Discounting the Benefits of Climate Change Policies Using Uncertain Rates

Richard Newell and William Pizer

Evaluating environmental policies, such as the mitigation of greenhouse gases, frequently requires balancing near-term mitigation costs against long-term environmental benefits. Conventional approaches to valuing such investments hold interest rates constant, but the authors contend that there is a real degree of uncertainty in future interest rates. This leads to a higher valuation of future benefits relative to conventional methods that ignore interest rate uncertainty

Most environmental policies involve a trade-off between short-term costs and longer-term benefits. Investments in cleaner technologies, for example, require up-front expenditures that lead to future environmental improvements. Climate change presents a dramatic need for balancing costs and benefits over time because the benefits of mitigation measures are linked to the lifespan of greenhouse gases (GHGs), which may remain in the atmosphere for centuries.

How do we compare costs and benefits that are separated by many decades or even centuries? When an individual saves for retirement, or a business invests in new equipment, the market interest rate allows us to convert costs and benefits at different points in time into comparable costs and benefits at a single point in time. This procedure is known as discounting.

But few markets exist for assets with maturities exceeding 30 years, making the interest rate beyond that horizon highly uncertain. This uncertainty has important consequences for the valuation of distant benefits from current policies, yet it has been virtually ignored.

We start by using one of several available models that estimate the time-profile of the benefits associated with reducing one ton of carbon emissions in the year 2000—see Figure 1. Regardless of any disagreement about the magnitude of climate consequences, the figure depicts a sensible pattern of mitigation benefits—a delayed, then an increasing, and finally a declining effect, as the climate adjusts first to the increase in carbon dioxide (CO_2) and then to its gradual decay. It turns out that only the overall shape of the path of benefits, not the magnitude, matters for our analysis of the effect of interest rate uncertainty.

The standard approach is to convert the model's path of benefits into equivalent discounted values in 2000, based on a single interest rate, and add them up. Applying
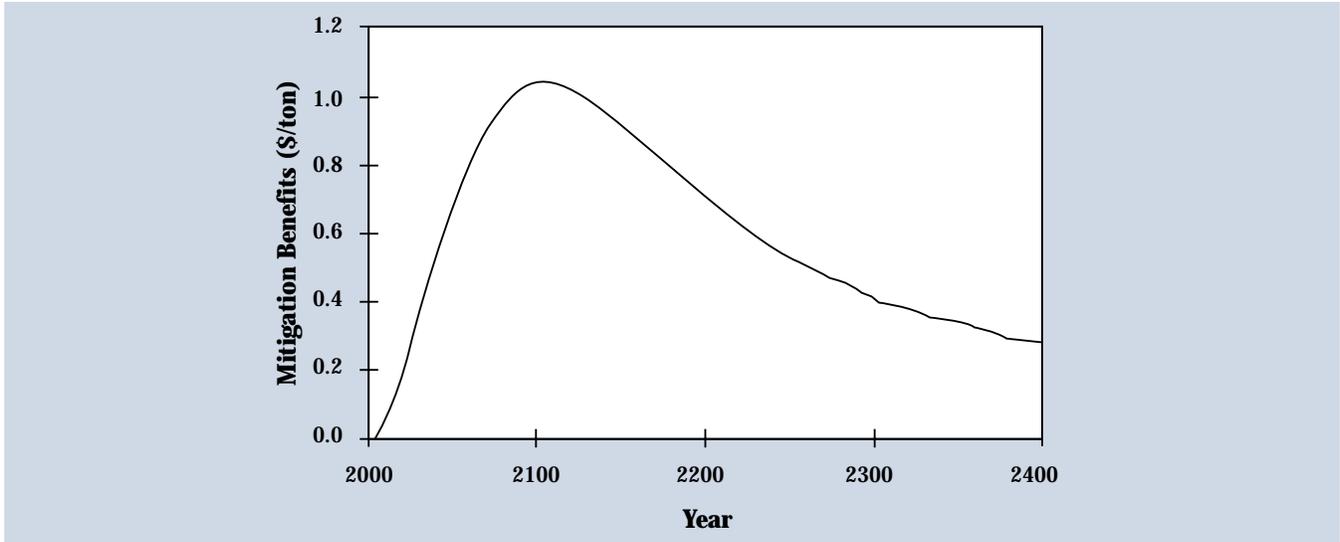
Figure 1: Time Profile of Benefits from Reducing 1 Ton of Carbon Emissions in 2000
Note: Based on William Nordhaus' Dynamic Integrated Climate Economy (DICE) Model

an interest rate of 4%—the average rate of return to government bonds over the past 200 years—one obtains a discounted value of about $6 per ton. This value can be balanced against marginal mitigation costs to determine optimal reductions or directly interpreted as the optimal tax on CO_2 emissions.

Despite the appealing simplicity of that approach, no one knows whether the interest rate will be 4% for the next 400 years. How, then, can we calculate the value of tomorrow's benefits in today's dollars?

Discount Rates

The term *discounting* arises because individuals typically value future consumption less than present consumption—they discount the future. Discounting is tied to the interest rate, which reflects the rate at which wealth can be traded across time. For example, investing $100 at 7% yields $107 at the end of the year. That $100 today can be traded for $107 next year indicates equivalence between these values. One would say that the future (next year) is discounted at 7%.

The investment criterion used in business provides another way of looking at the rationale behind discounting. Here's an example. Let's say private firms can borrow funds at 7% interest. If $100 invested in research or equipment yields a net pay-off of more than $7 every year, they can repay creditors and have something left over. Otherwise, they lose money. This is the net present value rule: if the net benefits from a project discounted

at 7% are greater than zero, the project is desirable.

Enter taxes. Because individuals pay up to 50% in federal, state, and local income taxes on their 7% pretax return, their actual return is closer to 4%. This consumption rate of interest is a measure of the rate at which people trade off their spending over time. Individuals can forgo consumption today, invest the money, and consume the after-tax proceeds from the investment at some future date.

The type of investment raises another complication, because riskier assets compensate investors by paying a higher rate of return. Thus, while equities have had an average return of about 7%, bonds have had an average return of only 4% before and 2% after taxes. To separate risk from discounting, we need to identify low-risk investments. Government bonds are considered very safe and a benchmark for the consumer interest rate absent any risk premium.

Applied 400 years into the future, however, the 2%–7% range of plausible discount rates has a corresponding difference in discounted values of 200 million-to-1. On top of this enormous variation depending on the choice of rate, we must consider how these rates may change in the future.

Consider the history of interest rates on long-term U.S. government bonds (Figure 2). Treasury bonds represent the highest-quality, lowest-risk market investment consistently available in the United States over the past 200 years. There have been persistent fluctuations in the real interest rate over the past
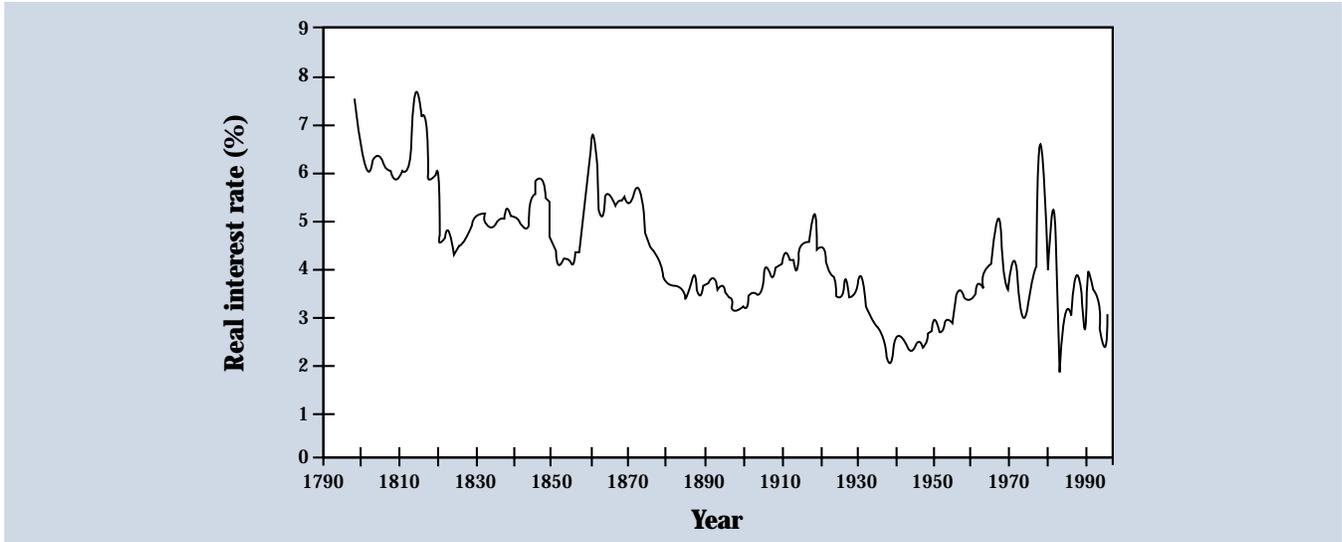
Figure 2: Market Interest Rate on U.S. Long-Term Government Bonds (1798–1999) (adjusted for inflation)

200 years, and it should not be surprising if interest rates continue to change by 3% or more—up or down. We need to evaluate the impact of this behavior on future valuations.

The Effect of Uncertainty on Future Valuations

Suppose we all agree that the current discount rate should be about 4%, based on the average market return to government bonds. Arguably, future rates might decline to as little as 1% over the next 100 years—or rise to 7%. If they fall to 1%, $100 dollars in 2100 is worth $20.28 today. But if they rise to 7%, $100 in 2100 is worth only $0.20 today. Placing equal weight on these two outcomes, the expected value of $100 in 2100 would be $10.24.

Now consider the same analysis for the present value of $100 in 2101—just one year later. Based on a rate of 1% in 2100, the $20.28 would be worth only $20.08 (20.28 ÷ 1.01 = 20.08). Similarly, at 7% in 2100, the $0.20 would decline to $0.19 (0.20 ÷ 1.07 = 0.19). Averaging these results, the expected value of $100 delivered in the year 2101 would be $10.13. The expected value thus declines by 1% (10.24 ÷ 10.13 = 1.01).

That is, with equal probability on 1% and 7%, the effective discount rate is very close to the lower value, not the average of the two values. As it turns out, it is discount factors, not discount rates, that one should average—and this distinction makes a big difference for long time horizons. (Discount factors multiply future values to convert them into today's dollars.)

Why does one effectively use the low rate rather than the average? Intuitively, discounting benefits 100 years hence depends only on the lower rate because the higher rate discounts future benefits to such an extent that they add very little to the expected value. The expected value of $10.24 almost equals the value when the rate falls to 1%, $20.28, multiplied by the probability of that outcome, 50%. In fact, the expected value would be virtually the same if the high-value interest rate were 10%—or 110%—instead of 7%. In this way, the change in value between periods comes to depend solely on the lower rate.

Next we need to model the fluctuations in interest rates. Do they take "random walks"? That is, just as when a drunk meanders down the street, his movement is random, and wherever he is now, that is the best guess about where he will be in the future. We might therefore assume that current rates represent the best estimate of future rates. Or do interest rates, whatever their short-term random movement, tend to revert to a long-run average or "mean"?

Unfortunately, the statistics neither confirm nor reject either model, and yet the choice makes an enormous difference. Under the mean-reverting model, which assumes that interest rates cannot remain high or low indefinitely, uncertainty about future interest rates has a much smaller effect on future valuation. Although the random walk model is more compelling to us, we report results for both models because subjective opinions could differ.

Based on statistical estimation of historical interest rates, we can simulate future interest rate paths. We repeat this process

Table 1. Value Today of $100 in the Future

Years in future	Discounted rate model			Value relative to constant discounting	
	Constant 4%	Mean reverting	Random walk	Mean Reverting	Random walk
0	$100.00	$100.00	$100.00	1	1
20	45.64	46.17	46.24	1	1
40	20.83	21.90	22.88	1	1
60	9.51	10.61	12.54	1	1
80	4.34	5.23	7.63	1	2
100	1.98	2.61	5.09	1	3
120	0.90	1.33	3.64	1	4
140	0.41	0.68	2.77	2	7
160	0.19	0.36	2.20	2	12
180	0.09	0.19	1.81	2	21
200	0.04	0.10	1.54	3	39
220	0.02	0.06	1.33	3	75
240	0.01	0.03	1.18	4	145
260	0.00	0.02	1.06	5	285
280	0.00	0.01	0.97	7	568
300	0.00	0.01	0.89	11	1,147
320	0.00	0.01	0.83	16	2,336
340	0.00	0.00	0.78	26	4,796
360	0.00	0.00	0.73	43	9,915
380	0.00	0.00	0.69	74	20,618
400	0.00	0.00	0.66	131	43,102

tens of thousands of times, each time drawing a different random path. Finally, we can make future benefits comparable with current costs by using a discount factor that translates future dollars into today's dollars. From the simulations, we have tens of thousands of equally plausible values for the discount factor at a particular point in the future. Common sense—and indeed economic theory—would tell us to average them to find an expected discount factor and, multiplied by the valuation in the future, an expected present value.

Table 1 presents our estimates, under both models, of discount factors over the next 400 years based on a 4% return in 2000 and using historical data on long-term government bonds to quantify interest rate uncertainty. For comparison, we present discount factors from a constant 4% rate. Discount factors are expressed in terms of the value today of $100 provided at various points in the future—that is, the discount factor multiplied by 100.

After only 100 years, conventional discounting at a constant 4% undervalues the future by a factor of 3 compared with the random walk model of interest rate behavior. After 200 years, conventional discounting is off by a factor of about 40. After 400 years, it is off by a factor of more than 40,000. The mean-reverting model produces less dramatic yet still significant results, raising the discount factor by a factor of about 130 after 400 years.

We also run the numbers starting from initial interest rates of 2% and 7%—our upper and lower bounds—in the random walk model and find that the relative effect of interest rate uncertainty rises as the initial rate rises. For example, the effect after 400 years raises the valuation by a factor of 530 million based on an initial 7% rate, but the factor is a little over 100 based on an initial 2% rate. Intuitively, the effect must be smaller for low discount rates because the range of possible lower rates (0–2%) is narrower.

The difference between valuations using different initial rates is generally smaller when uncertainty about future rates is incor-

porated. The ratio of discount factors using a 2% versus a 7% initial rate (based on the random walk model) becomes about 40 after 400 years. Though still substantial, that compares favorably with a factor of 200 million based on constant discount rates. In other words, the effect of uncertainty renders the choice of discount rate less important.

Valuing Future Climate Change Consequences

We can now apply our uncertainty-adjusted discount factors to the consequences of climate change caused by CO_2 emissions. Take the estimated benefits every year in the future due to a one-ton reduction in CO_2 emissions in the year 2000, multiply by the discount factor for that year, and sum. The results are shown in Table 2.

Based on a random walk model and an initial rate of 4%, uncertainty about future interest rates raises the estimated present value of reducing carbon emissions from about $6 per ton to $10—an increase of more than 80%. Using the mean-reverting model, we find a more modest effect of about 14%. An initial rate of 7% yields a 95% increase, and an initial rate of 2% yields an increase of about 55%. This result—that the relative effect of uncertainty is larger when the initial rate is higher—reflects the greater opportunity for uncertainty to lower rates (versus a low initial rate that simply cannot go much lower).

Because we focus on a 400-year horizon, our results are con-servative; extending the horizon further into the future intro-duces damages that are counted more heavily in the presence of uncertainty. Applying the uncertainty-adjusted discount fac-tors to longer-lived GHGs (such as methane or sulfur hexafluoride) or including catastrophic or permanent events (including species loss) also generates larger increases in dis-counted climate damages because the consequences would be more heavily concentrated in the future. In general, the greater the proportion of benefit flows occurring in the distant future, the greater will be the error introduced through discounting that ignores uncertainty in the discount rate itself.

Conclusion

The evaluation of environmental policies frequently requires bal-ancing near-term mitigation costs against long-term environmental benefits. To make these costs and benefits comparable, economic theory suggests discounting future consequences based on the market rate of return to investment. In this way, one gains assur-ance that environmental policies provide welfare improvements that are at least as good as other productive activities.

Here, we have considered the effect of uncertain future interest rates on the valuation of future benefits. Because unexpectedly low discount rates raise valuations by a much larger amount than unex-pectedly high discount rates reduce them, uncertainty raises future valuations relative to analyses that assume a fixed discount rate.

Table 2. Expected Discounted Value of Climate Mitigation Benefits (per ton Carbon)

		Benefits from 1 ton of carbon mitigation	Relative to constant rate
Government bond rate (4%)	Constant 4% rate	$5.74	—
	Random walk model	$10.44	+82%
	Mean-reverting model	$6.52	+14%
2% rate	Constant 2% rate	$21.73	—
	Random walk model	$33.84	+56%
	Mean-reverting model	$23.32	+7%
7% rate	Constant 7% rate	$1.48	—
	Random walk model	$2.88	+95%
	Mean-reverting model	$1.79	+21%

After studying past interest rate behavior, simulating uncertain rates in the future, and computing discount factors for various time horizons and alternative base rates, we have found that valuations rise and the effect of uncertainty is larger for higher base interest rates. Comparing the discount factors directly, we conclude that the valuation of future benefits is less sensitive to the choice of initial discount rate when uncertainty is taken into account.

Because today's environmental decisions affect future generations, many economists have argued that it is unethical to discount the well-being of future generations. Others have argued that the intergenerational discount rate need not equal the rate used by individuals within their own generation. These arguments have led to a tendency to simplify the problem by applying lower rates over longer horizons. Long horizons, however, eventually become short.

We find that using market rates between 2% and 7% and accounting for uncertainty lowers the effective discount rate such that all generations are essentially treated the same after a certain horizon. In that sense, our findings can be viewed as an argument for intergenerational equity that originates from conventional economics.

Using conventional discounting techniques to value benefits over hundreds of years renders future benefits insignificant and, to many people, that somehow seems "wrong." Our results show that constant discount rates do in fact undervalue the benefits of GHG abatement measures. We can at least partially address that problem—without abandoning conventional economic theory—by viewing future interest rates as uncertain.

For more information

Journal of Environmental Economics and Management. 1990. Special Issue 18(2).

Newell, R., and W. Pizer. 2000. "Discounting the Distant Future: How Much Do Uncertain Rates Increase Valuations?" Discussion paper 00-45. www.rff.org/disc_papers/PDF_files/0045.pdf. Washington, D.C.: Resources for the Future.

Newell, R., and W. Pizer. 2001. *Discounting the Benefits of Climate Change Mitigation: How Much Do Uncertain Rates Increase Valuations?* Economics Technical Series: Pew Center on Global Climate Change. www.rff.org/reports/PDF_files/discountbenefits.pdf. Washington, D.C.

Portney, P.R., and J.P. Weyant, eds. 1999. *Discounting and Intergenerational Equity.* Washington, D.C.: Resources for the Future.

Weitzman, M.L. 1998. Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate. *Journal of Environmental Economics and Management* 36(3): 201–208.