has a constant elasticity of the marginal utility of consumption.[8] Then, on the optimal growth path, where consumption grows at a constant rate, differentiating and rearranging (1) yields the well-known Ramsey equation:

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

where the long-term social discount rate r is the sum of two terms. The first is the UDR, often interpreted in this context as reflecting the time discount rate across generations. The second is the product of the elasticity of marginal utility η, often interpreted as the degree of inequality aversion across generations, and of the consumption growth rate g.

Calibration of the Ramsey equation is fundamental to IAMs of climate change, as well as long-term benefit cost analysis more generally. We will have more to say about η and g later in the paper, but our primary concern for the time being is δ. As discussed previously,

[8] Specifically, the functional form assumption is $U(C_t) = C_t^{1-\eta}/(1-\eta)$, where η is the constant elasticity of the marginal utility of consumption.

a simplified assessment of the literature is that there are two camps for choosing values. One side interprets δ as an ethical parameter about concern for future generations, and this perspective typically leads to values at or very close to zero (e.g., Stern 2007). The other side emphasizes that r represents the real return on capital and should therefore be calibrated to real-world interest and savings rates (e.g., Nordhaus 2007), and this perspective typically favors higher values of the UDR after accounting simultaneously for η and g.

Our approach differs in that we seek to derive a mortality-based estimate of the utility discount rate. Specifically, we consider the UDR that a social planner might choose to represent an existing population under the assumption that long-term discounting is based on mortality risk. Note that we are not considering the risk to a population based on the chances of a catastrophe, which is sometimes invoked as a justification for using a non-zero UDR (e.g., Weitzman 2009; Dasgupta 2007; Goulder and Williams 2012). Instead, we consider individual risks based on mortality rates and life expectancy. In doing so, we exploit the fact that many generations are alive at any point in time, and the UDR can reflect an aggregation over how these generations care about their own future utility.

Our aim is to provide an empirically-based estimate that can serve as a useful benchmark for evaluating normative judgments and the potential importance of heterogeneity across populations (e.g., countries). While the approach clearly misses other possible motives that are likely to affect long-term discounting, some of which we discuss later in the paper, we argue that it provides a useful benchmark to a question in economics that generates much controversy with little direction on how the debate should be resolved.

It has long been recognized that uncertainty about survival affects the way individuals discount the future and therefore make intertemporal choices. Frederick, Loewenstein, and O'Donoghue (2002) provide a quotation from Rae (1834) that goes back almost a century before Ramsey:

> When engaged in safe occupations, and living in healthy countries, men are much more apt to be frugal, than in unhealthy, or hazardous occupations, and in climates pernicious to human life. Sailors and soldiers are prodigals. In the West Indies, New

> Orleans, the East Indies, the expenditure of the inhabitants is profuse. The same people, coming to reside in the healthy parts of Europe, and not getting into the vortex of extravagant fashion, live economically. War and pestilence have always waste and luxury, among the other evils that follow in their train (Rae 1834 p. 57).

More recently, Fisher (1930) is well-known for having shown how survival probabilities are important for understanding trade-offs between present and future consumption, and Samuelson (1958) uses mortality as a foundation in his seminal life-cycle model of lending markets.

Closely related to our approach in this paper, Eckstein (1961) describes a way that one can quantitatively infer a mortality-based UDR. He writes that

> The utility to be enjoyed at each future moment must be multiplied by the probability of being alive at that time, and since this probability falls with the remoteness of the period, a kind of pure discount factor emerges (Eckstein 1961 p. 456).

Eckstein (1961) goes on to describe that while this approach assumes individuals place no bequest value on wealth they leave behind upon death, it does suggest a pure rate of time preference that can be used for comparative purposes across countries where mortality rates may differ substantially.[9]

To begin operationalizing the approach, assume that individuals have fixed preferences over time, and a time varying discount factor, denoted $\beta^i(t)$. We can therefore write an individual's intertemporal utility function as

$$U^i = \sum_{t=0}^{T^i} \beta^i(t) u(c_t^i), \tag{3}$$

where T^i is the individual's expected years left to live from year $t = 0$. Because we are interested in a mortality-based discount factor, we can think of $\beta^i(t)$ as a probabilistic survival function to year t, which is itself a function of the individual's probability of death

[9] Beyond the general idea, our approach differs from what Eckstein (1961) actually does in his application to the United States and India. We describe how the approaches differ after establishing our framework.

at age in year t, denoted $\gamma^i(t)$. It follows that (3) can be expanded to

$$U^i = \sum_{t=0}^{T^i} \prod_t (1 - \gamma^i(t)) u(c_t^i). \tag{4}$$

Note that as the probability of death increases with age (over time), the discount factor decreases.

The social planner is then tasked with choosing a long-term UDR, δ, for use in the social welfare function specified in (1). We therefore seek an estimate of δ^i for $i = 1, ..., n$ in the population to represent each individual's preference for a long-run UDR, after which we consider different aggregation rules the social planner could employ over the n individuals.

To capture individual long-term preferences for one's own UDR, we need a statistic to summarize the time varying $\beta^i(t)$ in equation (3) over one's expected lifetime. Under the assumption of a constant rate, the natural solution is to take the geometric mean of the mortality-based discount factors that the individual is expected to face over $t = 0, \ldots, T^i$. Specifically, this implies a constant discount factor of

$$\hat{\beta}^i = \left[\prod_{t=0}^{T^i} \left(1 - \gamma^i(t)\right) \right]^{\frac{1}{T^i}}. \tag{5}$$

Raising both sides of this expression to T^i, a useful property of the statistic is that

$$(\hat{\beta}^i)^{T^i} = \beta^i \left(T^i\right). \tag{6}$$

That is, our summary statistic of a constant discount factor implies the same probability of survival in the year of life expectancy as the cumulative effect of the time varying mortality rates over the individual's expected life years remaining.

With this estimate of the discount factor in hand, we can back out the implied UDR for the individual, which as indicated above we denote as δ^i. By definition, the UDR must satisfy $\hat{\beta}^i = 1/(1+\hat{\delta}^i)$, and this implies

$$\hat{\delta}^i = \frac{1}{\hat{\beta}^i} - 1. \tag{7}$$

Implicitly, each individual has a mortality-based UDR that is a function of future mortality rates at age and life expectancy.

Returning now to the social planner's perspective, there is the important question about how to aggregate $\hat{\delta}^i$ for $i = 1, ..., n$ into a single measure of δ for use in the social welfare function (1). Any aggregation requires a normative stance on the weighting across individuals, and there is an existing literature on aggregating individuals' time preferences into a planner's objective function.[10] Here, however, we are generally agnostic about how such weighting should occur, but consider two aggregation rules because of their simplicity and frequent application—mean and median. The mean UDR among individuals in the population is simply

$$\bar{\delta} = \frac{1}{n}\sum_{i=1}^{n}\hat{\delta}^i. \tag{8}$$

One justification for using the mean is that it represents the mortality-based rate of the representative (i.e., expected) individual in the population. The median UDR is defined as

$$\tilde{\delta} = \text{Median}(\hat{\delta}^1, ..., \hat{\delta}^n). \tag{9}$$

While this approach provides a useful point of comparison, it can also be justified as consistent with the democratic principle of majority rule.

Regardless of the aggregation, the population estimates of the UDR built up in this way can be interpreted in two ways. The first is representative of the current population from $t = 0$ to $t \to \infty$. The second is a time-invariant estimate for a stable population structure. The latter is compelling because future generations are implicitly taken into

[10] Papers that focus on efficiency conditions include Li and Löfgren (2000) and Gollier and Zeckhauser (2005). A recent paper by Millner and Heal (2014) compares economic and political approaches to aggregation across information and commitment conditions.

account: as individuals age they are always replaced by those who are younger and face the same mortality risks, resulting is a stable estimate of the UDR through time. Both interpretations are consistent with frequent scenarios requiring a long-term discount rate, and we examine the stability of estimates over time in the next section.

Relation to previous studies.—As mentioned previously, Eckstein (1961) derives an estimate of the social UDR for select countries based on mortality rates, but his approach, in addition to a subsequent application by Kula (1985), differs from ours. Specifically, they estimate an individual's UDR as the geometric mean of expected mortality rates over the life cycle, rather than the geometric mean of the implied discount factor. In our view, there is no consistent basis for taking the geometric mean of the mortality rates, whereas there is for the discount factor because it actually follows a geometric process (see equation 4). Moreover, a mortality rate in any period will have a different interpretation than a discount rate. This follows because we know that $\beta = 1-\gamma = 1/(1+\delta)$, which implies $\delta = \gamma/(1-\gamma)$ and therefore $\gamma < \delta$ rather than $\gamma = \delta$, which is what Eckstein (1961) and Kula (1985) implicitly assume. This explains, in part, why our approach results in slightly higher estimates of the UDR for the select countries that Eckstein and Kula consider (the United States and India, and the United Kingdom, respectively) when using the same data. The other reason the estimates differ is that our approach is calibrated to exactly match the mortality rates individuals are expected to face at their life expectancy (see equation 6), whereas Eckstein and Kula's approach substantially overestimates the probability of survival, which lowers the discount rate as a consequence. More generally, our approach is also consistent with that taken in the recent macroeconomics literature that seeks to account for survival probabilities in life-cycle models (Carvalho, Ferrero, and Nechio 2016; Gagnon, Johannsen, and Lopez-Salido 2016; Eggertsson, Mohrotra, and Robbins 2017).

3 Estimation of Social Utility Discount Rates

We now turn to estimating mortality-based UDRs for nearly all countries of the world and for the world as a whole. We obtain demographic data from two sources. The first is country-specific life tables from the Global Health Observatory (GHO) data repository of the World Health Organization (WHO).[11] These tables report age-specific mortality rates by gender and binned in the following age classes: < 1 year, 1-4 years, 5-9 years,..., 90-94 years, 95-99 years, and 100+ years. They also include life expectancies at age (i.e., the expectation of additional years to live) for each bin and gender. The life tables are available for 194 countries. We use the 2012 tables for our primary estimates, but also use tables for 1990 and 2000 to examine how the results have changed over time.

The second source of data is country-specific population estimates from the United Nations Population Division.[12] These include the number of people in each country by five-year age groups and by gender. The estimates are available every five years. We associate these data for the year 2010 with the 2012 WHO life tables. When conducting the same analysis back to 1990 and 2000, we associate the UN and WHO data for that same year.[13]

These two sources of data are sufficient to estimate a population-level, social UDR as described in the previous section for nearly all countries of the world. To see the precise steps involved, first consider how to derive the UDR for an individual of a particular age within a specific country. Take the example of a 52 year old female in the United States. Based on the 2012 WHO life table for the United States, she has a remaining life expectancy of 33.15 years; that is, she has a full life expectancy of 85.15 years conditional on having reached age 52. For each of her expected remaining years, we also have an estimate of her

[11] We obtained the data with queries through the GHO's web service, Athena. Links with instructions on how to make data queries are available at http://apps.who.int/gho/data/node.resources.api

[12] The data are available at https://esa.un.org/unpd/wpp/Download/Standard/Population/

[13] When merging the two data sets, one adjustment is needed in the first age bin. The WHO data on mortality rates and life expectancy disaggregates the first age bin (0-4 years) into two, providing data for individuals <1 year old and individuals 1-4 years old. In the UN data, however, the population statistics are for the whole bin of 0-4 years old. We can nevertheless decompose the population statistics in the UN data using the mortality rates in the WHO data. After doing so, our analysis is based on bins from <1, 1-4, and 5-year increments all the way up to 100+.

survival probability from the WHO data, although the estimate is the same for each year within an age bin. We can therefore take the geometric average as described in equation (5) with the following numerical values:

$$\hat{\beta}^i = [(0.994)^3(0.991)^5(0.987)^5(0.987)^5(0.980)^5(0.968)^5(0.946)^5(0.871)^{.15}]^{(\frac{1}{33.15})} = 0.978,$$

where the numbers in parentheses are 1 minus the mortality rate for the corresponding year. Using this estimate, we then solve for the individual's UDR using equation (7) to find that $\hat{\delta}^i = 0.022$, or equivalently 2.2 percent.

Our procedure for individuals in a population begins with the same steps for the median age in each bin and by gender.[14] This produces an estimate of the UDR for each age group and gender. Population estimates are then derived using the aggregation rules in either equation (8) or (9), that is, the mean or median, based on the UN population data. The mean estimate is therefore a population weighted average of the UDRs across age groups and gender. The median estimate is the gender-weighted, average UDR for the bin containing the person with the 50th percentile UDR.

3.1 Country-Specific Results

We estimate social UDRs for 182 countries, all of those for which complete data are available. We report the mean and median results in Appendix Table 1 for the most recent year, 2012. We report the results for 1990 and 2000 in Supplementary Material Table S1, and make explicit comparisons with the 1990 results below. We begin our analysis with a focus on the mean aggregation, before making comparisons to the median.

Figure 1 (panel A) shows the distribution of the mean estimates across countries that range from 1.44 (Cambodia) to 3.50 (Bulgaria).[15] The distribution is left skewed, and the

[14] For the first two and last categories we do not use the median, but rather ages 0, 2, and 100, respectively.

[15] Countries with the 10 lowest estimates, in ascending order, are Cambodia, Guatemala, Rwanda, Honduras, Gambia, Kenya, Ethiopia, Tanzania, Syria, and Qatar. Countries with the 10 highest estimates, in descending order, are Bulgaria, Ukraine, Latvia, Russia, Serbia, Belarus, Hungary, Romania, Croatia, and Lithuania.

median across the mean estimates is 2.01 percent. Figure 1 (panel B) illustrates the geographic heterogeneity. There is a clear pattern of higher rates in the northern latitudes, especially in the former Soviet Union countries. The lower rates tend to be clustered in Africa, Central America, and the Middle East. Underlying these results are two offsetting yet related effects. The first is that countries with longer life expectancies will have lower UDRs, all else equal. This follows because a longer life expectancy means more years over which individuals experience high survival rates. Yet empirically these same countries also tend to have older populations, and this is the second effect that pushes in the opposite direction. Older populations will have higher rates, all else equal, because there are fewer years over which to live, and these years include those with low survival rates.

It follows that two countries can have the same mortality-based UDR for very different reasons. The United States and Lesotho provide an example. We find that both countries have mean UDRs of 2.4 percent, yet they differ substantially in their demographics. Life expectancies at birth in the two countries are 78.6 and 48.8 years, respectively, while the median ages are 37.2 and 20.1. The United States population is older and tends to live longer, and these differences offset each other in comparison to Lesotho's younger population with a shorter life expectancy at birth or any given age.

Figure 2 illustrates the relationship between life expectancy, median age, and our estimates of the UDR across countries. As one would expect, median age increases with life expectancy. Longer life expectancy tends to decrease the UDR, holding median age constant, while an older median age tends to increase the UDR, holding life expectancy constant. As both are reduced (or increased), the figure shows how the UDRs change less, and something close to level sets within the figure's UDR bins emerge. Note, however, that median age is only one possible indicator of a population's age distribution, and the estimated UDRs are a function of life expectancies at age, rather than at birth. Nevertheless, the figure illustrates how a population's demographic structure affects the estimate. In particular, it explains why differences do not necessarily align with a country's level of development. For the same UDR, one country may be developed with a longer life expectancy and an older population, while another may be developing with a shorter life expectancy and younger population. A second example of this phenomenon is Australia and South Africa with UDRs of 2.2 percent, and respective life expectancies at birth of 81.8 and 59.3, and median ages of 37.0 and 24.3.

We have thus far focused on the mean rate for the population aggregation rule in equation (8), but we also consider the median rate for a population as described in equation (9). To show how the estimates compare, Figure 3 (panel A) plots the median estimate against the mean for all countries. In all cases the median is less than the mean, reflecting the general leftward skew of population distributions towards more younger people. Hence we find that using the median aggregation rule uniformly provides lower estimates of the mortality-based UDR. The percentage point difference is greater among countries with higher estimates of the mean UDR. Figure 3 (panel B) shows the distribution across countries of the percentage change in the estimate when converting from the mean to median aggregation rule. Many of the smaller declines occur in the Middle East, whereas many of the larger declines occur in Eastern Europe.[16] The percentage decline tends to be greater in countries where the population is older and life expectancy is shorter. On average across countries, the UDR decreases 33 percent, and for 95 percent of the countries the decrease is greater than 25 percent. These differences illustrate how the aggregation rule can have important consequences, and we return to this topic later in our discussion.

3.2 Global Results

We now turn to a global estimate of the mortality-based UDR. We follow the same procedure, but now treat the world as a single population using the world data from the WHO and UN data sets. Using the mean aggregation, we estimate a global UDR of 2.13 percent. Using the median aggregation, we estimate a rate of 1.33 percent. Interestingly, these estimates are surprisingly close to those employed in the literature when calibrating discount rates

[16] Countries with the 10 lowest percentage declines, in ascending order, are United Arab Emirates, Qatar, Bahrain, Kuwait, Oman, Saudi Arabia, Lesotho, Cambodia, Libya, and Brunei Darussalam. Countries with the 10 highest percentage declines, in descending order, are Hungary, Ukraine, Japan, Albania, Iceland, Serbia, Armenia, Jamaica, Uruguay, and Czech Republic.

to the Ramsey rule with applications to climate change. As discussed previously, some use rates at or near zero (e.g., Cline 1992; Arrow 1999; Stern 2007), but others employ rates between 1 and 3 percent (e.g., Nordhaus and Yang 1996; Weitzman 2007; Nordhaus 2007, 2008). Moreover, a recent survey of expert opinion among economists finds a mean estimate 1.1 percent for the UDR, with a standard deviation of 1.47 and a range between 0 and 8 percent (Drupp *et al.* 2015).

While these estimates are consistent with treating the world as a single population, we note that other aggregation rules may be considered reasonable among countries. One could, for example, use the median across countries of the mean or median country-specific estimates, yielding 2.01 and 1.37 percent, respectively. Alternatively, one could take some weighted average of the country specific-estimates, based on population or some other normative criteria. We find, for example, a population-weighted mean of the mean and median aggregation yields estimates of 2.25 and 1.53 percent, respectively.

As mentioned previously, our aim here is not to advocate one aggregation rule over another, either between countries or within countries. Instead, we employ the most basic rules (means and medians) as benchmarks to compare against estimates currently used in the literature. In doing so, our finding is that the choice of the UDR used for calibration of the Ramsey rule—within IAMs for climate change and more generally—are very much in line with the estimates here based on demographic mortality risks.

3.3 Changes Over Time

Our estimates of the social UDR are based on a population's existing age structure and life expectancies at each age. The aim is to develop a procedure for estimating long-term UDRs that can serve as useful benchmarks. If the population age structure is constant over time, our procedure generates estimates that are time invariant. It is nevertheless reasonable to ask the empirical question: How do UDR estimates change over time? To make such comparisons, we follow the same procedure and estimate UDRs with the UN and WHO data for the years 1990 and 2000. The year 1990 is the earliest that comparable data is available for the broad sample of countries. We report the results for all countries, both years, and aggregation rules in the Supplementary Material Table S1.

We focus discussion here on the largest time span from 1990 to 2012. Figure 4 plots the natural log of the 2012 estimate against the 1990 estimate for all countries, showing the mean and median aggregation separately. The figure shows how the estimates both increase and decrease across countries with nearly the same variance across the range of 1990 UDRs. Over the 22 year period, the mean change across countries for the mean aggregation is an increase of 2.4 percent with a standard deviation of 11.1. For the median aggregation, the mean difference is an increase of 4.2 percent with a standard deviation of 12.8. While we interpret these results as showing a reasonable degree of stability for long-term discounting, the differences across countries are a function of how demographics have changed: a shift towards a younger (older) population with longer (shorter) life expectancies will decrease (increase) the estimated UDR.[17] Other factors that may influence the differences are changes in data availability within countries and adjustments to the methods of estimating parameters of life tables.[18]

When considering global estimates of the UDR, there is relatively little change over time. For all three estimates in 1990, 2000, and 2012, the mean aggregation remains nearly constant at 2.04, 2.10 and 2.13 percent, respectively. The same holds for the median aggregation with UDRs of 1.27, 1.39, and 1.33 percent. The stability of these estimates builds further support for using the demographic characteristics of the worlds existing population to inform long-term discount rates.

[17] Countries that make the "bottom" 10 for a decrease in the UDR for both the mean and median aggregation are Zambia, Ethiopia, Antingua and Barbuda, Liberia, Rwanda, Angola, Eritrea, and Uganda. With respect to the "top" 10 for an increase in the UDR, there is greater heterogeneity across the aggregation rules. The top 10 for the mean aggregation are Lesotho, Montenegro, North Korea, Nicaragua, Armenia, Algeria, Serbia, Uzbekistan, Philippines, and Macedonia. Those for the median aggregation are Lesotho, China, Thailand, Montenegro, Cuba, Algeria, Saudi Arabia, Morocco, Lithuania, and Swaziland.

[18] See, for example, a description of the WHO methods and data sources for generating life tables 1990-2015 (WHO 2015).

4 Relation to the Social (Consumption) Discount Rate

The primary focus of our analysis is on deriving demographically-based estimates of the UDR. But this is only one component of the overall social (consumption) discount rate, defined in equation (2), that is used for economic evaluation of long-term projects. In this section, we derive overall social discount rates using our estimates of the UDR as an input.[19] The intent is to place our results in context for exploring heterogenous social discount rates across countries. In doing so, we combine estimates of the different parameters in the Ramsey equation to produce an estimate of the overall social discount rate. In the next section, however, we show how our estimates of the UDR can be used in a calibration exercise to match observed interest rates.

We use the following procedure to obtain estimates of the other parameters in the Ramsey equation. The elasticity of the marginal utility of consumption η is the mean value of 1.35 from an expert opinion survey conducted by Drupp *et al.* (2015).[20] For the growth rate of per capita real consumption g, we use forecasts about real Gross Domestic Product (GDP) per capita. Although consumption itself is the correct measure rather than GDP, such data are only available for a small set of countries. Following Gollier (2012, 2015), we use the International Macroeconomic Data Set constructed by the Economic Research Service of the U.S. Department of Agriculture.[21] The dataset provides historical and projected real GDP per capita for 189 countries that account for more than 99 percent of the world economy. For each country and the world as a whole, we take the arithmetic average of growth rates for all years 2013 through 2030. We then use these estimates along with those for the UDRs and η to examine heterogeneity in the overall social discount rates across countries. We use the mean aggregation of the UDR for illustrative purposes and to be consistent with the

[19] Clearly, we are following convention here and throughout the paper by assuming a constant social discount rate. For recent discussions about the potential use of declining discount rates over time,.see Arrow *et al.* (2013) and Cropper *et al.* (2014).

[20] The survey responses range from 0 to 5, and it is straightforward to run alternate scenarios with different values.

[21] These data are available online at https://www.ers.usda.gov/data-products/international-macroeconomic-data-set/.

implicit averaging in GDP per capita.[22]

Figure 5 (Panel A) shows the distribution of the most recent estimates across countries. We also report the specific estimate for each country in Appendix Table 1. The mean social discount rate is 5.07 percent, with a range from -1.32 to 10.56 percent.[23] The few negative rates arise because of sufficiently large forecasts of negative GDP growth through 2030. Here again we find that, in general, the results are well within the range of those used in the academic literature and in practice. As a point of reference the U.S. Office of Management and Budget recommends using a social discount rate between 3 and 7 percent for regulatory impact analysis (OMB 2003). Using our procedure to estimate the social discount rate for the United States, we find a rate of 4.32 percent. This is also very close to the overall world estimate of 4.61 percent.

Panel B of Figure 5 illustrates geographic heterogeneity of the social discount rates. The highest rates tend to be clustered and China, India, and Southeast Asia, where forecasts of GDP growth per capita tend to be large. More generally, however, we find that the social discount rates are not driven primarily by either the forecasts of GDP growth or the UDRs. Both contribute somewhat equally because they have somewhat similar magnitudes, and η at 1.35 provides a roughly equal weighting between the two. Finally, the estimates of δ and g are relatively uncorrelated, with a pairwise correlation coefficient of only 0.15.

5 Application to the RICE Model

We have previously discussed how much of the renewed debate about the choice of discount rates stems from the importance of discounting in IAMs of climate change. In this section, we consider how our heterogenous estimates of the UDR across countries affect the results of one

[22] It is nevertheless a simple exercise to generate comparable results using the median aggregation of the UDR. In this case, however, one might also want to use a measure of median income growth for consistency. This would imply in the United States, for example, a social discount rate approximately equal to the median UDR because median income growth has been close to zero.

[23] Countries with the 10 lowest estimates, in ascending order, are Syria, Equatorial Guinea, Yemen, Venezuela, Burundi, Libya, Brunei Darussalam, Central African Republic, Belize, and Cyprus. Countries with the 10 highest estimates, in descending order, are India, China, Myanmar, Latvia, Vietnam, Bangladesh, Moldova, Laos, Cuba, and Cambodia.

such model. Our illustration requires a regionally specific model, and we use the archetype and publicly available Regional Integrated Climate-Economy (RICE) model (Nordhaus and Yang 1996; Nordhaus 2010). In contrast to the previous section where we derive social discount rates from parameter estimates, the RICE application is a calibration to observed interest rates by region subject to our estimates of the region-specific UDRs.

The RICE model is a dynamic, optimal growth model based on the Ramsey framework. The model's objective is to maximize present discounted utility of consumption through time. Population and technology grow exogenously, but capital accumulation is endogenous, based on the rate at which forgone consumption today is traded off against increased consumption in the future. The buildup of greenhouse gases in the atmosphere causes economically harmful climate damages. Investments in emission reductions operate in much the same way as capital. Emission reductions are costly, they lower consumption today, but increase future consumption possibilities by avoiding future climate damages. A key feature of the model for our purposes is its parameterization to 12 different regions. In the original formulation, Nordhaus and Yang (1996) compare a market scenario, where there is no correction for the climate-change externality, to a globally optimal scenario, where emissions are controlled efficiently across time and regions.

We follow the same approach here, but instead compare the results of two different calibrations. The first is one where all 12 regions of the model have the same global estimate of the UDR, which is the case in Nordhaus and Yang (1996) and Nordhaus (2010). Specifically, we assume a UDR of 2.13 percent for all regions, corresponding with our 2012 global estimate of $\bar{\delta}$. This scenario falls between previously published versions of the RICE model, where Nordhaus and Yang (1996) use 3 percent in their original analysis and Nordhaus (2010) subsequently uses 1.5 percent. The second calibration that we employ uses heterogeneous estimates of the UDR for each of the 12 regions. To derive these estimates, we apply our procedure described previously to the pooled population demographics for all countries within a region.[24] Table 1 lists the 12 regions and the UDR for each used in our homogeneous and

[24]Note that this is not a weighted average across countries, but rather a weighted average across age bins and life expectancies for all individuals in the population defined by the countries that comprise a RICE

heterogenous calibrations, along with the difference. The heterogenous estimates range from a low of 1.81 for Africa to a high of 3.33 for Russia. Compared to the homogeneous calibration, the heterogenous UDR is lower in four regions, Africa, Middle East, Latin America, and Other.

When adjusting the UDRs in the RICE model, globally and regionally, the calibration also requires adjustments to the elasticity of the marginal utility of consumption η. This is done to match the same initial conditions of the model for the overall discount rate and rate of consumption growth. Nordhaus (2007) follows a similar procedure to match observed market conditions when calibrating the related DICE model using different values of δ in response to Stern (2007).

Figure 6 (Panel A) shows the simulated annual emissions corresponding with the market and optimal scenarios for both the homogeneous and heterogeneous calibrations. We find that introducing heterogeneity in the UDRs has very little affect on the annual emissions for the market scenario. The emissions profile is also very similar for the optimal scenario until about 2065, when emissions start to diverge and are lower with heterogeneous UDRs. Panel B of the figure shows the uniform, optimal carbon tax for both calibrations. Consistent with the differences in optimal emissions, the carbon tax begins to be greater with the heterogenous UDRs around 2065. The difference is 28 percent higher by the end of the century.

Because aggregate emissions may mask some important heterogeneous effects, we now look at region-specific results. Changes in the discount rate affect both the market and optimal scenarios, and it is helpful to look at how each region's emission profile changes even without climate policy. Figure 7 shows the percentage change in annual emissions for each region when moving from the homogenous to heterogenous calibrations of the market scenario. A clear pattern emerges whereby regions with lower UDRs increase emissions and those with higher UDRs decrease emissions. The reason stems from the fact that a greater UDR, for example, means less concern for the future compared to the present. This implies

region. In other words, a RICE region is treated as a population in the language of our model.

a lower savings rate, less capital accumulation, and a decrease in future in output. Then, because emissions are proportional to output in the RICE model, we see a decrease (increase) in emissions for regions that shift to a higher (lower) UDR. See, for example, how after an initial adjustment Africa and the Middle East regions increase business as usual emissions by about 1.5 percent, and Russia decreases its business as usual emissions more than 9 percent by the end of the century.

These results underscore the importance of macroeconomic adjustments to changes in the parameters of the discount rate. While researchers focused on climate change often emphasize how a lower UDR supports greater concern for future climate damages, these results also illustrate how the lower UDR also changes the baseline to favor future consumption and therefore future emissions.

What do these differences in the baseline emissions mean for optimal climate policy across regions? Figure 8 shows the percentage change in optimal abatement across regions and over time when moving from the homogenous to heterogenous UDRs. The panel for each region is essentially a difference-in-differences calculation because abatement is the difference in emissions between the market and optimal scenarios. Here again there is a clear pattern. Regions with lower UDRs, and therefore higher baseline emissions, abate more in all periods after an initial adjustment, with the increase in abatement reaching about 15 percent by century's end. Regions with sufficiently higher UDRs, which have lower base line emissions, undertake less abatement until just before 2080. The regions with relatively little change in the UDR—i.e., India, Other High Income, United States, and China—have very little change in abatement until it increases just before 2080. The differences across regions offset each other such that there is relatively little change in aggregate emissions between the homogenous and heterogenous calibrations for the optimal scenarios prior to 2075 (see Panel A of Figure 6). Yet aggregate emissions begin to diverge and are lower for the heterogenous case later in the century, when the large emitting countries, including the United States and China, begin increasing their abatement.

6 Concluding Remarks

The Ramsey discounting rule is a cornerstone of macroeconomic modeling. It is also fundamental to the economics of climate change through its use in IAMs. As originally conceived, the Ramsey model is based on an infinitely lived representative agent. Its interpretation in the climate change literature is generally still that of a representative agent, and the time steps are taken to represent a sequence of non-overlapping generations. While the Ramsey model provides an organizing framework for pulling together the different components of a long-term discount rate, the difficulty is that the framework itself provides little guidance about how to calibrate the Ramsey rule in practice.

The question of how to choose a social discount rate has long been a subject of debate among economists and philosophers. Comparisons between the two primary schools of thought—a prescriptive or descriptive approach—identify the fundamental difference as explicit or implicit assumptions about compensation among generations (Arrow *et al.* 1995). This narrows the focus somewhat on the choice of the social UDR. Should the UDR be chosen as an ethical parameter, or be backed out of a calibration exercise to match observable market interest rates? The current state of affairs in economics remains one where applied researchers must choose, or remain agnostic and undertake sensitivity analysis that covers a wide range of values. One respect in which the options are particularly unsatisfactory is that the choice between a prescriptive versus descriptive approach is typically inseparable from whether one thinks the discount rate should be low or high, respectively.

In this paper, we present an alternative, demographically-based approach that can serve as a useful point of comparison. The starting point of our analysis is recognition that even a representative agent must die. Specifically, we show how age-specific mortality rates and life expectancy imply a natural UDR for individuals at each age in a population. This part of the analysis is descriptive. The other part, where individual UDRs are aggregated to the population level, is necessarily prescriptive because it implies weights among those currently alive. For this step, we fall back on simple means and medians as an aggregation rule, though note the possibility of others. The most striking part of the analysis is that the results across countries and for the world as a whole fall within the range of UDRs employed in the literature. The results might therefore be interpreted as providing external validly to much of the current practice, or at least showing how current practice aligns with the implications of a basic demographic approach.

We are aware that a leading criticism of our approach is that focusing only on mortality risk oversimplifies the basis for individual pure rates of time preference. The criticism is certainly warranted, yet we contend that arguments can be made that the approach provides either over- or under-estimates. That individuals are well-known to be impatient even without mortality risk could be used to argue for a higher UDR. In contrast, the presence of bequest motives for future generations would imply a lower UDR. While many other arguments are certainly possible, the advantage of a purely mortality-based approach is transparency, an empirical basis, and broad data availability—that is, the mortality-based approach gives a non-arbitrary starting point for further adjustments. A further advantage of our approach is that it facilitates transparency with respect to decisions about how different generations are actually weighed.

Indeed, we show how the approach can be used to explore heterogeneity of overall social discount rates across countries, with application to IAMs for climate change. We find that introducing regional heterogeneity of UDRs into the RICE model has little affect on the business-as-usual trajectory of global emissions. It does, however, change the trajectory of optimal emissions and the corresponding carbon tax. With heterogeneity, regions with lower UDRs (e.g., Africa, the Middle East, and Latin America) would be responsible for greater emission reductions, whereas those with higher UDRs (e.g., Japan, Eurasia, and Russia) would be responsible for less. Although our intent here is primarily illustrative, such results in future research can have important implications for understanding burden sharing across countries and their willingness to participate in international climate agreements.

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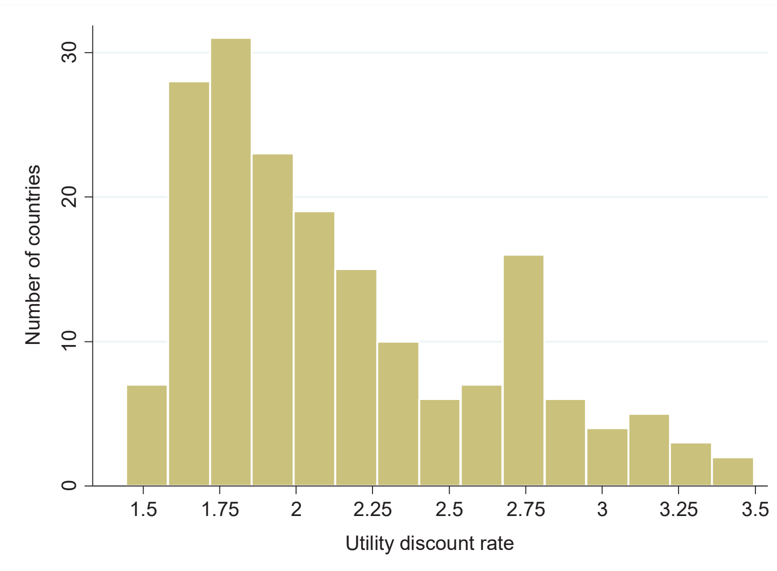
Table 1: Utility discount rates used in the RICE model for each region

	Utility discount rate (δ)		
Region	Homogeneous	Heterogeneous	Difference
Africa	2.13	1.81	-0.32
Middle East	2.13	1.82	-0.31
Latin America	2.13	1.91	-0.22
Other	2.13	2.00	-0.13
India	2.13	2.17	0.04
Other High Income (OHI)	2.13	2.31	0.19
United States (US)	2.13	2.43	0.31
China	2.13	2.45	0.33
European Union (EU)	2.13	2.69	0.57
Japan	2.13	2.81	0.69
Eurasia	2.13	2.89	0.77
Russia	2.13	3.33	1.21

Notes: Reported rates are percentages and based on the mean aggregation within the corresponding region or country.

Panel A



Panel B

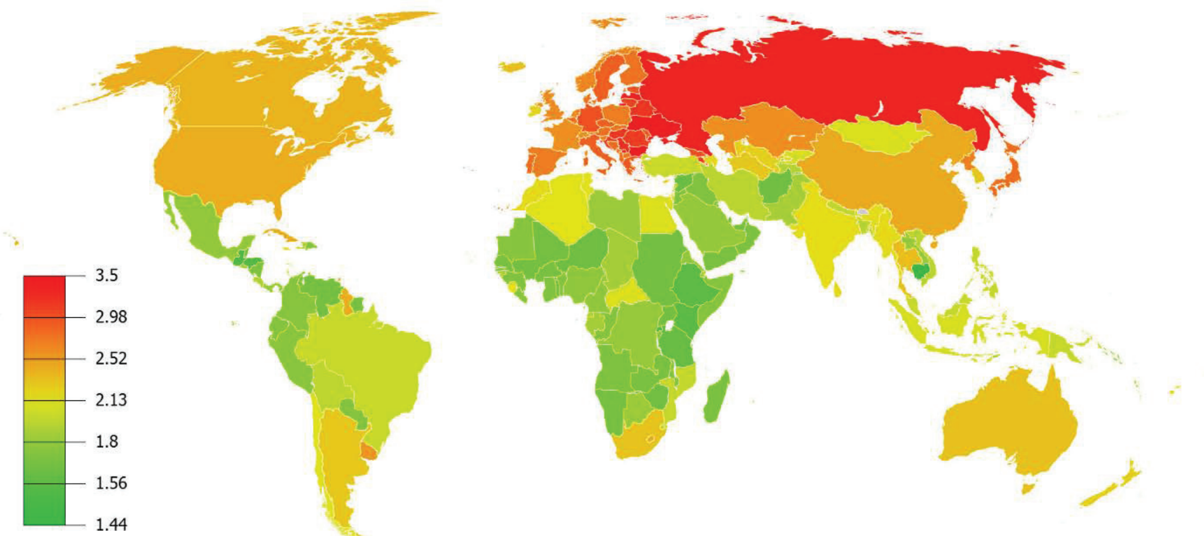


FIGURE 1: Histogram (panel A) and map (panel B) illustrating the distribution of the 2012 estimates of the utility discount rates across countries, using the mean aggregation

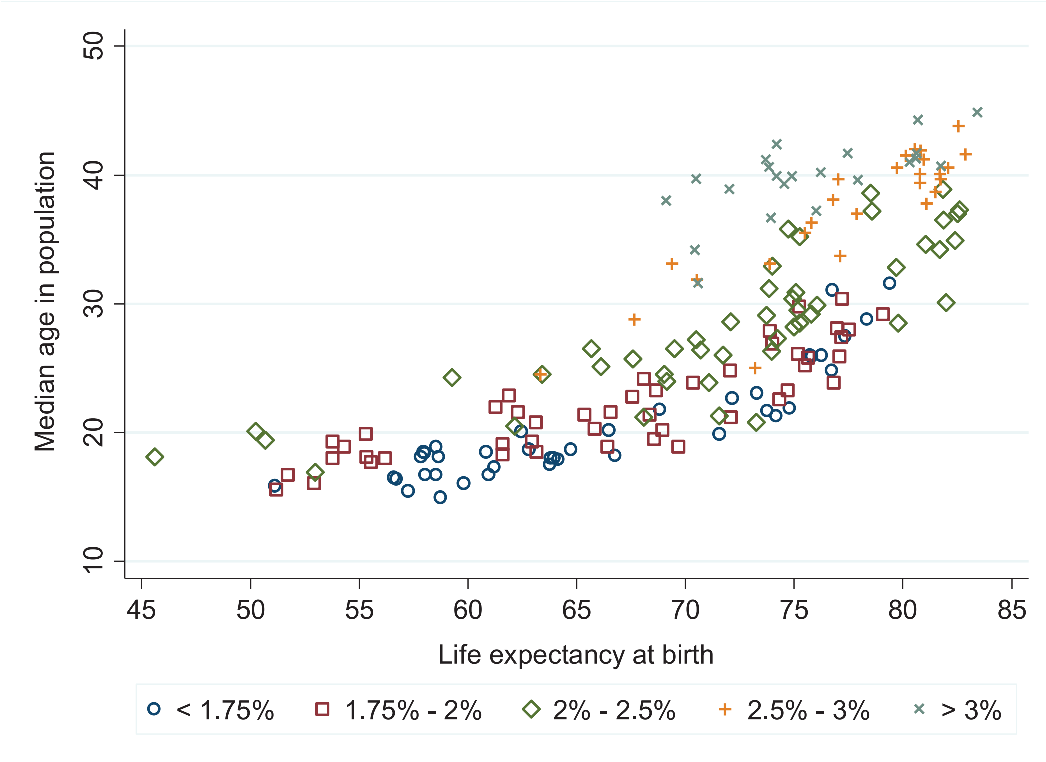
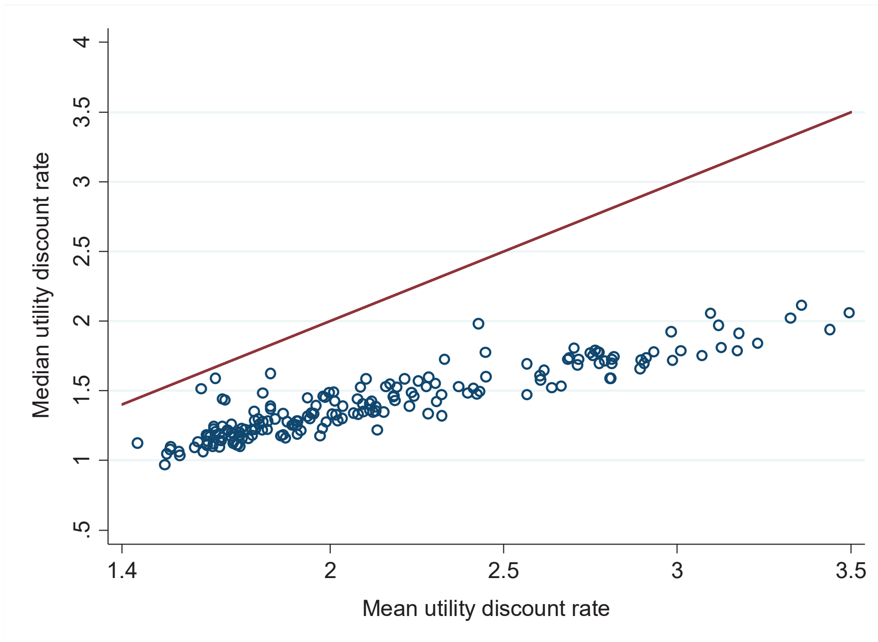


FIGURE 2: The relationship between life expectancy, median age, and the 2012 estimates of the utility discount rates across countries (bins denoted in the legend), using the mean aggregation

Panel A



Panel B

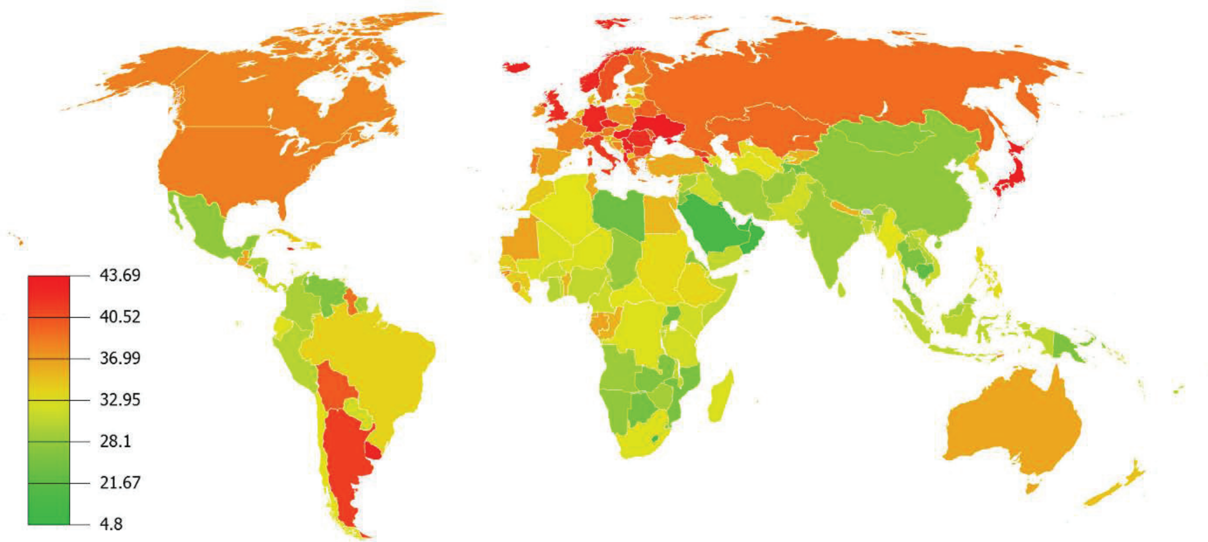


FIGURE 3: Scatter plot of each country's median estimate of the 2012 mortality-based utility discount rates against its mean, along with the 45-degree line (Panel A); Geographical illustration of the percentage decrease when moving to the median from the mean estimate for each country, i.e., $-100[\tilde{\delta} - \bar{\delta}]/\bar{\delta}$ (Panel B)

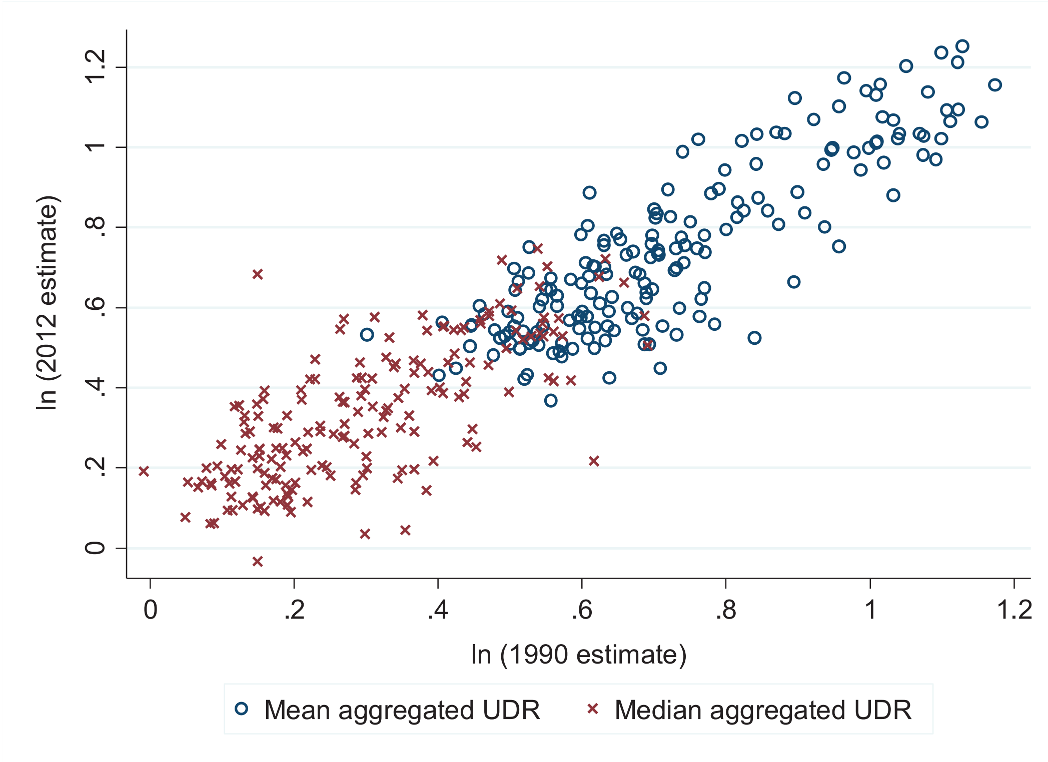
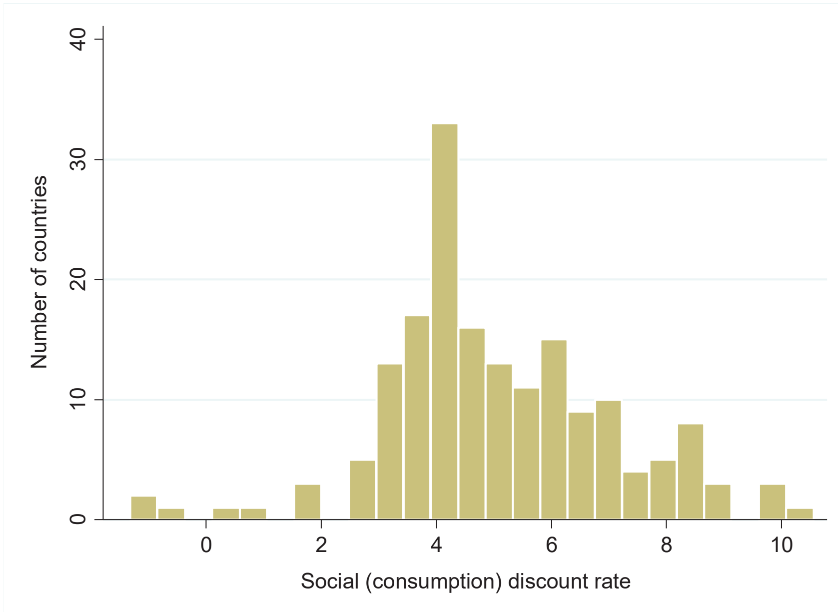


FIGURE 4: Scatter plot of the 2012 mortality-based utility discount rates against the 1990 estimates for all countries, showing the mean and median aggregation rules

Panel A



Panel B

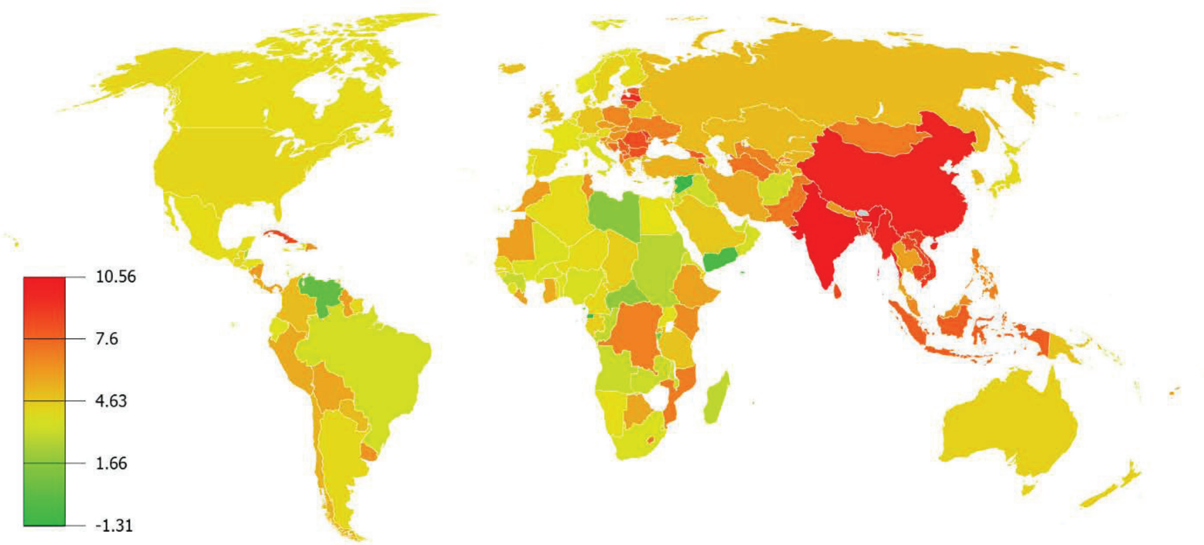
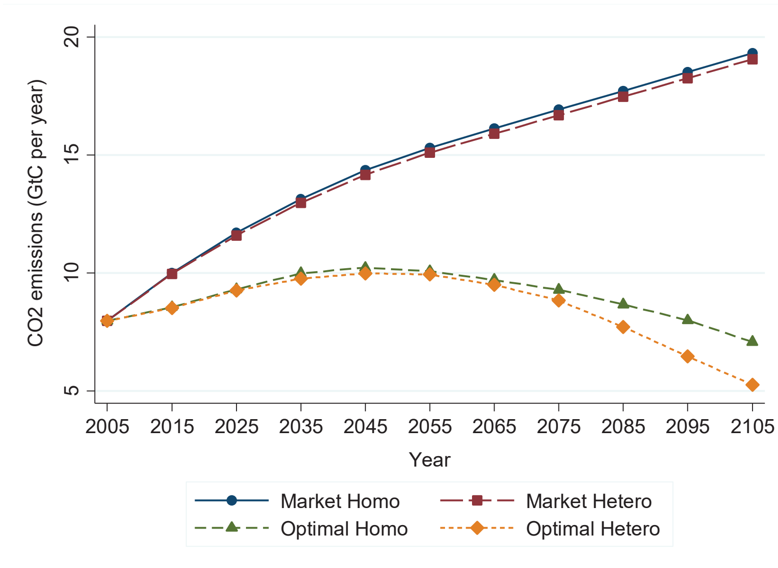


FIGURE 5: Histogram (panel A) and map (panel B) illustrating the distribution of Ramsey social (consumption) discount rates across countries, using the mean aggregation for the utility discount rates, an elasticity of marginal utility of 1.31, and forecasted GDP growth per capita through 2030 for the consumption growth rate

Panel A



Panel B

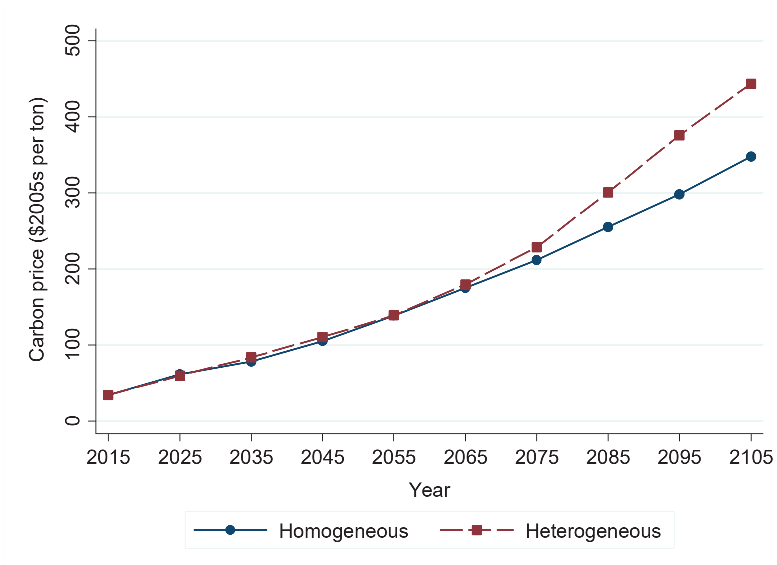


FIGURE 6: Global annual carbon dioxide emissions, market versus optimal scenarios, homogenous and heterogeneous utility discount rates (Panel A); the optimal carbon price for homogenous and heterogeneous utility discount rates (Panel B)

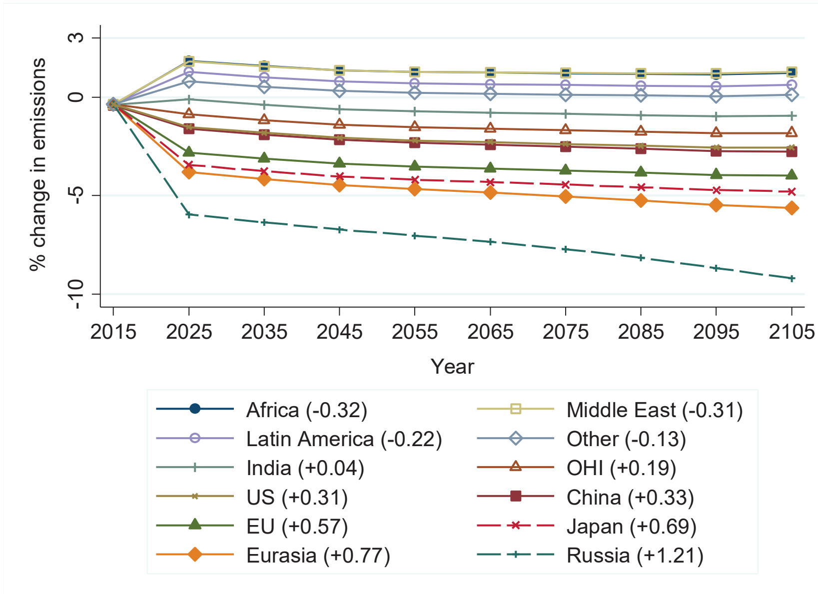


FIGURE 7: Percent change in annual emissions by region when moving from the homogenous to heterogeneous utility discount rates for the market scenario; percentage point change in the UDR is given in parentheses

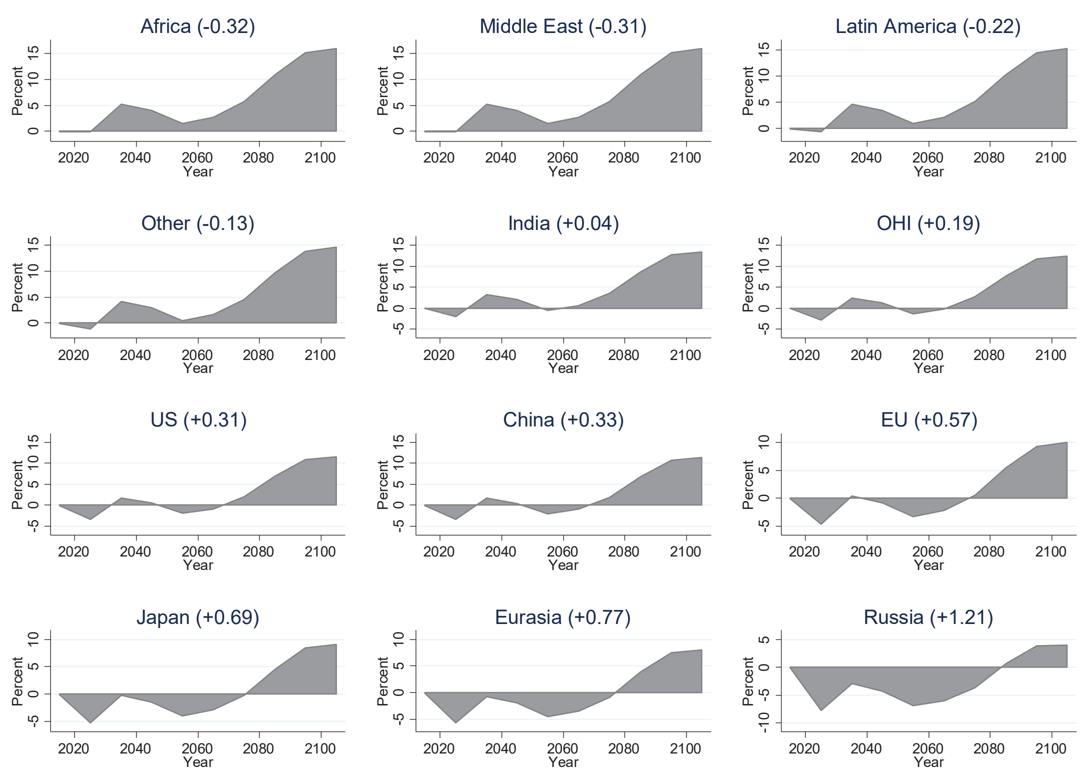


Figure 8: Percentage change in optimal abatement across regions when shifting from the homogenous to heterogeneous utility discount rates; percentage point change in the UDR is given in parentheses

APPENDIX TABLE 1: Mean and median estimates of the 2012 utility discount rate for each country

Country	Mean UDR	Median UDR	Ramsey r	Country	Mean UDR	Median UDR	Ramsey r
Afghanistan	1.65	1.18	3.41	Fiji	2.16	1.53	6.02
Albania	2.81	1.59	6.95	Finland	2.78	1.70	4.20
Algeria	2.12	1.42	4.18	France	2.60	1.61	3.97
Angola	1.70	1.22	3.24	Gabon	1.86	1.18	4.50
Antigua and Barbuda	1.94	1.30	4.20	Gambia	1.54	1.10	4.98
Argentina	2.28	1.34	4.30	Georgia	3.01	1.78	7.89
Armenia	3.07	1.75	8.36	Germany	2.99	1.72	4.87
Australia	2.32	1.47	4.47	Ghana	1.72	1.20	5.58
Austria	2.79	1.71	4.24	Greece	2.93	1.78	5.33
Azerbaijan	2.18	1.45	4.30	Grenada	2.11	1.36	4.40
Bahamas	2.04	1.39	3.41	Guatemala	1.52	0.97	4.39
Bahrain	1.83	1.63	4.44	Guinea	1.72	1.13	3.20
Bangladesh	1.94	1.34	9.04	Guinea-Bissau	1.91	1.19	4.18
Barbados	2.37	1.53	4.35	Guyana	2.42	1.48	5.91
Belarus	3.18	1.91	4.72	Haiti	1.89	1.26	3.74
Belgium	2.81	1.70	3.92	Honduras	1.54	1.08	3.96
Belize	1.64	1.18	2.53	Hungary	3.17	1.79	6.31
Benin	1.73	1.11	3.71	Iceland	2.32	1.32	5.02
Bhutan	1.80	1.26	8.54	India	2.17	1.55	10.56
Bolivia	1.97	1.18	5.77	Indonesia	2.08	1.44	7.90
Bosnia and Herzegovina	2.82	1.74	7.46	Iran	1.96	1.39	5.61
Botswana	1.83	1.37	5.74	Iraq	1.71	1.17	3.31
Brazil	2.02	1.33	3.45	Ireland	2.23	1.39	5.21
Brunei Darussalam	1.78	1.35	1.72	Israel	2.13	1.39	4.80
Bulgaria	3.50	2.06	8.30	Italy	2.91	1.70	3.68
Burkina Faso	1.68	1.15	3.74	Jamaica	2.13	1.22	3.80
Burundi	1.74	1.20	0.99	Japan	2.81	1.59	4.23
Cabo Verde	1.89	1.25	4.35	Jordan	1.72	1.26	3.45
Cambodia	1.44	1.12	8.61	Kazakhstan	2.61	1.58	5.14
Cameroon	1.78	1.22	4.26	Kenya	1.56	1.06	6.52
Canada	2.40	1.48	4.18	Kiribati	1.84	1.30	--
Central African Republic	2.09	1.41	1.81	Kuwait	1.69	1.44	2.71
Chad	1.86	1.34	4.56	Kyrgyzstan	2.08	1.33	5.31
Chile	2.11	1.41	5.36	Laos	1.82	1.28	8.65
China	2.45	1.77	9.78	Latvia	3.36	2.11	9.64
Colombia	1.75	1.23	5.08	Lebanon	2.04	1.30	4.14
Comoros	1.78	1.18	3.98	Lesotho	2.43	1.98	7.17
Congo	1.73	1.11	3.08	Liberia	1.75	1.15	5.96
Costa Rica	1.90	1.25	5.63	Libya	1.83	1.39	1.57
Croatia	3.12	1.97	5.93	Lithuania	3.10	2.05	8.02
Cuba	2.45	1.60	8.63	Luxembourg	2.41	1.52	3.69
Cyprus	2.31	1.42	2.69	Madagascar	1.69	1.14	2.98
Czech Republic	2.89	1.66	6.01	Malawi	1.72	1.19	3.39
North Korea	2.69	1.74	--	Malaysia	2.01	1.42	6.56
D. R. Congo	1.80	1.22	6.82	Maldives	1.98	1.46	7.33
Denmark	2.78	1.77	4.39	Mali	1.66	1.12	3.65
Djibouti	1.90	1.28	4.52	Malta	2.70	1.80	5.98
Dominican Republic	1.72	1.14	6.43	Mauritania	1.74	1.10	5.95
Ecuador	1.74	1.17	3.75	Mauritius	2.25	1.57	6.64
Egypt	2.09	1.35	4.01	Mexico	1.79	1.30	4.14
El Salvador	1.86	1.18	4.31	Micronesia	1.91	1.28	3.16
Equatorial Guinea	1.91	1.21	-1.17	Mongolia	2.09	1.53	7.07
Eritrea	1.78	1.29	3.46	Montenegro	2.77	1.78	--
Estonia	2.98	1.92	8.17	Morocco	2.19	1.43	6.01
Ethiopia	1.57	1.04	5.87	Mozambique	2.00	1.49	6.98

APPENDIX TABLE 1: Continued

Country	Mean UDR	Median UDR	Ramsey r
Myanmar	2.18	1.46	9.71
Namibia	1.67	1.21	4.12
Nepal	1.99	1.27	6.17
Netherlands	2.68	1.72	4.38
New Zealand	2.24	1.46	4.55
Nicaragua	1.70	1.21	6.06
Niger	1.65	1.11	4.17
Nigeria	1.77	1.22	3.59
Norway	2.67	1.53	3.93
Oman	1.70	1.43	3.55
Pakistan	1.88	1.28	7.08
Panama	1.78	1.22	6.02
Papua New Guinea	2.01	1.49	4.84
Paraguay	1.74	1.18	5.14
Peru	1.75	1.22	5.61
Philippines	2.01	1.33	6.84
Poland	2.71	1.68	6.69
Portugal	2.81	1.72	4.00
Qatar	1.63	1.51	--
Republic of Korea	2.28	1.60	5.13
Republic of Moldova	2.91	1.74	8.98
Romania	3.13	1.81	8.42
Russian Federation	3.33	2.02	5.13
Rwanda	1.53	1.05	5.41
Saint Lucia	2.15	1.35	4.25
St Vincent & Grenadines	1.98	1.23	5.64
Samoa	1.93	1.32	3.07
Sao Tome and Principe	1.63	1.06	6.40
Saudi Arabia	1.80	1.48	4.76
Senegal	1.68	1.10	4.32
Serbia	3.23	1.84	7.91
Seychelles	2.21	1.59	5.95
Sierra Leone	2.12	1.35	3.99
Singapore	2.10	1.59	3.71
Slovakia	2.76	1.75	6.39
Slovenia	2.75	1.77	6.78
Solomon Islands	1.76	1.16	3.44
Somalia	1.74	1.20	--
South Africa	2.30	1.55	3.66
South Sudan	1.82	1.22	--
Spain	2.72	1.72	4.23
Sri Lanka	2.19	1.52	8.47
Sudan	1.66	1.10	2.81
Suriname	1.68	1.19	4.31
Swaziland	1.99	1.45	3.40
Sweden	2.90	1.72	4.44
Switzerland	2.62	1.65	3.77
Syrian Arab Republic	1.62	1.13	-1.32
Tajikistan	1.93	1.45	5.51
Thailand	2.33	1.73	5.94
Republic of Macedonia	2.76	1.79	7.56
Timor-Leste	1.87	1.16	--
Togo	1.65	1.14	4.34
Tonga	2.07	1.34	4.52
Trinidad and Tobago	2.57	1.69	4.96
Tunisia	2.13	1.36	6.31
Turkey	2.02	1.28	5.43
Turkmenistan	2.28	1.53	7.26
Uganda	1.66	1.24	4.04
Ukraine	3.44	1.94	6.90
United Arab Emirates	1.67	1.59	3.31
United Kingdom	2.64	1.52	4.85
Tanzania	1.61	1.09	4.86
United States	2.43	1.49	4.32
Uruguay	2.57	1.47	6.26
Uzbekistan	2.23	1.48	6.84
Vanuatu	1.80	1.28	2.92
Venezuela	1.67	1.22	0.28
Viet Nam	1.95	1.34	9.06
Yemen	1.69	1.16	-0.53
Zambia	1.69	1.24	3.30
Zimbabwe	1.65	1.17	--
WORLD	2.13	1.33	4.61

SUPPLEMENTARY MATERIAL TABLE S1: Mean and median estimates of the 1990 and 2000 utility discount rate for each country

	1990		2000	
Country	Mean UDR	Median UDR	Mean UDR	Median UDR
Afghanistan	1.85	1.33	1.73	1.24
Albania	2.32	1.34	2.53	1.49
Algeria	1.69	1.12	1.87	1.27
Angola	2.08	1.44	1.89	1.34
Antigua and Barbuda	2.45	1.55	2.07	1.37
Argentina	2.26	1.38	2.23	1.34
Armenia	2.45	1.58	2.68	1.86
Australia	2.36	1.50	2.34	1.54
Austria	2.93	1.72	2.82	1.60
Azerbaijan	2.16	1.41	2.19	1.60
Bahamas	1.83	1.21	1.79	1.16
Bahrain	1.76	1.53	1.83	1.53
Bangladesh	1.67	1.15	1.79	1.30
Barbados	2.26	1.34	2.31	1.39
Belarus	2.76	1.66	3.15	2.09
Belgium	2.91	1.73	2.89	1.60
Belize	1.67	1.12	1.63	1.09
Benin	1.81	1.14	1.80	1.16
Bhutan	1.97	1.35	1.84	1.24
Bolivia	1.84	1.09	1.87	1.17
Bosnia and Herzegovina	2.39	1.50	2.70	2.05
Botswana	1.58	1.14	2.85	2.49
Brazil	1.86	1.29	1.90	1.41
Brunei Darussalam	1.83	1.42	1.63	1.40
Bulgaria	3.09	1.88	3.43	1.90
Burkina Faso	1.88	1.21	1.87	1.28
Burundi	1.89	1.28	2.00	1.49
Cabo Verde	1.84	1.15	1.84	1.17
Cambodia	1.75	1.24	1.55	1.13
Cameroon	1.81	1.16	1.89	1.28
Canada	2.33	1.48	2.39	1.54
Central African Republic	2.16	1.33	2.42	1.70
Chad	2.15	1.44	2.08	1.48
Chile	2.08	1.39	2.04	1.35
China	2.05	1.31	2.23	1.42
Colombia	1.56	1.10	1.62	1.13
Comoros	1.82	1.22	1.79	1.20
Congo	1.86	1.21	1.99	1.38
Costa Rica	1.66	1.18	1.78	1.30
Croatia	2.94	1.87	3.11	1.82
Cuba	2.20	1.26	2.23	1.46
Cyprus	2.48	1.39	2.54	1.47
Czech Republic	3.18	1.99	2.95	1.79
North Korea	2.10	1.50	2.51	1.54
D. R. Congo	1.89	1.25	1.90	1.27
Denmark	3.00	1.76	2.91	1.71
Djibouti	1.75	1.19	1.86	1.22
Dominican Republic	1.61	1.15	1.62	1.13
Ecuador	1.66	1.21	1.65	1.11
Egypt	1.96	1.19	2.04	1.34

SUPPLEMENTARY MATERIAL TABLE S1: Continued

	1990		2000	
Country	Mean UDR	Median UDR	Country	Mean UDR
El Salvador	1.72	1.12	1.78	1.22
Equatorial Guinea	2.16	1.42	2.06	1.29
Eritrea	2.15	1.57	2.50	2.13
Estonia	3.02	1.72	3.14	1.93
Ethiopia	2.03	1.35	1.83	1.25
Fiji	1.92	1.36	2.00	1.37
Finland	2.83	1.77	2.78	1.62
France	2.55	1.39	2.63	1.51
Gabon	1.99	1.07	1.98	1.14
Gambia	1.69	1.17	1.62	1.14
Georgia	2.60	1.60	2.80	1.60
Germany	3.08	1.75	2.94	1.85
Ghana	1.65	1.11	1.69	1.13
Greece	2.77	1.73	2.87	1.64
Grenada	2.14	1.31	2.01	1.24
Guatemala	1.68	1.16	1.52	1.02
Guinea	1.91	1.19	1.88	1.20
Guinea-Bissau	2.01	1.19	1.93	1.18
Guyana	2.18	1.64	1.97	1.39
Haiti	1.99	1.21	1.98	1.20
Honduras	1.49	1.05	1.48	1.00
Hungary	3.24	1.99	3.18	1.90
Iceland	2.28	1.31	2.29	1.39
India	2.09	1.44	2.11	1.40
Indonesia	1.94	1.31	2.03	1.28
Iran	1.74	1.14	1.82	1.24
Iraq	1.71	1.17	1.67	1.15
Ireland	2.55	1.43	2.53	1.55
Israel	2.10	1.38	2.12	1.29
Italy	2.81	1.70	2.90	1.79
Jamaica	2.01	1.13	2.00	1.07
Japan	2.41	1.56	2.56	1.71
Jordan	1.68	1.16	1.68	1.15
Kazakhstan	2.32	1.60	2.76	1.73
Kenya	1.53	1.09	1.80	1.39
Kiribati	1.87	1.33	1.82	1.16
Kuwait	1.63	1.31	1.78	1.50
Kyrgyzstan	2.03	1.35	2.15	1.41
Laos	1.94	1.24	1.81	1.17
Latvia	3.07	1.71	3.12	1.93
Lebanon	2.10	1.22	2.12	1.40
Lesotho	1.84	1.16	2.56	1.98
Liberia	2.19	1.47	1.93	1.26
Libya	1.72	1.16	1.81	1.27
Lithuania	2.74	1.63	2.80	1.83
Luxembourg	2.81	1.75	2.60	1.62
Madagascar	1.84	1.21	1.75	1.19
Malawi	1.98	1.41	2.54	2.11
Malaysia	1.88	1.36	2.01	1.37
Maldives	1.97	1.30	2.01	1.35
Mali	1.99	1.20	1.94	1.24
Malta	2.57	1.60	2.58	1.75
Mauritania	1.73	1.11	1.73	1.11

SUPPLEMENTARY MATERIAL TABLE S1: Continued

	1990		2000	
Country	Mean UDR	Median UDR	Country	Mean UDR
Mauritius	2.12	1.40	2.21	1.54
Mexico	1.59	1.10	1.70	1.23
Micronesia	1.73	1.16	1.80	1.16
Mongolia	2.02	1.26	2.15	1.47
Montenegro	2.14	1.37	2.55	1.67
Morocco	1.82	1.13	1.97	1.27
Mozambique	2.07	1.35	2.08	1.48
Myanmar	2.01	1.34	2.07	1.31
Namibia	1.77	1.17	1.94	1.38
Nepal	1.96	1.24	1.87	1.17
Netherlands	2.66	1.54	2.71	1.64
New Zealand	2.40	1.54	2.32	1.38
Nicaragua	1.35	0.99	1.47	1.05
Niger	1.80	1.17	1.74	1.15
Nigeria	1.95	1.28	1.94	1.31
Norway	2.93	1.74	2.78	1.57
Oman	1.64	1.16	1.65	1.30
Pakistan	1.76	1.13	1.80	1.14
Panama	1.67	1.12	1.68	1.12
Papua New Guinea	2.08	1.42	2.03	1.36
Paraguay	1.56	1.05	1.63	1.18
Peru	1.50	1.08	1.72	1.14
Philippines	1.66	1.14	1.69	1.28
Poland	2.72	1.68	2.72	1.83
Portugal	2.83	1.52	2.88	1.64
Qatar	1.75	1.55	1.72	1.61
Republic of Korea	2.06	1.44	2.19	1.55
Republic of Moldova	2.52	1.55	2.86	1.83
Romania	2.70	1.65	2.91	1.66
Russian Federation	2.86	1.74	3.31	2.23
Rwanda	1.89	1.42	2.09	1.52
Saint Lucia	1.88	1.19	1.94	1.22
St. Vincent & Grenadines	1.89	1.27	2.04	1.23
Samoa	1.99	1.31	1.95	1.26
Sao Tome and Principe	1.77	1.09	1.71	1.08
Saudi Arabia	1.64	1.17	1.74	1.32
Senegal	1.70	1.12	1.73	1.12
Serbia	2.62	1.63	3.11	1.99
Seychelles	2.23	1.41	2.24	1.42
Sierra Leone	2.60	1.56	2.55	1.61
Singapore	2.03	1.46	2.09	1.51
Slovakia	2.75	1.72	2.78	1.68
Slovenia	2.74	1.58	2.80	1.73
Solomon Islands	1.79	1.22	1.74	1.16
Somalia	2.04	1.34	1.84	1.24
South Africa	2.02	1.47	2.14	1.47
South Sudan	2.09	1.35	1.92	1.28
Spain	2.58	1.47	2.70	1.57
Sri Lanka	1.91	1.25	2.18	1.44
Sudan	1.72	1.16	1.68	1.14
Suriname	1.70	1.18	1.59	1.09
Swaziland	1.69	1.17	2.17	1.73
Sweden	3.04	1.66	2.95	1.55

SUPPLEMENTARY MATERIAL TABLE S1: Continued

	1990		2000	
Country	Mean UDR	Median UDR	Country	Mean UDR
Switzerland	2.77	1.64	2.67	1.52
Syrian Arab Republic	1.61	1.15	1.63	1.15
Tajikistan	1.82	1.23	1.83	1.27
Thailand	2.01	1.30	2.08	1.51
Republic of Macedonia	2.28	1.46	2.57	1.66
Timor-Leste	1.90	1.33	1.68	1.07
Togo	1.67	1.12	1.73	1.20
Tonga	2.00	1.27	2.10	1.23
Trinidad and Tobago	2.22	1.39	2.35	1.52
Tunisia	1.88	1.27	2.00	1.35
Turkey	1.85	1.20	1.93	1.15
Turkmenistan	2.02	1.33	2.16	1.50
Uganda	2.00	1.48	2.38	1.98
Ukraine	3.00	1.93	3.39	2.11
United Arab Emirates	1.69	1.51	1.69	1.50
United Kingdom	2.98	1.79	2.89	1.67
Tanzania	1.77	1.21	1.89	1.40
United States	2.46	1.49	2.48	1.62
Uruguay	2.68	1.55	2.53	1.53
Uzbekistan	1.84	1.23	2.06	1.43
Vanuatu	1.82	1.16	1.79	1.15
Venezuela	1.65	1.20	1.63	1.13
Viet Nam	1.79	1.24	1.86	1.23
Yemen	1.63	1.07	1.70	1.18
Zambia	2.31	1.85	2.89	2.53
Zimbabwe	1.56	1.09	3.52	3.20