Chapter 6

Modeling the Economic Impact of Climate Change

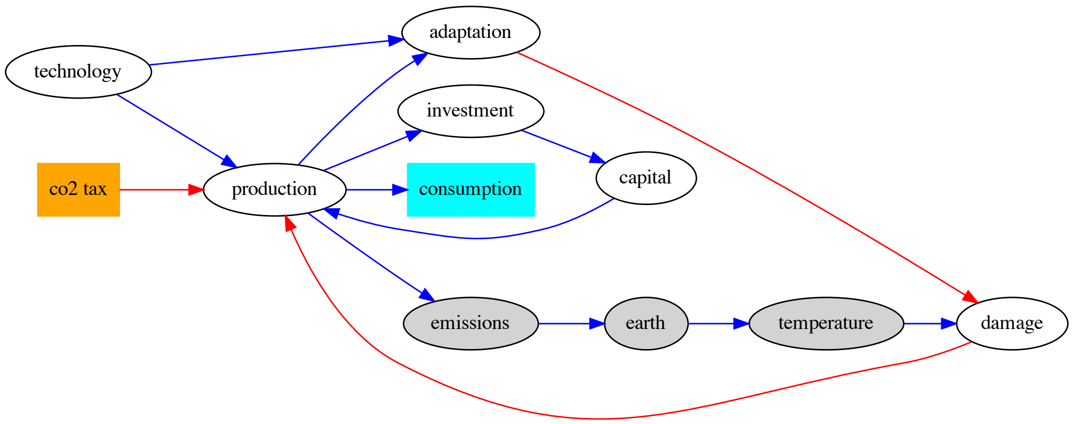
The first part of our book explained energy needs and earth sciences from a largely non-interventionist perspective — an essentially do-nothing scenario. The previous chapter explained some key economics principles — for example, the role of taxes in the control of pollution. This chapter puts earth 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**. Even his starkest critics build directly on his models.

1 An Economic Sketch of Earth

Figure 6.1. 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 García-León**.

Figure 6.1 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 input into the model 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 human pleasure derived from a natural environment with species diversity, but typical models usually employ narrower measures. The ultimate goal (of the modeler) is to adjust the CO_2 tax 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 to invest 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 and 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 plentiful that even Nordhaus says that he often does not intuitively understand how an adjustment of the inputs will change the outputs until 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.

Some specific 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 total 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 concept in more detail in Section 4. 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 Year X" or "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. This social welfare is the sum of all human future (discounted) consumption, today and in the future. Because of discounting, the value of consumption in future years depends on the discount rate. Future consumption is less valuable than current consumption.

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. A case where the world intervenes to limit the average temperature increase to 2°C by 2100. 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.

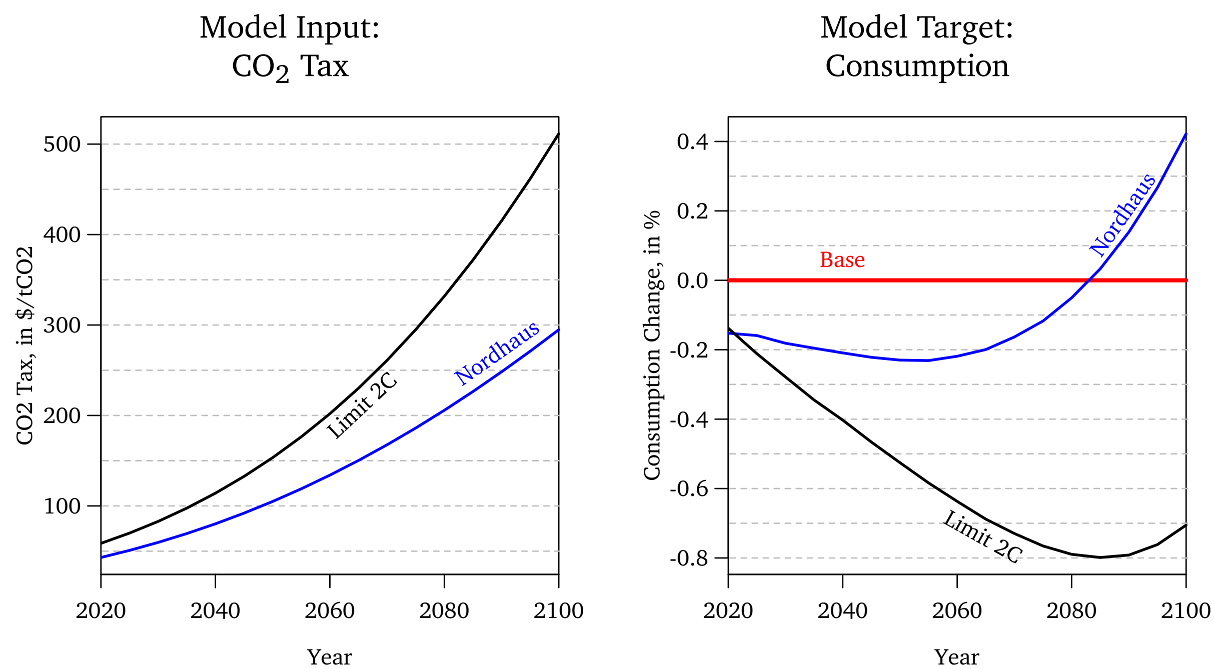
The left plot in Figure 6.2 shows the 200 knob settings for the 200 (future annual) global CO_2 taxes. They are stated in terms of dollars per ton of CO_2 emitted. Unfortunately, the optimal CO_2 taxes are also usually called the "**social cost of carbon**" instead of the "social cost of carbon-dioxide," which is what they really are.[1] (As if the subject were not difficult enough, the experts have found yet another way to make understanding even simple concepts more confusing!)

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. By the end of the century, only the most exceptional activities that produce CO_2 would still remain viable. The 2°C-limit scenario requires imposing taxes more aggressively — reaching \$200/tCO_2 two decades earlier than under Nordhaus' preferred solution. At the end of the current 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 but increase ever more steeply. This is because the sudden imposition of a high CO_2 tax would not allow industries to adapt. A more

[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....

Figure 6.2. 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 2100 below 2°C.

sudden tax of, say, $200/t$CO_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 6.2 shows how taxes 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' sacrifice — around 2090, their consumption will exceed what they would have had if no mitigation measures had ever been instituted.

In contrast, the 2°C limit 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.)

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 6.3: 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 2°C 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.

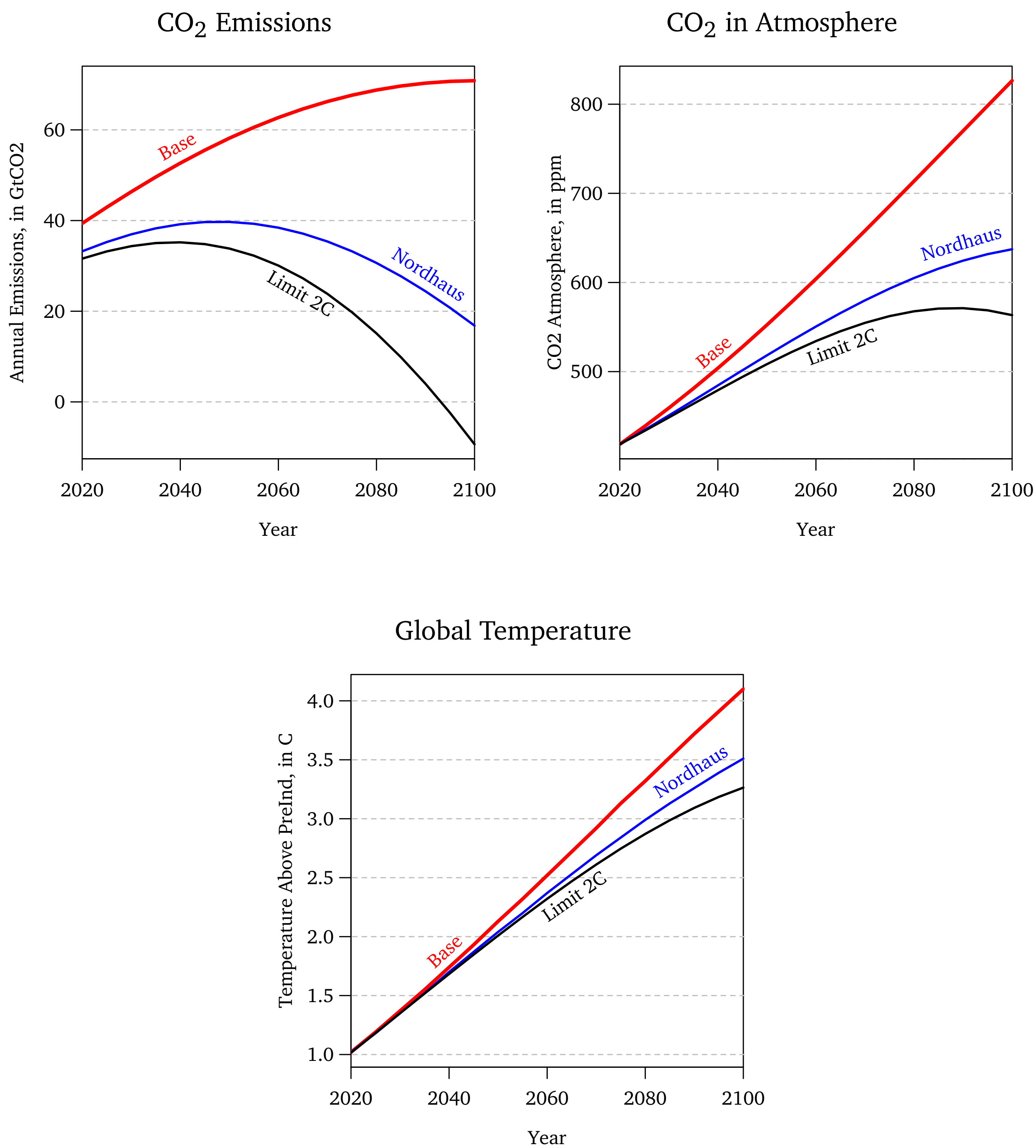
The bottom plot shows that planetary temperature responds slowly to changes in atmospheric CO_2. Thus, even the 2°C plan "only" reduces temperature by about 1°C relative to the base case scenario (an increase of 3.2°C instead of 4.2°C). The Nordhaus scenario allows for about a 0.3°C greater temperature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

potential 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.

[2] It is a weakness of the models in that they care only about consumption over a century or two, ignoring planetary changes altogether. What happens to earth in a millennium is practically ignored.

Figure 6.3. Nordhaus Earth Outputs



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 was too conservative in its assessment of technological progress, 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.

For example, how will technology and preferences influence how industry and consumers will curtail activities if each 1 tCO_2 imposes a tax of $50? It is easy to estimate the reduction on the margin for the first ton or even the first billion tons. It is difficult to estimate the reduction for all 30 billion tons emitted today.

The integrated assessment modelers also have to update their models constantly. The world is changing and the models are becoming better. This is the case for both the economics and the earth sciences components. There are also disagreements. The adoption of different parameters has led different researchers to recommend different global CO_2 taxes.

Table 6.1 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 6.1. Various Estimates of An Appropriate CO_2 Tax (ca. 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 $50/$tCO_2$ today. The leading alternative take was published by economist **Nicholas Stern** in 2006 (in a 700-page "page turner," called the "**Stern Review**.") As early as 2006, Stern advocated a global carbon tax of $85/$tCO_2$, where it still stands today (rising to $100/$tCO_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/tCO_2.

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/tCO_2e** 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 them is practically irrelevant. Both numbers are so high that both mean the same thing for practical purposes today: immediate drastic CO_2 tax increases and CO_2 emission reductions.

In sum, the most reasonable estimates, as of 2021, seem to suggest an appropriate global CO_2 tax in the range of \$50–\$100/tCO_2, rising ever more steeply into the future. 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 Federal Reserve. It advocated a tax similar to that suggested by the basic Nordhaus model.

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, it is even worse. The **International Monetary Fund** (IMF) has estimated that global fossil-fuel subsidies were **\$500 billion** (or \$15/tCO_2) in 2017.[3]

When we write that humankind needs to *move the needle* now, the differences between Nordhaus and Stern, or economists and climate scientists, no longer seem so large in light of the world's actual negative tax rate. 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.

What a CO_2 Tax Means

Most of us do not know intuitively what a CO_2 tax really means. Thus Table 6.2 translates a tax per ton of CO_2 into more familiar terms. For example, at \$100/tCO_2, the gasoline price would double, i.e., gasoline would cost in the United States what it already costs in Europe. We will explain in Chapter 9 that coal is price-wise already on the ropes, even with common coal subsidies. Coal would become uncompetitive given any reasonable CO_2 tax in most parts of the world. In a sense, a \$100/tCO_2 on coal might as well be a \$1,000/tCO_2 tax. Natural gas prices would double, thereby doubling winter heating

[3]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 6.2. Price Increases With a CO_2 Tax

	tCO_2e	Addtl Tax per tCO_2				Price
	/Unit	\$0	\$50	\$100	\$200	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	(Exceeds 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.

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 cost increases. For instance, people could drive less and in smaller electric cars. New heating and cooling systems with tank reservoirs could charge during those times of the day when electricity would not be more expensive but *less* expensive than it is today. Planting trees would become more economical with appropriate subsidies, and thus so would probably anything constructed out of wood. In addition, governments could and should reduce other taxes if they can collect necessary revenues through fossil-fuel taxes instead.

Another way to look at the cost of a CO_2 tax is to add up the typical spending increase it would cause based on the numbers above. The 2°C path in Figure 6.2 suggests a 0.5% loss in consumption in about one decade when the tax reaches about \$100/tCO_2. In the figure, this loss was partly mitigated by adaptation, made easier by a CO_2 tax that starts low. A more immediate and sudden \$100/tCO_2 tax would reduce consumption by about 1%.

Let's translate a 1% consumption reduction into more meaningful terms. None of the following calculations are exact, but they do convey the intuitive implication of CO_2 reductions. The median household in the United States today earns about \$65,000/year (many with two earners) and pays about \$13,000/year in rent. Thus, a \$100/tCO_2 tax with its 1% net consumption cost[4] effectively would cost the median household the equivalent of about two weeks' rent, about $250 per year. The Nordhaus plan would be only about three days' rent (0.2%). The Stern plan would be about one month's rent.

If the whole enterprise of reducing emissions is to be successful, it has to be global. Poorer people and countries cannot afford to pay as much, but it is important that they contribute, too. Fighting climate change just in rich countries is like fighting a fire only on one side of the house while letting it expand on the other side. And recall that the middle-income China alone already emits more than the entire West together. Nevertheless, richer countries and people would probably have to pay a higher share. Therefore, the consumption sacrifice for Americans would probably have to be more than proportional. Thus, you can imagine something like about one week's rent under the Nordhaus plan, one month under the 2°C plan, and two months' rent for the Stern plan.[5]

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. It is intended to put the needed contribution on a "fairer" and "more equally affordable" basis. It is *not* a suggestion for how to tax best — 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.

In the United States, the 1% consumption sacrifice would mean an extra annual "global warming tax" of about $250 for the typical family. Richer people, like the average resident of **Manhattan or Palo Alto**, would have to pay more. Think an extra $1,000 or $2,000 per year. In China, where rents are about **20%** lower, the "global warming tax" would be about $200 per year. In India, where rents are 70% lower, it would mean about about $75 per year. A global compact to reduce emissions would have to force roughly these kinds of taxes on all households of the world. Fortunately, households could reduce these taxes by polluting more frugally, because the tax would be assessed primarily on CO_2 emissions. That's the whole point of the tax, after all.

Are you an environmentalist worried about global warming? Have you been advocating for action? If so, are you okay with paying this much for this kind of tax? We sure hope so.

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[4] We explained in the previous chapter that the tax is not lost. Thus, the tax could well be $1,000, but $750 may substitute out other taxes, like the income tax.

[5] Truly ending all CO_2 increases immediately — as some climate scientists suggest is necessary — could cost as much as six months' rent. So high an immediate goal is not only stupid, it is also unrealistic. Whoever tried this would end up on the guillotine — if not literally, then in their public influence. (Faster technological progress could reduce all estimated costs, but it would also suggest delaying much implementation.)

4 What are the Right Model Parameters?

How Do We Value Future Generations' Welfare?

Remarkably, the biggest disagreement between advocates of lower and higher CO_2 taxes (from Table 6.1) 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 6.3 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 6.3. Social Cost of CO_2 By Discount Rate in Nordhaus' Model

Assumed Real Discount Rate	Today $1 in 100 years	Best CO_2 Tax, in 2018-$/$tCO_2$ 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 stock market, then the same return should be required when investing $1 to reduce climate change — i.e., it should avoid damages of $100. This $100 was chosen because it happens to be close to the historical average inflation-adjusted rate of return per year after taxes (about 5%).[6]

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 today. His inflation-adjusted discount rate view lies thus somewhere between 0.1% and 1.5% per year.

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

The Ethical Choice?

The knee-jerk reaction is that Stern offers the ethical answer and Nordhaus the egotistical 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 was **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 workers would earn a standard of living only 20 times higher than our own rather than 30 times — i.e., if climate change caused by our current actions were to rob them of, say, one-third of what they would otherwise earn? With six times more income, they will be able to afford or remedy more damages than we can.

The consensus among economists today is that it was Nordhaus who got the discount rate right and Stern who got it wrong. 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 model — such as uncertainty about the future climate and the possibility of climate catastrophes. 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 in the future may collectively be better off, it is 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 agree 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, you are probably in the majority — justifying to yourself that other people should pay for lowering CO_2 emissions, just as long as it is not you. After all, was it really your

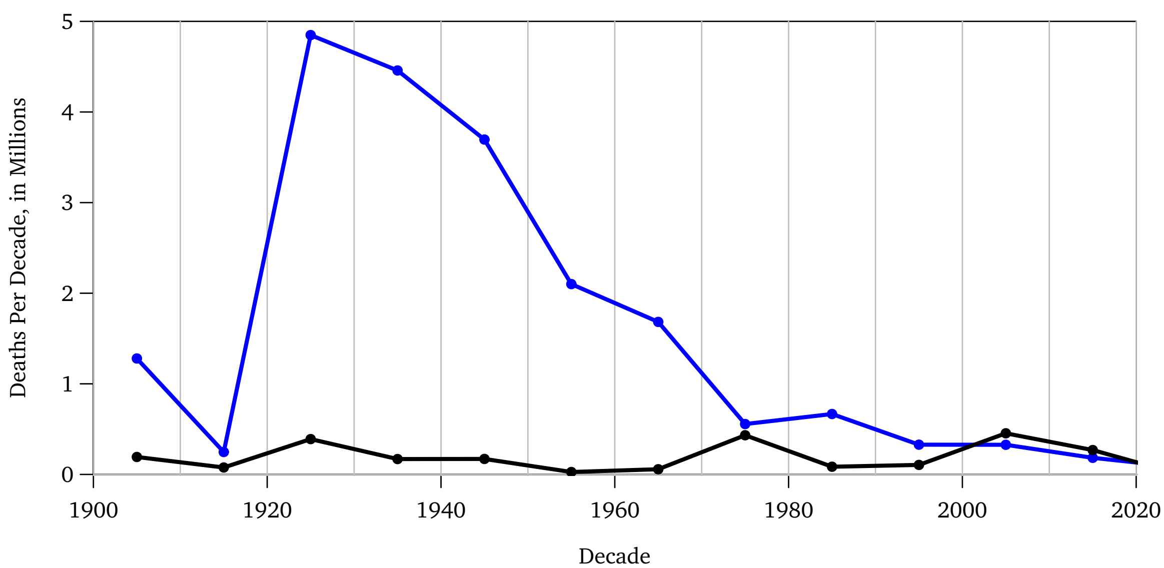
[7] Both the Nordhaus and the Stern discount rates are sketches of what they actually use. The real deal requires a lot of detailed economics.

fault or that of some anonymous oil barons? The average American is **willing to pay about $1/month** in higher electricity cost, not $500/month.

Adaptation

Another such 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. What makes the damage function so difficult to forecast 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 and unlike many other scientists, Lomborg has a lot more faith in human inventiveness when their own hides are at stakes.

Figure 6.4. Disaster Deaths By Decade



Note: Climate catastrophes (in blue) are floods, droughts, storms, wildfires, and extreme temperatures. Non-climate catastrophes (in black) are earthquakes, tsunamis, and volcanoes.

Source: **Original Source: Lomborg** and **International Disaster Database**.

Historically, Lomborg and the economists have been more right than wrong. Other scientists and environmental activists have consistently underestimated humanity's ingenuity. In one of his examples, he shows that deaths from climate-related catastrophes have not increased but decreased markedly over recent decades (Figure 6.4). Even though global warming has probably increased the strength and frequency of storms, these storms have caused not more but less harm. When you watch news about how climate change has brought about the latest stronger hurricanes or cyclones, just remember that not that long ago, these storms used to kill many millions of people every year. Today, it's "only" a few hundred thousand (too many, of course). Over time, people have learned and will continue to learn how to improve weather forecasts and how to protect themselves with better escape plans and stronger structures. If the world and shore-dwellers become wealthier, expect less harm, not more.

Innovation

Activists also often fear that global warming will devastate crops. This factor is often the biggest component of the damages 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 are not sure whether this will succeed until we try it.

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** have argued 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 main question is when — sooner or later?

The faster relevant technological progress occurs, the less pain the clean-energy transition will create. Almost all interested scientists agree that civilization should invest heavily in relevant technology and R&D. This could accelerate its progress at a cost that is relatively low. But here is a problem. 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 doing nothing today but subsidize and accelerate research progress and start implementing only in a decade or later. 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 had not incorporated uncertainty and risk. They can be thought of as working with expected scenarios. Newer models have become better. They base the case for steeper CO_2 taxes as much on the potential for worse-case outcomes as on the most likely outcome. We share their concern. 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.

The IAMs have always asked the question about what fossil-fuel tax should we bear today, and they now involve also some worse-case scenarios. But we believe that they need to go further and explore a second 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? 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 be ready to reduce billions of casualties?

5 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 7.8 billion now. 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? Should the world be considered better or worse off with 15 billion (possibly poor) people than with 1 billion (possibly wealthier) people? What is the lost welfare attributable to people who were never born? If harm were to be apportioned, should people with more children pay higher taxes to cover their children's future CO_2 emissions?

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

How Does the Model Take Account of Income Inequality?

In the previous chapter, we pointed out that pollution taxes 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 will become uninhabitable. Over the spans of decades, many of those negatively affected 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.

Most of the harm from climate change will squarely fall on the poor and on poorer nations. 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. Inhabitants of hotter states can buy more air conditioners.

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

potential 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. These arguments have again been best articulated by Bjorn Lomborg. Let us explain why we find them as **inconvenient a truth** as climate change itself.

The United Nations estimates that almost 1 billion people live in **extreme poverty** today, 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 all global child malnutrition. We could lift everyone out of extreme poverty for about \$100 billion per year — about 5–10% of what the Paris Agreement demands we spend not to stop but just to slow down global warming by a 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 0.1°C less global warming?[8]

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 charity 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 this failure as a great collective shame of the human race. (The ethicist **Peter Singer** has a lot more to say on this subject.)

6 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" (which also happens to be an entirely unrealistic proposition). The world will not come to an end. Thus, although IAMs have many deficiencies, they are our best tools for analyzing the relationships 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 conceptual advice on what factors governments should address and at what orders of magnitude. They inform us that a global social cost of carbon-dioxide of say, \$20/tCO_2, is almost surely below the true social cost of emissions, and that \$200/tCO_2 is almost surely above. The models can confidently tell us that we don't need to debate anything beyond

[8] 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.

these two extreme price points: The world is better off when it reduces CO_2 when it costs less than \$20/tCO_2 and it is worse off when it costs more than \$200/tCO_2. In between, the world has 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 very 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 aggressively 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.

So, how should humanity be getting ready and planning its escape route?

Further Readings

Books

- **Robert J. Gordon**, 2016, **The Rise and Fall of American Growth**, Princeton University Press, New York, 2020: A detailed argument that growth will slow because the low-hanging fruit of technology has been picked.
- **Bjorn Lomborg**, 2020, **False Alarm: How Climate Change Panic Costs Us Trillions, Hurts the Poor, and Fails to Fix the Planet**, Hachette Book Group, New York, 2020: A skeptic's view of climate-change mitigation costs, with alternative suggestions for aid. Also, Bjorn Lomborg's **website**.
- **Andrew McAfee** and **Eric Brynjolfsson**, 2016, **The Second Machine Age**, W.W. Norton, New York, 2016. A more optimistic take on technological innovation and economic growth.
- **Varun Sivaram**, 2018, **Taming the Sun**. An overview of the solar industry and solar technology.

Reports and Academic Articles

- **Michael Barnett**, **William Brock**, and **Lars Hansen**, 2020, **Pricing Uncertainty Induced by Climate Change**.
- **David K. Levine**, 2019, **Global Warming: What Sort of Mess Have We Made?**: An explanation for economists of the issues with spending too much on climate-change mitigation now.
- **John H. Cochrane**, 2021, **Climate Policy Should Pay More Attention to Climate Economics**. An advocacy piece on the tradeoff between growth and policies to mitigate climate change.
- **Robert S. Pindyck**, 2019, **The Social Cost of Carbon Revisited**, Journal of Environmental Economics and Management, 94, 140-160.
- **The Stern Report**, with Nordhaus' **evaluation** and a **New York Times explanation** by **Hal Varian** comparing the choices of discount rates in the Stern and Nordhaus models.
- **Nicholas Stern** and **Joseph E. Stiglitz**, 2021, **The Social Cost of Carbon, Risk, Distribution, and Market Failures: An Alternative Approach**, **NBER WP 28472**. A critique of standard lower estimates of the social cost of carbon derived from IAMs.

Shorter Newspaper and Magazine Articles and Clippings

- **Economists' Statement**, published in the Wall Street Journal on January 16, 2019.
- **García-León, David**, 2015, **Adapting to Climate Change: An analysis under uncertainty** provided the original inspiration to our simple IAM schematic.

Websites

- https://www.epa.gov: Environmental Protection Agency, incl. **GHG Equivalence Calculator**.

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