Chapter 7

Modeling The World Economic Impact

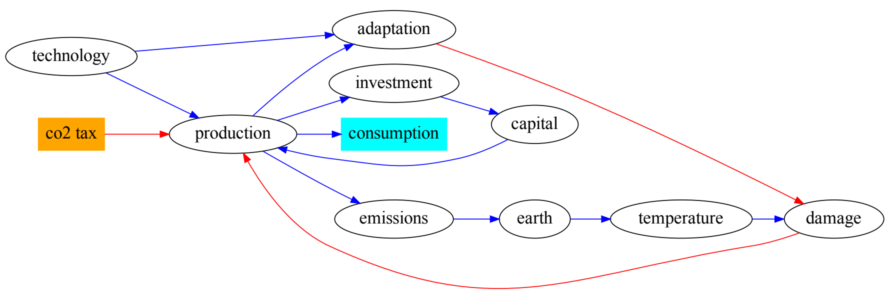
The first part of our book explained energy needs and earth sciences from a largely non-interventionist perspective — an essentially do-nothing scenario. The previous chapter explained some key economics principles — for example, the role of taxes in the control of pollution. This chapter puts earth sciences and social sciences together: what exactly *should be* the right amount of taxation to control global warming?

The models discussed in this chapter are not just dry economics from the "Land of Ivory-Tower Theory." Instead, they form the bases of all climate negotiations, including, e.g., those in the Paris Accord of 2016. The formal names for models that integrate all scientific areas for the purpose of assessing potential policies are "integrated assessment models" (IAMs). The primary purpose of IAMs is to recommend the appropriate level of global tax on CO_2, not just today but also in the future.

On a historical note, these models were pioneered by William Nordhaus and justly earned him a Nobel Prize.

1 An Economic Sketch of Earth

Figure 1. A Simple Schematic for a Typical Integrated Assessment Model



Note: Blue arrows are positive feedback; red arrows are negative feedback. Gray nodes are earth-science-based. The modeler tweaks the CO_2 tax controls (in orange) to maximize consumption (in light blue).

Source: Inspired by a DICE schema by David Garcia-León.

Figure 1 shows a basic diagram of an integrated assessment model, largely based on Nordhaus' prominent Dynamic Integrated Climate-Economy (DICE) model. DICE is a relatively simple model — there are far more intricate ones. The diagram, though *not* complete, retains the most important blocks and links. Each of the blocks contains a lot more detail in the actual model and relies on parameters that have to be set by the modeler.

On the left are the two external inputs into the model. The first input is in the orange box, labeled CO_2 tax. It is under the control of the modeler, who can tweak it to see what the outcomes will be. For arrows, we use red in the model to indicate negative input or feedback and blue to indicate positive input or feedback. Higher taxes reduce production — there is less money available to the producer — which is why the arrow is red. The second external input is technology. In the basic DICE model the rate of technical improvement is constant but tunable by the researcher. Technology marches steadily upward and improves production (and also adaptation), which is why the arrow is blue.

The cyan box in the middle of the diagram is consumption, the key output. Consumption here is to be interpreted broadly, including all goods and services.

It could and should include such aspects as human pleasure derived from a natural environment with species diversity. (Unfortunately, typical models usually employ only narrower measures.) The ultimate goal of the modeler is to adjust the annual CO_2 taxes to obtain the highest possible time path of consumption.

Digging deeper into the graph offers a few more insights. The production output can be consumed, or it can be used to fund adaptation (such as building dykes or purchasing air conditioning), or it can be invested in future production. But more production also increases emissions. At this point, the earth sciences from Chapters 1–4 come into play (gray boxes) — determining how human emissions change Earth's global temperatures. The damages caused by rising temperatures then feed back and reduce production, and thereby consumption.

There are many nodes and links not included both in this stylized diagram and in the actual full DICE model. For example, the model does not even have a node for population growth, although population growth influences nearly every other aspect of the economic model. Instead, there is some assumed rate of population growth that is simply fed into the model. Furthermore, technology could affect investment, investment could affect adaptation, and so on.

Yet even with the simplified structure, the feedback effects in DICE are so numerous that even Nordhaus says that he often does not understand intuitively how an adjustment of the inputs will change the outputs before he tries it out. For example, consider this feedback effect: if temperature rises, it creates damages which lower production, which lowers emissions, which can then lower temperature in the future, and so on.

The most important and ethically most contentious parameter is not even visible in the diagram. It is the *discount rate*. Discounting is the process of determining how much humanity would be willing to pay today (a concept called present value) in order to avoid $1 of harm in the future (a concept called future value). Different discount rates are also needed depending on how far in the future the harm is expected to occur — in DICE, it could be in a century or later. Discount rate assumptions are necessary to make it possible to add up the welfare of people living in different centuries in order to arrive at one overall "social welfare" measure.

A simpler verbal version of the discount rate question is this: How should humanity value one extra dollar for a person living today compared to one extra dollar for a person living 100, or even 500, years from now? As simple as the question appears, it is fiendishly difficult to answer — and it is really more of a philosophical than a scientific question. We will explain this in more detail in Section 5. For now, just take note of the fact that the choice of discount rate can have a large effect on the optimal CO_2 tax prescribed by DICE and other integrated assessment models.

2 What Goes In and What Comes Out?

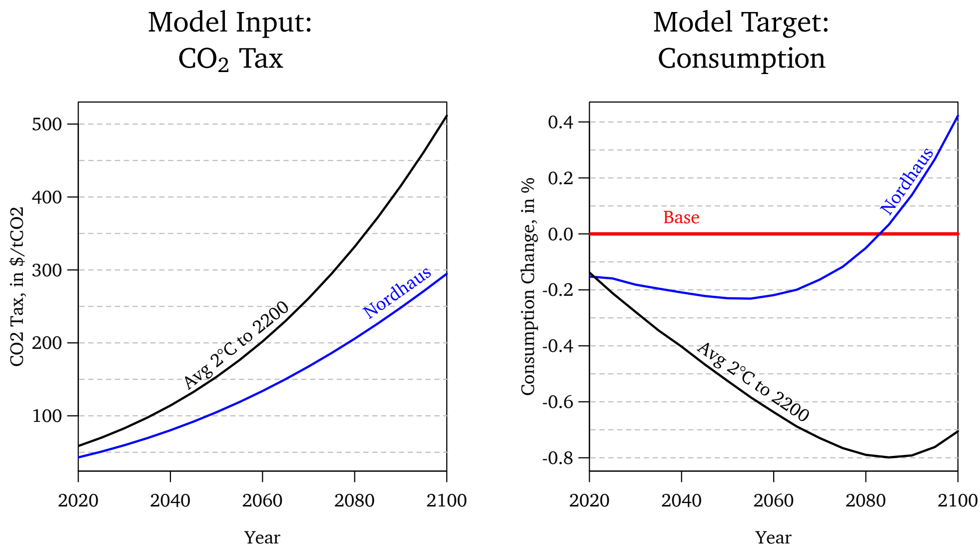
The DICE model considers *only* the next 200 years. Thus, Nordhaus can play with about 200 "knob settings" labelled "Global Tax on CO_2 in Future Year X." They could also be labeled "emission-control incentives." By twisting these control knobs, Nordhaus can determine how various settings will likely change the total social welfare. He fiddles with the knobs until he finds the 200 settings (one for each year) that maximize social welfare.

Nordhaus' latest model considers many scenarios ("cases"), but we focus on just three:

1. A "base" case, which was essentially Earth without any active intervention as predicted in 2010–2015, i.e., before clean technology truly took off. It is now viewed as a more pessimistic scenario.
2. An "aggressive" case, in which the world intervenes to limit the *average* temperature increase to 2°C by 2200. This case is inspired by the Paris Accord, but the limit is softer in that it may be briefly exceeded.
3. A Nordhaus preferred optimal cost-benefit solution, tuned to maximize social welfare, somewhere in between the previous two cases.

The left plot in Figure 2 shows the 200 knob settings for the 200 (future annual) global CO_2 taxes. They are stated in terms of dollars per ton of CO_2 emitted. Unfortunately, the optimal CO_2 tax is often also called the "social cost of carbon"—and this most common conversational use is actually not precisely either a social cost or (about) carbon. For the latter, the experts really mean carbon-dioxide and not carbon. For the former, because industries need time to adapt, the immediately optimal tax is below the social harm done by the

Figure 2. Nordhaus CO_2 Tax and Consumption Change



Note: The base scenario is pessimistic and without intervention. The Nordhaus scenario is a welfare-maximizing solution on aggregate consumption (not per-capita). The Limit 2°C scenario is a constrained welfare-maximizing solution, keeping the average temperature by 2200 below 2°C.

release of an extra tonne of CO_2.[1] (As if the subject were not difficult enough, the experts have found yet another way to make understanding even simple concepts more confusing!) Nevertheless, in the grand scheme of things, just pretend that "social cost of carbon" discussions are about how society should tax CO_2 release and ignore the fineprint.

Under Nordhaus' parameter settings (especially, but not only, the discount rate), the optimal CO_2 tax starts at about \$40/tCO_2 today, rises to about \$50 by mid-decade, \$100 by mid-century, \$200 by 2080, and \$300 by 2100.[2]

[1] We mentioned in Chapter 2 that 1 ton of carbon (C) turns into 3.67 tons of CO_2 when burned. When the experts write about a social cost of carbon of \$50 per ton, if taken literally, this would imply that it would be \$183 per ton of CO_2. However, this is not what they mean. Instead, they mean \$50 per ton of CO_2. Grrrr....

[2] Estimation of the social cost of carbon-dioxide remains controversial. Based on a meta analysis, Peter Howard and Thomas Sterner report that when the Nordhaus damage function is replaced by their preferred estimate of the temperature-damage relationship, the result is a

By the end of the century, only the most exceptional activities that emit CO_2 would still remain viable. The 2°C-average-limit scenario by 2200 requires imposing taxes more aggressively — reaching \$200/tCO_2 two decades earlier than under Nordhaus' preferred solution. At the end of the 21st century, with its CO_2 tax of \$500/tCO_2, emissions will have already dropped into negative territory. (Not shown, the Paris Accord would require even steeper taxes.)

Both tax functions start reasonably low today but increase ever more steeply. This is because the sudden imposition of too high a CO_2 tax would not allow industries to adapt. A more sudden tax of, say, \$200/tCO_2 next year would bankrupt a lot of businesses that could not switch instantly to cleaner sources of energy. The smooth and predictable rising tax greatly reduces this economic harm.

Pollution Taxes and Welfare

The right plot in Figure 2 shows how tax schedules influence the time path of consumption. Any CO_2 abatement imposes some current consumption diminution compared to the base case. However, under the Nordhaus plan, the reduction is fairly mild. It remains under about 0.2% of current consumption. (With global GDP of about \$90 trillion, this is still almost \$200 billion!) Moreover, children born today will still reap some of the benefits of their parents' sacrifices — around 2090, their consumption will exceed what they would have had if no mitigation measures had ever been instituted.

As we mentioned in the previous chapter, if the OECD were to have to pay for the reduction alone (without the help of China, India, etc.), a rough estimate would be that the OECD's GDP-proportional cost would be about 0.5% of consumption in 2050; if the US were to do it alone, its cost would be about 1%.

In contrast, the more aggressive 2°C average limit by 2200 is far more costly, with the largest losses of nearly 1% imposed on our children. This plan is also never optimal in the sense of maximizing consumption. The 2°C sets a target that will make not only us but our children worse off. (This assessment could, however, be wrong if the Nordhaus model is wrong. Then again, all assessments are based on models that could be wrong.)

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three- to four-fold increase in the SCC relative to the 2015 DICE model. Burke et al. estimate significantly higher damages of about 20% of GDP. If they are correct, the SCC should be much higher. This will be an interesting field of research for economists for many years.

Earth Temperature and Others

After Nordhaus has found his best 200 knob settings, his model yields three other interesting outputs. They are plotted in Figure 3: human CO_2 emissions, CO_2 concentration in the atmosphere, and the increase in average global temperature.

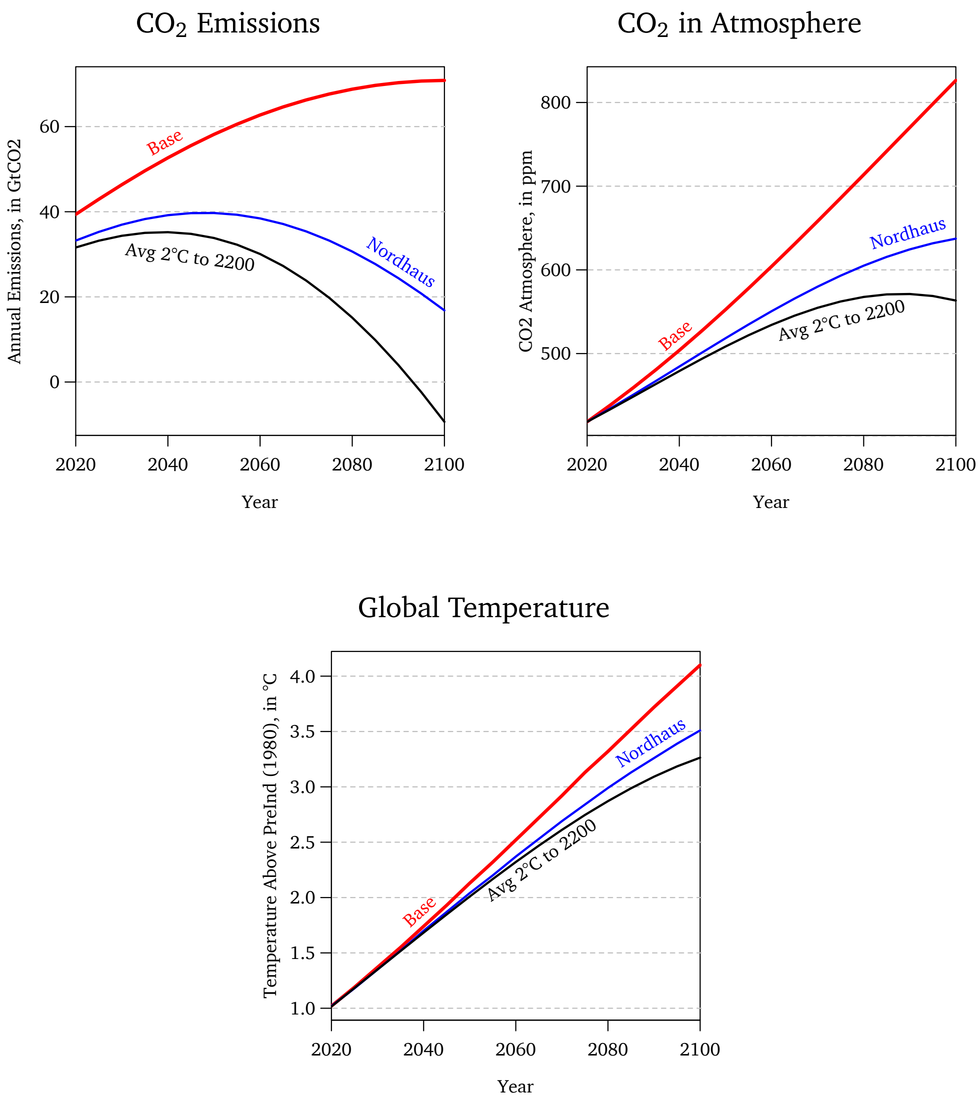
The plot on the top left shows how both Nordhaus and the 2°C goal curtail emissions in comparison to the base case. In the base case, CO_2 emissions rise throughout the century, before leveling off at about 70 $GtCO_2$/year. Limiting the temperature increase to an average 2°C by 2200 requires pushing human emissions below zero before the end of the century. The Nordhaus plan is more forgiving, pushing emissions to about 20 $GtCO_2$/year.

The plot on the right shows that the Nordhaus plan allows atmospheric CO_2 exceeding 600 ppm for a while, whereas the 2°C plan limits it to about 580 ppm. Both plans are still much better than the pessimistic base case, which has atmospheric CO_2 reaching levels of approximately 850 ppm by century's end and continuing upwards beyond that. Fortunately, this base case is largely technologically obsolete by now.

The bottom plot shows that planetary temperature responds slowly to changes in atmospheric CO_2. Thus, even the aggressive 2°C plan "only" reduces temperature by about 1°C relative to the base case scenario (an increase of 3.2°C instead of 4.2°C). The Nordhaus scenario allows for about a 0.3°C greater temperature increase than the 2°C average-limit scenario by the end of this 21st century. However, both curves continue to rise beyond the year 2100. Visually, they suggest that the average temperature will rise by more than 4°C over a 200-year time frame.[3]

[3] The model's welfare calculation includes only consumption over a century or two. Our understanding is that this is ok, because fossil fuels are likely to be exhausted in about 100-200 years.

Figure 3. Nordhaus Earth Outputs



Source: Courtesy of William Nordhaus. Temperature is relative to 1980. (Thus, 2020 is 1°C.)

sidenote

The 2021 IPCC report now includes Shared Socioeconomic Pathways (SSPs). These can be viewed as a step or component on the way to an IAM. They attempt to guess how different government policies, economic growth, and environmental aspects might flow into different Representative Concentration Pathways (RCPs), explained earlier in Chapter 4). For example, SSP 1 paints a low-economic growth picture based on pervasive environmentalist sentiments all over the world, with reduction of inequalities. SSP-5 paints a high-economic growth picture fueled by fossil fuels. In our opinion, the SSPs are poor alternatives to a full IAM. We are not fans of the SSPs.

3 What is the Scientific Consensus?

The methods of the Nordhaus model have been widely accepted by the scientific community. Even his critics have adopted his approach to modeling the economic impact of climate change. But this does not mean that they agree with his model parameter choices or conclusions. Many of these parameter choices are model inputs that require judgment.

For example, what is the rate of technological change? In its first version "DICE 1.0," Nordhaus' model turned out to have been too pessimistic, especially with regard to clean-energy technology. No one expected it to advance as quickly as it did. Even Nordhaus did not — though economists generally tend to be more optimistic than other scientists about human inventiveness *when money is at stake*.

In addition, it is easy to estimate the cost of reducing emissions "*on the margin*," i.e., what it would take to eliminate the first Gigatonne of CO_2. But it is much more difficult to estimate how much it will cost to eliminate humanity's total of 30 Gigatonnes.

Furthermore, although economic long-term growth rates have been steady for many decades, what will be the growth rate of the world economy over the next 100 years and what will be the damage caused by global warming? Economists cannot accurately predict economic activity over such long horizons.[4]

[4]This makes it all the more remarkable how confident some natural scientists at the IPCC seem to be about assessing the same economic growth and damages that economists are so reluctant to assess.

The integrated assessment modelers also have to update their models constantly. The world is changing. And the economics and earth sciences components are improving. Nonetheless, there are disagreements. The adoption of different parameters has led different researchers to recommend different global CO_2 taxes.

Table 4 illustrates a range of estimates for the first year's recommended tax. (In all models, CO_2 taxes would rise smoothly in future years.)

Table 4. Various Estimates of An Appropriate CO_2 Tax (circa 2020)

Politics		Model-Based Estimates				Pindyck Survey	
Trump	Biden	IAWG	Nordhaus	Stern	Typ Range	Economists	Climatologists
≤$5	$51	$50	$50	$80	–$15 to $2,500	$80	$120

Note: These taxes are often referred to the "social cost of carbon," though "social cost of carbon-dioxide" would have been a far better name. (No one is thinking of taxing graphite.) The numbers in the table are reasonably representative but not exact. IAWG is the Interagency Working Group, whose estimates are used by the U.S. government for planning purposes.

The most prominent recommendation for the social cost of carbon-dioxide is Nordhaus' updated estimate, which stands at about $50/t$CO_2$ today. The leading alternative take was published by economist Nicholas Stern in 2006 (in his 700-page "page turner," called the "Stern Review.") As early as 2006, Stern advocated a global carbon tax of $85/t$CO_2$, where it still stands today (rising to $100/t$CO_2$ as early as 2030). In 2006, this high a recommendation was a shock to policy analysts — a time when Nordhaus was still advocating $30/t$CO_2$. Today, the two estimates are no longer far apart.

There are also other estimates developed by international organizations and U.S. government agencies. For instance, the *U.S. Interagency Working Group* (IAWG), first formed during the Obama administration to help planning for climate change, suggests $51/t$CO_2$e in 2021. There have also been numerous surveys conducted by various experts, including academics. Typically, economists recommend lower taxes than climate scientists ($80 vs $120). However, in line with the theme of our book, the differences among these estimates are unimportant. Both numbers are so high that they mean the same thing for practical purposes: immediate drastic CO_2 tax increases causing CO_2 emission reductions.

In sum, the most reasonable estimates, as of 2022, seem to suggest an appropriate global CO_2 tax in the range of \$50–\$100/tCO_2, rising over time. Despite their natural cantankerousness, it's remarkable how many prominent economists agree. An Economists' Statement published in the Wall Street Journal in January 2019 was signed by over 3,000 economists including all living Nobel Prize winners and all past heads of the U.S. Federal Reserve. It advocated a tax similar to that suggested by the basic Nordhaus model. We will return to this statement in Chapter 8.

Where are we now? Ironically, the actual worldwide tax on CO_2 seems to be *negative*. For example, in the United States, the fossil-fuel industry benefits from large direct subsidies — estimates range from about \$2 to \$60 billion for the \$180 billion industry, the equivalent of a subsidy of about \$0 to \$50/tCO_2. Worldwide, the International Monetary Fund (IMF) has estimated that global fossil-fuel subsidies were \$500 billion (or \$15/tCO_2) in 2017.[5]

In light of the world's actual negative tax rate, the differences between Nordhaus and Stern, or economists and climate scientists, no longer seem so large. Arguing about \$50 vs. \$80 next year is creating discord for no good reason. Where it matters, all agree. The world today has a ridiculously low and harmful tax rate on CO_2 emissions.

4 CO_2 Taxes and Consumption Losses

Most of us do not have good intuition for what CO_2 taxes and consumption sacrifices quoted in percent really mean. Let's translate these abstract figures into more meaningful terms.

Energy Costs

Table 5 shows that at \$100/tCO_2 (which all plans reach in reasonable short order), the price of gasoline would roughly double, i.e., gasoline would cost in the United States what it already costs in Europe. Coal would become uncompetitive given any reasonable CO_2 tax in most parts of the world. In a sense, a \$100/tCO_2 tax on coal might as well be a \$1,000/tCO_2 tax. Natural

[5] It rises to a misleading headline estimate of \$5.2 trillion (a stunning 6.5 percent of global GDP in 2017) if speculative estimates of worldwide pollution and global-warming harmful effects are added.

Table 5. Price Increases With a CO_2 Tax

	tCO_2e /Unit	Addtl Tax per tCO_2 $0	**$50**	$100	$200	Price Increase
Oil, 1 Barrel	0.43	$50	**$75**	$100	$150	50%
Gasoline, 1 Gallon	0.01	$2	**$3**	$4	$5	50%
Coal, Railcar /1000	0.18	$5	**$15**	$25	$35	5×
Natural Gas, 1 MCF	0.055	$3	**$5**	$8	$15	2×
Tree, 1	–0.06	$0	**–$3**	–$6	–$12	(> Planting Cost)

Source: CO_2e/unit emission estimates are from the EPA Calculator Equivalences. The natural gas is emissions at the smokestack and excludes emission on the supply chain. The boldface $50/$tCO_2$ column is the immediate tax recommended by most economists. The $100/$tCO_2$ tax would be reached in short order.

gas prices would double, thereby doubling winter heating costs for most U.S. households — more if gas leaks are taken into account. (Not shown here, electricity costs would likely also double at $100/$tCO_2$.)

Fortunately, sensible adaptation would allow most people to offset much of the tax increases. For instance, people could drive less and in smaller electric cars. New systems could greatly reduce heating and cooling costs. Planting trees would become more profitable, and thus so would probably anything constructed out of wood.

Ideally, governments could and should reduce other taxes commensurately if they can collect necessary revenues through fossil-fuel taxes instead. Unfortunately, real-world politicians rarely end up lowering other taxes, leaving most ordinary consumers with frustrations about ever-increasing taxes. It is difficult to see how the public would support fossil fuel taxes without forced bundling of tax relief.

Consumption Loss

Another way to look at the cost of a CO_2 tax is to add up the expected economic cost and spending reductions (Figure 2). We will work with rough characterizations. The Nordhaus plan is the most relaxed approach, suggesting a cost peaking at about 0.2% of GDP in about one generation. A more Stern-like approach would likely peak at about 0.5% of GDP. The even more stringent 2°C path considered by Nordhaus reaches 0.8% loss in consumption in about one decade (when the tax reaches about \$100/tCO_2). Finally, the less economically and more environmentally oriented Paris plan would likely reach about 1.0%. In all plans, we should expect to start out with costs of about 0.2% pf GDP to allow for adaptation.

➤ Compared To Public Expenditures

The United States has a GDP of about \$20 trillion per annum. State and local governments spend about the following:

Roads	Higher Education	Health and Hospitals	Military (Federal)
\$200 bn	\$300 bn	\$300 bn	\$800 bn

On the high side of fighting climate change, a 1% consumption loss would be about \$200 billion. Thus, the required public expense would be about the same as the current public expense on infrastructure; or two-thirds of the expense of all state and local higher education. It would however be only 25% of our <u>Federal</u> military budget — about the same cost as the U.S. Navy. These are obviously large sums of money.

On the low side, 0.2% would be about \$40 billion. Fighting climate change would then cost only about the equivalent of the another *Department of Housing and Urban Development* (i.e., all public housing) or another *Department of Homeland Security* (with its 240,000 employees).

➤ Compared To Private Housing Rent Costs

Instead of public expenses, we can also look at private expenses. The median household in the United States today has two earners bringing home about \$65,000/year and pays about \$13,000/year in rent (\$35/day). Thus, the Nordhaus plan would cost the equivalent of about three days' rent; the Stern plan about ten days' rent; and the Paris-like plan about 20 days' rent.

➤ Global Sharing

Thinking in terms of rents, the above calculations implicitly assumed proportionality. Everyone would pay their 0.2% to 1.0% of consumption to fight climate change. Richer people, like the average resident of Manhattan or Palo Alto, would have to pay more in absolute but not in relative terms. Think an extra $2,000 per year (instead of $500 to 1,000 per year). In China, where rents are about 20% lower, the rent-proportional "global warming tax" would be about $200 per year. In India, where rents are 70% lower, it would mean about $75 per year. And fortunately, unlike rent, households could reduce CO_2 taxes by polluting less. That's the whole point of the tax, after all.

However, the United States would realistically have to cover more than its proportional share of the world's belt-tightening. Poorer countries will almost surely not be willing to volunteer a proportional share, especially because the OECD is responsible for most of the CO_2 in the air today. A more realistic and possibly fairer estimate would be twice what we calculated above: think one week for the Nordhaus plan and one month for the Paris plan.

In future chapters, when we discuss potential tax solutions, we will use a "one month's rent" (for an aggressive but incomplete CO_2 abatement plan) as an intuitive benchmark cost. Of course, basing taxation on housing rent is *not* a suggestion for best polity — it is a thought device to put a CO_2 tax in perspective — akin to the Economists' Big Mac Index for measuring price levels across countries.

➤ Summary

Are you an environmentalist worried about global warming? Have you been advocating for action? If so, please answer this one simple question: *how much tax would **you** be willing to pay?*

5 What are the Best Model Parameters?

How Do We Value Future Generations' Welfare?

Remarkably, the biggest disagreement between advocates of lower and higher CO_2 taxes (from Table 4) has nothing to do with uncertain or contentious scientific forecasts. Instead, it is about the previously mentioned parameter that is almost entirely philosophical and subjective: how should humanity value the welfare of future generations — not just in 100 years, but in 200 or 300 years?

In the model, the answer to this question enters as the discount rate. Table 6 shows how sensitive the social cost of CO_2 (i.e., the optimal tax) is to different discount rate assumptions. Reasonable variations in the discount rate can swamp the effects of tinkering with almost all other inputs.

Table 6. Social Cost of CO_2 By Discount Rate in Nordhaus' Model

Assumed Real Discount Rate	Today's $1 in 100 years	Best CO_2 Tax, in 2018-$/t$CO_2$ 2015	2020	2050	2100
0.1%	$1.11	$970	$966	$917	$665
1%	$2.70	$497	$515	$614	$657
3%	$19	$93	$104	$179	$361
5%	$131	$23	$27	$55	$126

Source: Nordhaus, Nobel Lecture, American Economic Review, 2019, 109 (6): 1991–2014, p.2006. See also IAWG, Feb 2021, Table ES.1.

Nordhaus assumes that any investments to slow climate change must compete with other investments for profitability. If $1 today can be expected to earn $100 (inflation-adjusted) in 100 years when invested in the real economy or the stock market, then the same return should be required when investing $1 to reduce climate change — i.e., it should avoid damages of $100. We chose this $100, because it happens to be close to the historical average inflation-adjusted rate of return per year after taxes (about 5%).[6]

[6] $\$1 \cdot (1 + 4.75\%)^{100} - 1 \approx \$100$. A fairer number could be $50, because the after-tax return is lower than the pre-tax return. On the other hand, some retirement income and estate transfers are usually tax-exempt.

Stern rejected this view, arguing that humankind today should treat its future generations more like itself. If $1 today can avoid $1-$3 worth of damages in 100 years, it is good enough to warrant investing this $1 into emission reductions today. His inflation-adjusted discount rate view lies thus somewhere between 0.1% and 1.5% per year.

The Ethical Choice?

The knee-jerk reaction is that Nordhaus offers the egotistical answer and Stern the ethical answer — that is, people today should take as good care of future generations as of their own generation.[7] Humanity should be the stewards of the planet for its children! This ethical high ground is also why the Stern report intuitively appeals to a lot of people — including many scientists. But is it really the *ethically* correct choice?

Despite two world wars, the average American now has an inflation-adjusted income (GDP) that is about six times higher than it was 100 years ago. The trends in other parts of the world were similar. It is a reasonable guess that in 200 years (about six generations), the average person will earn about 30 times (in real inflation-adjusted terms) as much as the average person today. Would it really be so unethical if these future people would have a standard of living only 20 times higher than our own rather than 30 times? Moreover, with many times our income and wealth, they would be able to afford or remedy damages more easily than we can.

The consensus among economists today is that it was Nordhaus who got the discount rate right. However, many of the same economists also believe that Stern's steeper tax recommendations are better than Nordhaus' for reasons that are not explicit in either original base model — mostly because of uncertainty about the future climate and the possibility of climate catastrophes that the original Nordhaus model did not take into account. We will come back to this issue.

There is also a more practical aspect to consider. Self-interest limits what is politically viable. Miles' Law says that "where you stand depends on where you sit." Recall our warning from the previous chapter that even good taxes can create winners and losers. Even if the sum of humanity today and humanity

[7] Both the Nordhaus and the Stern discount rates are sketches of what they actually use. The real deal requires a lot of detailed economics.

in the future may collectively be better off, it is also the case that all the losers (those who will sacrifice to a CO_2 tax) are alive today and all the winners (those who will benefit) will be alive in the future. This lopsidedness makes it difficult to build support among the living today to vote to sacrifice. Even the grandchildren of the distant future have not been born yet.

Take a quick self-test. How much would you be willing to sacrifice today to prevent the world's great-great-great-great-great grandchildren from "suffering" in the sense of only having 20-times more than you vs. having 30-times more than you? If you answered "a lot," write a check for one month's rent now made out to great-great-great-great-great grandchildren. (This covers your necessary contribution just this year on behalf of generations 200 years from now. You will have to write it again next year, of course.) Stare at it for a while. If you are still ok with sending it, you are consistent. If you are not ok, you are probably in the majority that would convince themselves that *other* people should pay for lowering CO_2 emissions — just as long as it is not you. After all, is the CO_2 in the atmosphere really your fault or was it the fault of some anonymous oil barons? The average American is willing to pay about \$1/month in higher electricity cost, not \$500/month.

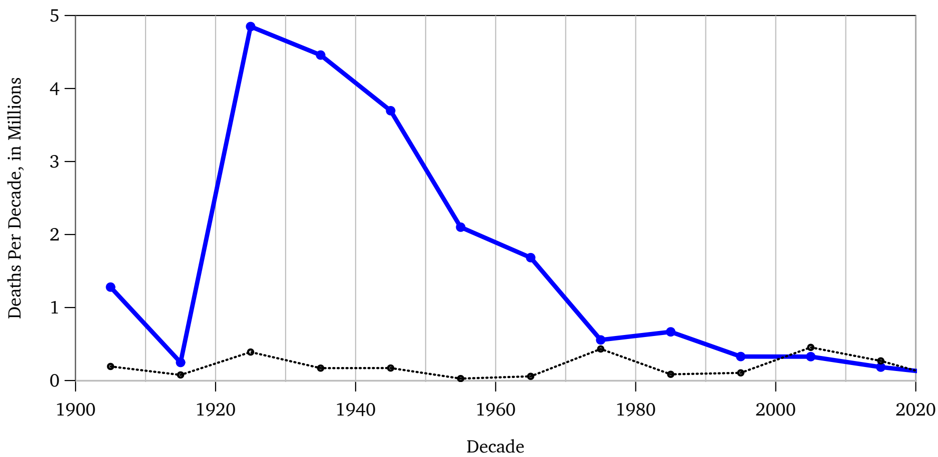
Adaptation

Another subjective parameter in the Nordhaus model is the damage from global warming. Simply put, scientists today can only guess what the damage will be. There are no certainties. A big reason is the role of adaptation. Bjorn Lomborg's book False Alarm is highly controversial and provocative, but it makes many good points, too. It points out that some alarmism has been naïve because "the stories assume that while the climate will change, nothing else will." Like most economists (including us) and unlike many other scientists, Lomborg has a lot more faith in human inventiveness

But you can't blame everything on global warming!

when their own hides are at stakes (and a lot less faith when it comes to the capabilities of real-world governments to make good choices).

Figure 7. Disaster Deaths By Decade



Note: Climate catastrophes (in fat solid blue) are floods, droughts, storms, wildfires, and extreme temperatures. They peaked in the 1920s and have been coming down since. Non-climate catastrophes (in black at the bottom) are earthquakes, tsunamis, and volcanoes, and give an intuitive benchmark. (Their death tolls have remained constant — even though the population has increased greatly, people have been moving out of the way.)

Source: Original Source: Lomborg and International Disaster Database.

Historically, Lomborg and the economists have been more right than wrong — although this is no guarantee that this will also be the case in the future. Scientists and environmental activists have consistently underestimated humanity's ingenuity and ability to adapt.

In one of Lomborg's examples, he shows that deaths from climate-related catastrophes have not increased but decreased markedly over recent decades (Figure 7). Even though global warming has probably increased the strongest hurricanes, these storms have caused less harm. When you watch news about how climate change has brought about the latest stronger hurricane or drought, just remember that not that long ago, such weather used to kill many millions of people every year. Today, it's "only" a few hundred thousand (too many, of course). Over time, forecasts have become better and people have learned to adapt. If the world becomes wealthier, and thereby more able to adapt, expect less harm, not more.

Innovation

Activists also often fear that global warming will devastate crops. This factor is often the biggest component of damage estimates incorporated into IAMs. However, there may be much less crop damage than they fear. There is a new potential adaptation. Geneticists can now alter crops to take better advantage of higher CO_2 levels and warmer temperatures. Engineered plants could require less water, fertilizer, and pesticides, and be more nutritious and healthy, to boot. Innovations could even increase agricultural output as the world warms. Obviously, this is also still a guess. We will not know for sure whether this will work until we try.

The relevant subjective parameter in the Nordhaus model is the rate of technological innovation. Innovation can be thought as another form of adaptation. New technology contributes to making our children richer than us. This helps to pay for mitigation of and adaptation to climate change.

Is the relevant technological growth slowing down or not? Some scientists argue that the low-hanging fruits of technology innovation have already been picked, and therefore future growth rates will be slower. Other scientists argue that innovations in fields such as biotechnology and artificial intelligence will keep the economy growing at historical rates. It's not clear. In the two areas most relevant to climate change — energy and biotechnology — the evidence suggests that technological innovation is going strong. These innovations will likely eliminate most CO_2 emissions from the energy sector and beyond. The question seems to be only how fast — sooner or later?

Almost all interested scientists agree that civilization should invest heavily in relevant clean technology and R&D. This could accelerate its progress at a cost that is relatively low. But here is a puzzle. As we explained in the previous chapter, the faster the pace of innovation, the more we should *not* implement new technologies now, but wait just a little longer. In the extreme, if technological progress (especially in energy technology) is fast enough, humanity may even be better off not installing any clean energy today and doing nothing today other than to subsidize and to accelerate research progress. But what if scientists have miscalculated and the technology will not improve as fast as we forecast?

Catastrophic Scenarios

Many first-generation integrated assessment models did not incorporate uncertainty and risk. They can be thought of as having worked only with expected scenarios. Newer models have become better. The potential for worse-case outcomes advises more caution and higher CO_2 taxes. As we pointed out in Chapter 4, our worst fears are not about the likely outcomes and they are not even about a typical “worse-than-expected” outcome. Instead, they are about unknown and unknowable outcomes such as CO_2 sinks that could suddenly be exhausted or feedback loops or tipping points that we do not know about.

And there is another good question: how much should the world invest today to be ready to react tomorrow? There are events that can not be foreseen today. What if humanity triggers some runaway warming process that had not been triggered for millions of years? Or what if a supervolcano were to erupt, an asteroid were to hit Earth, or Sun activity were to diminish or flare up? Do we want scientists to learn how to be ready to reduce billions of casualties?

6 What Else Should Be in the Model?

Models are models — simplified constructs to help scientists understand interesting phenomena. What else could have been put into the models?

Why Is Population Not a Policy Variable?

Our book started with explaining how population is the elephant in the room, having exploded from 1.6 billion people at the beginning of the twentieth century to 8 billion in 2022. But the integrated assessment models largely ignore how the climate or public policies can influence population growth.

There are good reasons for this omission. It is not even conceptually clear how to deal with population growth. For example, should social welfare be measured in per-capita terms or in total population terms? What is the lost welfare attributable to people who were never born? Should the world be considered better or worse off with 15 billion (possibly poor) people than with 1 billion (possibly wealthier) people? If harm were to be apportioned, should people with more children also pay higher taxes to cover their children’s future CO_2 emissions?

We do not have answers to these thorny questions. But our lack of answers does not render them less important.

How Does the Model Take Account of Income Inequality?

Climate change and fighting it creates winners and losers. Without emission reductions and a warming planet, some areas of Canada and Russia will become more habitable; other like the Sahel may become uninhabitable. Over the spans of decades, many of those harmed by climate change will migrate, itself a form of adaptation. Over centuries and millennia, even distant migration has been not the exception, but the rule. Of course, migration is also often accompanied by human misery — some short-term, some long-term. Historically, migrating populations often made war on and killed the previous settlers.

Most of the harm from climate change will squarely fall on the poor. Climate change is really only of second-order importance to the rich. They can adapt. They can move or emigrate. The United States can slow the future disappearance of Florida to rising seawater with appropriate water barriers — just as the Dutch have done for centuries — and, if this fails, Floridians can move. Arizonans can buy more air conditioners.

Such easy adaptation is not available to residents of the Indian subcontinent and Sub-Saharan Africa. The homes of millions of Bangladeshis likely be submerged. Northern India may lose its reliable water supply as the Himalayan glaciers shrink. The African countries in the Sahel could become uninhabitable (unless the rain patterns were to change, as they have in the past). Where could they go? Neither Indian nor African countries will likely be able to afford to move most of their populations to more hospitable environments. And rich countries have raised many barriers to reduce the inflow of poor immigrants. How should they deal not with a few million but with a few billion immigrants from different cultures?

anecdote

> “The disgusting irony of all of it is that the billionaires who have created this global atrocity are going to be the ones to survive it. They are going to be fine while we all cook to death in a planet-sized hot car.” — Sarah Silverman, comedian.
> (PS: In fairness, not just the billionaires but all of civilization has benefited.)

Spending Alternatives

Ironically, the strongest ethical arguments *against* fighting global warming also concern the global poor today — and they make us very uncomfortable.[8] Let us explain why we find them as inconvenient a truth as climate change itself.

The United Nations estimates that almost 1 billion people today live in extreme poverty, defined as living on less than $2 per day. It costs only $0.80/day to feed a child in a poor country. For a small fraction of the funds proposed to address climate change, the world could eliminate global child malnutrition. For about $100 billion, we could lift everyone out of extreme poverty — about 5–10% of what the Paris Agreement demands we spend not to stop but just to slow down global warming by a 0.3-0.5°C.

Or take malaria, which kills about 400,000 people and cripples about 200 million people per year. One may quibble about whether eradicating Malaria would cost $50 billion or $100 billion *one time* — but would eradicating malaria not give humanity more bang for the buck than 0.05°C less global warming?[9]

Who Cares?

An even more uncomfortable question to ponder is why the rich people and nations of this world are not already spending a lot more money on poverty today — regardless of how much the world should be spending on climate change. Why does it have to be just a few philanthropists (such as Bill Gates and Warren Buffet) who have stepped in and taken this task onto themselves, while we, the people, have failed? We can only characterize our failure as a great collective shame of the human race. (The ethicist Peter Singer has a lot more to say on this subject.)

[8] These arguments have again been best articulated by Bjørn Lomborg.

[9] Technological progress may allow us to eradicate or alter the specific mosquito that carries malaria for a pittance. The end of Malaria is in sight.

7 What Have We Learned from IAMs?

Winston Churchill famously said "that democracy is the worst form of Government except for all those other forms that have been tried." The same holds true for integrated assessment models. What are the alternatives? Intuitive back-of-the-envelope modeling is less likely to offer sensible quantitative CO_2 tax prescriptions. Assuming that "there is no problem" is also an integrated assessment model, though a very bad one, contradicted by the evidence. So is assuming that "the world will come to an end unless humanity fundamentally restructures and makes climate change its top priority." The world will not come to an end. Thus, although IAMs have many deficiencies, they are scientists' best tools for analyzing the collective tradeoffs between economic growth, environmental taxation, and climate change.

Just do not take them too literally please. Despite their complexities, these models remain simplistic sketches of a far more complex world. They give basic advice on what factors governments should consider and at what orders of magnitude. They inform us that a good global social cost of carbon-dioxide is greater than \$20/tCO_2 and less than \$200/tCO_2. The models can confidently tell us that we don't need to debate anything beyond these two extreme price points: The world will be better off when it reduces CO_2 when it costs less than \$20/tCO_2 worse off when it costs more than \$200/tCO_2. In between, *if the population of the world could make active choices*, it would have decisions to make. How humanity should be and is making these decisions will be the subject of the next chapters.

A good way to think about integrated assessment models is that they give us pixelated images of the future. As time goes by, the images will become clearer. Humanity should prepare and plan ahead — and do so a lot more intelligently than it has. Here is an analogy. Standing on the ocean shore, you see a dark blue something in the distance. Your great fear should be that it is not just clouds but a tsunami heading for you. It could be a false alarm, or it could be real. If you wait until the tsunami is close enough to see it clearly, it will be too late to flee. The smart thing to do now is to walk back to your car and plan your escape route, even if you may not need to start driving it just yet.

From our perspective, the models tell us that the world is collectively emitting too much CO_2. When any one country reduces its emissions, it has further benefits for the others. Yet the theme of our book is also that

IAMs are unrealistic to the point of being irrelevant. They contemplate a global decision-maker optimizing a global choice. However, in the real world, decisions are not made that way — they are made by individual countries. This is why year after year, everyone talks about what should be done, but little is actually been done.

Further Readings

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