Climate Change: Economics and Policy Options, or Why a Carbon Tax Makes Sense

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According to the National Academies,[i] global temperatures have increased since 1950 by over 1°F more than can be explained by natural causes alone. Models that include man's effects on climate (especially carbon dioxide from burning fossil fuel) predict this increase accurately. These models predict a further increase of about 5°F over the next century, which will cause increased extreme weather events, sea level rise, and other problems that will hurt our economy by a percent of GDP or more.

Technologies exist to cut dramatically our carbon dioxide emissions but are not deployed because they are not free. Therefore, the natural way to give people an incentive to reduce carbon dioxide emissions is to require expensive permits for emissions. Distributing permits through an auction causes less harm to the economy than giving them away for free.[ii] The revenue raised from selling permits would allow for a cut in income taxes which would stimulate the economy and reduce dramatically the overall economic disruption caused by necessary energy transformation. Regardless of the scheme used, the cost to polluters of buying or not selling permits is passed on to the consumer.[iii] Auctioned permits would hurt carbon intensive industries, while permits that are given away to past polluters for free would create windfall profits.

For technical reasons it is better to fix the price of the permits rather than the quantity.[iv] A permit auction with a fixed price is essentially just an emissions tax. I recommend taxing carbon dioxide emissions at about $20 per ton ($75 per ton of carbon).

According to the Congressional Budget Office,[v] research and development funding is helpful but much less cost-effective without a carbon tax to encourage people and companies to deploy the discovered technologies. Subsidies for specific technologies may be helpful, but the primary policy should be the carbon tax. The United States should also take the lead in extending international cooperation on climate change adaptation and mitigation strategies through successor agreements to the Kyoto Protocol.

In section 1, I briefly summarize the science of climate change. Section 2 describes various policy instruments to reduce carbon dioxide emissions from the burning of fossil fuels, including tradable permits and taxes. This section demonstrates why taxes are the best option. Section 3 offers my conclusions. Appendix A describes estimates of the economic damage that will be caused by global warming. Appendix B contains carbon dioxide emissions statistics.

To make it clear that my essay is based on well-established science rather than picking and choosing fringe opinions to support my views, I will cite primarily three impartial groups: the National Academy of Science, the Intergovernmental Panel on Climate Change, and the Congressional Budget Office.[vi] Many scientists are concerned that if the science develops in certain ways (e.g. glaciers have recently moved much faster than predicted previously[vii]), the dangers may be much worse than current predictions. For an example of how bad things might get,

note that the Stern Review[viii] predicts indefinite economic damage of 5-20% of GDP due to climate change.

1 Science

The basic physics behind global warming has been known for over a century.[ix] The first[1] analysis of the effects of carbon dioxide on global temperature was made by Nobel prize winner Svante Arrhenius in 1896.[x] Greenhouse gases such as carbon dioxide allow sunlight to pass through but absorb infrared (heat) radiation, re-emitting much of it back to Earth. This heats the planet as if inside a giant greenhouse (hence the name). The most important greenhouse gas is carbon dioxide. Measurements show that the concentration of carbon dioxide in the atmosphere has been increasing steadily over the past 50 years since measurements began.[xi] World-wide temperatures have increased over the past decade or so, and natural variation alone cannot explain this rise.[xii] Human activity, including the burning of fossil fuels as well as deforestation and other effects, is the primary cause of this increase. Unless we take action soon, temperatures will rise dramatically over the next few centuries.

Determining exactly how much the earth will warm and what other changes this will cause is much harder. One of the most important complicating factors is the reflection of sunlight by ice and clouds. This means that the Earth's temperature depends on how cloudy the planet will be. Predicting the weather is notoriously difficult, and this contributes a substantial level of uncertainty to climate models. Despite the uncertainties, we do know which direction global temperatures will go, and we can estimate how far. Geological history also offers insights into current and past temperatures, carbon dioxide levels, and sea levels.[xiii]

There are three major ways climate change will impact humankind. The first consequence of global warming is that the plant and animal life that we depend on for our food, clothes, and houses will have to adapt to changing temperature and rainfall patterns. There will be a general pattern of species moving north,[2] forcing farmers and others to either move with them or switch to different crops. Other industries will also be affected; for example, ski areas and other winter sports will need to adjust. Noxious plants and animals, such as malaria-carrying mosquitoes, will migrate to new areas as the climate changes. We have spent millennia adapting ourselves and our agriculture for the current climate. Adapting to another climate would be quite painful even if the new climate is as good as the old one. Many species will be unable to migrate or adapt and will go extinct.

As the Antarctic region and Greenland warm, the great ice sheets are already melting.[3,xiv] This dumps enormous quantities of water into the oceans, raising the sea level. If all the ice melted, sea level would rise by 220 feet.[xv] Since most of our major cities are on the coasts, the melting of even a tiny fraction of the ice would be disastrous. It is unclear how long it will take the ice sheets to melt. The current consensus is less than a meter of sea level rise this century.[xvi] However, many scientists are worried that Antarctic ice is melting faster than expected,[xvii] so this estimate may need to be adjusted in the near future. Even before the ice sheets melt enough to cause serious flooding, the influx of fresh water might upset the Gulf Stream, eliminating the conveyor belt of warmth that keeps Europe much warmer than expected for its latitude.[xviii]

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[1] Fourier wrote an 1824 paper that discussed the temperature of the earth, but that paper was too vague to count.
[2] Actually poleward, i.e. north in the northern hemisphere, south in the southern hemisphere.
[3] Melting sea ice does not change sea level, while melting glaciers on landmasses do.

Global warming increases the amount of warm moist air in the atmosphere, which drives extreme weather events. It is unclear whether and how much global warming contributed to the multitude of intense hurricanes we experienced in 2005. However, we do know that enormously damaging weather events, such as the disastrous 2005 hurricane season, heavy flooding in the Northeast, and wild fires in the west will become normal events as the planet warms.[xix] Changing climates may also make certain regions drier as changes in ambient wind and temperature affect rainfall. These continual natural disasters will cause far more damage than the terrorist-made disasters we have spent so much effort tackling lately. For a more complete discussion of the probable effects, see the intergovernmental panel on climate change reports,[xx] National Academy of Science reports,[xxi] or books.[xxii]

2 Policy

2.1 Pricing Carbon Domestically

So what can we do to reduce our carbon dioxide emissions to reduce global warming? There are countless ways, including using more fuel-efficient vehicles, replacing coal-fired power plants with wind or nuclear, etc. When people decide whether to buy a coal-fired or natural-gas fired power plant, they usually choose to make a coal-fired one because coal is cheaper, ignoring the damage this decision makes to future generations. A simple ban on certain technologies would be inefficient as it would induce people to do as little as possible to comply with regulations. A better way to solve this problem is to introduce incentives so that when people make selfish decisions they automatically take climate change into account.[xxiii] Currently, people and companies act as if the price of carbon were zero, oblivious of the contribution of carbon emissions to future catastrophes (this is called a tragedy of the commons[xxiv]). Society as a whole is best off when people pay as much for their inputs as their use of those inputs harms other people.[xxv]

Government action is therefore required to correct this market failure, raising the private price of carbon to equal the social cost of carbon. This can be accomplished by requiring people who remove fossil fuels from the ground to acquire a permit for each ton of carbon dioxide that will be emitted when the fuel is burned. Permits would have a price, discouraging carbon dioxide emissions.

There are three major qualitative choices to make:

1. whether the permits expire eventually and need to be replaced, or would last indefinitely,
2. whether to fix the price or quantity of emissions permits,
3. and, whether to give permits away or sell them.

Two combinations are popular: fixing the price and selling one-use permits (a traditional environmental tax), or fixing the quantity and giving reusable permits away (a traditional cap and trade scheme). Other combinations are also possible. One can easily fix the quantity and sell the permits by simply auctioning off a fixed number of permits. One can also achieve a fixed price when giving away permits by issuing a fixed number of free permits and then buying or selling them to keep the permit price at a desired level. Giving away permits that expire is a bad combination because emitters would be incentivized to maximize the number of permits they receive, minus the number they use. This would induce individuals to direct their attention to gaming the complicated allocation formulae or lobbying for changes to suit their special interest,

rather than working to reduce emissions.[xxvi] Unfortunately, many of the climate change bills being considered in Congress give-away short-term permits.

The question of price versus quantity is easily answered in favor of a price. Estimates of the optimal price of carbon are somewhat stabler than estimates of the optimal quantity, so it is better to fix the price than the quantity.[xxvii,4]

Our estimate of the severity of global warming will change as climate science progresses. Therefore our carbon policy should be flexible. If permits expire, one can simply adjust the price or quantity of newly issued permits as new information is available. If permits have no expiration date, further cuts require the government to buy back permits, which may be quite expensive. This is a key reason to prefer permits that expire.

The decision of whether to give permits away or sell them is more controversial. Political expediency suggests giving them away, but economics is strongly in favor of selling them. If permits are given away, emitters would pass the opportunity cost of selling their permits on to consumers, so prices for consumers would rise just as if there were a tax[xxviii]. This increase in prices would act as a brake on the economy. Emitters would enjoy increased profits, but everyone else would be hurt.[xxix] Giving permits away also grants regulators discretion in who gets how many permits, opening the door for corruption.

A much better option is to sell permits and use the proceeds to reduce income taxes, shifting the tax burden away from activities that should be encouraged (income) to activities that should be discouraged (pollution). Lowering income taxes would partially offset the harm to the economy caused by increased energy prices. This is called the *revenue recycling effect* in the literature. Some sources indicate that this revenue recycling effect might be strong enough so that GDP would actually increase,[xxx] but more likely the revenue recycling would dramatically lower but not eliminate the net economic cost.

Another advantage of lowering income taxes is that it helps balance the costs of carbon reduction between rich and poor households. Permits given away for free would help stock-owning (rich) households but hurt poor households.[xxxi] I recommend an appropriately progressive income tax cut to balance the costs so that no economic class would be unduly damaged. If bribing the fossil fuel industry is required for political feasibility, a small fraction of the permits could be given away. Giving away versus selling is a continuum, not an either/or.

As just discussed the best option is to sell permits that expire for a fixed price. This combination of decisions is better known as an emissions tax.

The next obvious question is what the price should be. Overall wealth would be maximized if the price of carbon permits were equal to the damages caused by one additional[5] unit of emissions. Based on a review of various studies described in Appendix A, this optimal tax rate is in the neighborhood of $20 per ton of carbon dioxide emitted.[6] The uncertainty in our knowledge of the optimal tax rate is less of a problem than it might appear. Firstly, any tax rate between zero and

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[4] There is actually a good third option: an auction where the amount of goods sold depends on the going price. This can eliminate the need for policymakers to estimate the costs of carbon abatement. The government would bid in the auction and units "sold" to the government would be discarded. I recommend this option, but excluded it from the main text for simplicity.

[5] In the parlance of economics, marginal damages (of emissions) or marginal benefits (of emissions reduction), depending on your point of view.

[6] $20 per ton of carbon dioxide is equivalent to about $75 per ton of carbon.

roughly twice the optimum rate would be somewhat better than no tax at all.[7] Secondly, the total net cost of setting the tax rate wrong is roughly proportional to the square of the size of the mistake, so setting the tax rate to either 50% or 150% of the optimal rate would achieve roughly three quarters of the benefits. It is far more important to get the tax rate in the right ballpark than it is to set it precisely. As we develop more information about the cost of carbon, this tax rate will need to be adjusted. A sudden imposition of a new tax would be more costly than a gradual increase, so the tax should be phased in over perhaps 10 years. To keep administrative costs low, the tax should be collected when fuel is removed from the ground or imported rather than when finally used.

So what would a $20 per ton of carbon dioxide tax do to energy prices? The following estimates consider only the direct influence of the tax, not indirect effects as supply and demand adapt to the new circumstances. The price of coal would increase from $29 per ton[xxxii] to about $100. The price of natural gas would increase from about $7 per million BTU[xxxiii] to $8 per million BTU.[xxxiv] Gasoline would increase by twenty cents per gallon.[8] If one assumes that the increase in electricity price would equal the total tax paid by the utilities divided evenly among the consumers, electricity prices would rise by 1.3 cents per kilowatt hour. These increases are smaller than ordinary energy price fluctuations.

One could introduce an energy subsidy to counteract these price increases, but that would be counterproductive. Reduction of energy consumption is a powerful way to reduce carbon emissions, but such an energy subsidy would reduce the incentive to do so. An energy subsidy would result in higher costs to the economy for the same level of overall carbon savings.[xxxv]

Coal is mostly carbon, so the biggest losers from a carbon tax would be coal mines, coal-fired power plants, and the workers who rely on them. Shareholders are paid to take risks and serve society, so I do not believe it is appropriate to compensate the companies that are hurt, especially owners of coal mines built since around 1995 when it became clear that carbon controls were probable. I believe that it is appropriate to help the workers find new jobs. Coal miners would have to change their way of life more than other workers in the new energy economy, and thus merit more compensation. There are about 112,000 coal miners in the US.[xxxvi] A $20,000 college or training subsidy for coal miners would cost less than $3 billion. This is far less than the damage caused by delaying action to avoid offending the coal miners.

2.2 International Issues

Allocating permits between countries is a problem analogous to the tax versus tradable permits options for allocating to companies within countries. The Kyoto Protocol is essentially a tradable emissions permit scheme for countries. An alternative approach[xxxvii] is to simply require every country to impose a carbon tax at a certain level. Each technique has political issues; fixed-quantity because of the need to negotiate per-country limits, and harmonized taxes because of the political toxicity of taxes in many countries. Overall, internationally harmonized taxes seem to be the best approach.

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[7]The calculations in this paragraph assume that the difference between marginal damages and marginal costs is linear in the quantity of emissions. A more sophisticated analysis would change the quantitative results, but the qualitative results should be robust.

[8] The dramatic increase in coal prices relative to the others is partly due to the carbon intensity of coal and partly to the fact that coal is relatively cheap.

The international problem has an additional wrinkle: the developing countries. Many argue that the developing world has contributed relatively little to historical emissions, and should therefore be allowed to continue emitting until they industrialize (operate without any international controls). This introduces a potential problem of carbon-intensive industries moving to developing countries to evade controls. The only practical solution I see to this problem is an import tariff on goods from countries that do not have carbon controls. (One might want to also subsidize exports at the same rate so that the playing field would be level for goods consumed in the developing world as well.) This would allow domestic producers to compete on a level playing field with producers in developing countries. In the long term it would be better to institute carbon controls in developing countries as well, but a tariff is a proper accommodating measure for the near term.

The United States is a member of the World Trade Organization (WTO), which limits tariffs. Fortunately, the WTO rules contain an exception that should allow a carbon tariff. From the General Agreement on Tariffs and Trade,[xxxviii] the core rules of the WTO:

> **Article XX: General Exceptions**
>
> Subject to the requirement that such measures are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between countries where the same conditions prevail, or a disguised restriction on international trade, nothing in this Agreement shall be construed to prevent the adoption or enforcement by any contracting party [*i.e. country*] of measures:
>
> [*a, c, e, f, h, i, j are irrelevant to this discussion and are omitted.*]
>
> (b) necessary to protect human, animal or plant life or health;
>
> (d) necessary to secure compliance with laws or regulations which are not inconsistent with the provisions of this Agreement, including those relating to customs enforcement, the enforcement of monopolies operated under paragraph 4 of Article II and Article XVII, the protection of patents, trade marks and copyrights, and the prevention of deceptive practices; [or]
>
> (g) relating to the conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption;

A tariff on carbon-intensive imports should be allowed by exception XXg. The ability of the atmosphere to absorb CO_2 is certainly an exhaustible natural resource. If the tariff were linked to the difference between the domestic carbon price and the foreign one, it would satisfy the "conjunction with restrictions on domestic production or consumption" and "unjustifiable discrimination ... same conditions prevail" restrictions.

Even if the WTO found such a tariff against the rules, this would not be a fatal problem. If the US passed a law giving minor carbon controls now, with major ones taking effect as soon as anti-leakage tariffs were available, the rest of the world would likely be willing to revise WTO rules as needed to allow carbon taxes to be collected on imports. China would probably object, but the argument in favor of such a tariff is convincing enough that they would probably concede eventually.

2.3 A rebuttal of two common but fallacious arguments

In this subsection I present some fallacious arguments commonly given against carbon taxes and explain why they are incorrect. It is tempting to argue that a scheme where permits are given away to end users is better than a carbon tax on fuel producers for two fallacious reasons:

1. **First fallacious argument:** A carbon tax will raise the costs of fuel and electricity producers who will naturally pass the costs on to users by raising prices, but permits that are given away will not raise costs and therefore will not lead to price increases.
2. **Second fallacious argument:** A carbon tax will drive domestic producers overseas to avoid the carbon tax (unless prevented by an import tariff), but free permits will not hurt domestic industry on average and therefore will not drive them overseas.

Both these arguments assume implicitly that companies will only raise prices or move overseas if their expenses exceed their income. In reality, managers change strategy whenever they see a way to increase profit or reduce a loss. I argue intuitively here from example, but these arguments can of course be made rigorous using simple economic theory.

Where the problem shows up depends on whether the level of permits received for free is tied to production or not. Here I focus on the more commonly proposed scheme where permit quantities are based on past actions rather than current production.

First, consider the increase in prices of electricity under a tradable permit scheme where permits are given away. Suppose you operate a power plant that costs $100 million to build and needs permits worth another $10 million to operate[9]. Suppose you decide that since the value of your plant has gone up by 10 percent when permits are free, you have a good excuse to raise prices by 10 percent. In the absence of carbon controls, this unjustified price hike would not work because another operator would build a new plant and undercut you. However, with carbon controls, new entrants would have to buy permits on the open market, paying $110 million for a permitted plant. For a new operator, the real out-of-pocket cost would include the price of the permits. Permits giveaways only help incumbents, not new entrants! Therefore, a new operator will not be able to undercut you and you will get away with this price hike and make a bundle.[xxxix]

The second fallacy is similar. Suppose that your US plant is getting old and needs replacement and you are deciding whether to rebuild in the US or in the developing world. For sake of argument, suppose that, except for carbon controls, the costs of both options are identical. Now suppose that this plant has $10 million worth of permits. If you move the factory overseas, you can sell those permits and make $10 million, but if you stay in the US, you have to keep the permits. So all else being equal, you would take the $10 million present from Uncle Sam, sell the factory, and move overseas. The import tariff of the previous subsection is designed to avoid this problem.

What about short-term permits that are given away based on current production? In that case, the permits given away are essentially a production subsidy, encouraging production of carbon-intensive goods. The "fallacious arguments" are actually more or less correct in this case; energy prices rise less with permits given away based on production. However, reducing prices of energy-intensive goods reduces the incentive to conserve, increasing emissions. Economic calculations show that all things considered the cost to the economy is higher if permits are given away based on current production rather than past production.[xl]

[9] These numbers were made up for exposition.

If this costly production subsidy effect is considered politically desirable, it can be achieved in any permitting scheme, not just short-term permits given away. Simply create explicit tax credits for production of certain goods! Such a subsidy would unfortunately gain political feasibility at the expense of increased harm to the economy.

2.4 Fixing other market failures: subsidies and R&D

If everything worked as economists wish, a carbon tax would be sufficient to achieve optimal behavior. Unfortunately, markets are not always efficient. Fixing some market inefficiencies would reduce the costs of a carbon emission reduction program. The programs discussed in this section are much less important than the carbon tax discussed previously.

Much of the benefit of research and development goes not to the researchers but to society at large. As a result, private companies under-invest in research and development. The government should therefore encourage research and development for climate-safe technologies, both through direct funding from the National Science Foundation and also subsidies for corporate research and development. The Congressional Budget Office[xli] found that the net benefits from a carbon pricing scheme are much higher than the benefits from research and development subsidies.

Once an energy saving technology is developed, people may be reluctant to deploy that technology due to fear and uncertainty. Few people enjoy working out the inevitable kinks of new technology, so it is helpful to provide deployment subsidies for new technologies. The long-term incentive, however, should be provided by a carbon tax rather than subsidies. The tax credit for hybrid vehicles offers a suggestive example of why subsidies should not be the primary regulation for encouraging carbon reductions. This credit encourages people to replace a 30-35 MPG traditional station wagon with a 30 MPG hybrid SUV! Such a move is indirectly useful because it pushes the development of hybrid technology, but is counterproductive. This particular perverse incentive can be avoided by giving a subsidy for fuel efficient vehicles rather than hybrid vehicles, but a subsidy system without excessive loopholes is inherently complicated. Furthermore, it is difficult to produce a subsidy to encourage lifestyle changes such as finding a job closer to home to reduce fuel consumption.

3 Conclusions

Science now knows beyond a reasonable doubt that human actions are causing the planet to warm. We are still determining precisely how devastating these consequences will be, but it is clear that the costs of doing nothing exceed the costs of fixing the problem. A carbon tax is the simplest and best way to effect the many changes that have to be made. The extra revenue should be offset by income tax cuts that are progressive enough to spread the burden fairly. This change would shift the tax burden from desirable income-earning activities to undesirable polluting ones.

I close with an analogy. Consider a person who is running out of wood to heat his house. Should he go to his neighbor's house, tear up the floor, and bring that wood home to burn? Or should he put on a sweater and turn down the heat? If we do not take strong action against global warming soon, the house with the torn up floor will be our children's planet.

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A Cost of carbon

An estimate of the amount of damage done by the emission of greenhouse gases in dollar terms, compared to the costs of mitigation, is critical for determining potential solutions to climate change. Before citing systematic attempts to value the cost of carbon, I give a few back of the envelope calculations to indicate the scale of the damage in the US. Weather can be extremely damaging: Hurricane Katrina cost about $200 billion,[xlii] and since 1980 there have been 4 other extreme weather events with damage exceeding $20 billion and 67 with damage exceeding $1 billion.[xliii] Our current GDP is about $13 trillion,[xliv] so a Katrina scale event costs around 2% of GDP[10]. Real estate in Florida is worth close to $2 trillion,[xlv] much of which is at risk of being flooded by rising sea level. For example, a 6 meter rise would put Miami and the Everglades underwater.[xlvi] Both damages from global warming and costs to avoid global warming are on the order of a percent of GDP. The developing world lacks the resources to adapt to a changing climate and is therefore at greater risk.

The important quantity for policy decisions is not the absolute amount of damages, but the amount of damage caused by emitting one *additional* ton of carbon dioxide (marginal damages in economics lingo). I will therefore focus on that measure of damage. See Barry Field's environmental economics textbook[xlvii] for an explanation of why this is.

There have been a number of estimates of the costs of carbon dioxide emissions.[xlviii] The greatest cause of uncertainty in these estimates is not the uncertainty in the science, but a critical economic detail called the discount rate. People prefer a dollar today to a dollar next year. A discount rate of 5% means that we consider a dollar today to be as valuable as $1.05 next year. At a discount rate of 5%, a dollar today is worth $131 in a century and $8942 trillion in 8 centuries. An economist would value the 6 billion people alive today at perhaps $10 million apiece, yielding a price of $6000 trillion. This means that if you choose the right discount rate, you can conclude that it is not worthwhile to spend a dollar today to save humanity from extinction in eight centuries![11] Many people believe that governments should take a longer view than private businesses, so when analyzing public projects such as national parks it is traditional to use a smaller discount rate than private market rates of return. Since the damages from carbon emissions continue over centuries, the choice of discount rate can make a difference of about a factor of 5 in estimated marginal damages when expressed in today's dollars.[xlix] One study found that the price of carbon should be about $2.70 per ton of CO_2 if one uses a market discount rate and about $44 if one uses a zero discount rate.[l]

The second controversial issue in valuing the cost of carbon is how to compare damages between the developing and developed world. Poor people value money more than rich people, so many studies consider a reduction from two dollars a day to one dollar a day for poor people to be much worse than a reduction from $101 per day to $100 per day for rich people. Considering a dollar in the developing world to be worth more than a dollar in the developed world makes a difference of about a factor of two in the estimated damages.[li]

Various studies yield a price of carbon between about $1.30 and $55 per ton depending on these and other assumptions.[lii] Most of the studies are near the lower end of this range. However, the

[10] Our GDP did not decrease because people reallocated money spent for other things to rebuilding.

[11] I ignored inflation, population growth, and increased wealth in this back of the envelope calculation, but those should not distract from the point. One might reasonably argue that we should value killing the last person a lot more than killing the first, so perhaps this conclusion is a bit extreme.

risk of unexpectedly high damages is much greater than unexpectedly low damages, and so it makes sense to choose a somewhat larger figure. A UK government analysis[liii] recommends a substantially larger price of 19 pounds ($36), on the grounds that an analysis giving that figure is more sophisticated than the others. I recommend $20 per ton of CO_2 as a reasonable guess for the time being.

The damages from warming grow faster than the carbon dioxide concentration – a lot of CO2 is much worse than a little CO2. Therefore, the higher the CO2 concentration, the higher the price of carbon. If abatement is cheaper than expected, we should respond by doing more of it. Combining these factors, one sees that the cheaper abatement is, the lower the price of carbon.[liv] For example, the Stern report[lv] gives a price of $85 per ton of CO_2 if we do nothing, and about a third of that if we act to reduce our level of the emissions to stabilize the concentration of carbon dioxide in the atmosphere.

Other studies suggest that the dependence of the price of carbon on abatement costs is pretty weak.[lvi,12]

[12] In technical terms, the marginal damages curve is relatively elastic (close to flat).

B Carbon Dioxide Emissions Data

Table 1, based on International Energy Agency data,[lvii] shows the population, gross domestic product, carbon dioxide emissions, and carbon dioxide emissions per capita for representative countries and regions. Note that our emissions per capita are almost double that of our European peers.

	Population		**GDP (PPP)**		**CO_2 (Fuel only)**		**CO_2/Pop.**	**CO_2/GDP (PPP)**
	billion	**%**	**trillion $**	**%**	**10^6 ton**	**%**	**ton**	**kg/$**
OECD	1.17	18%	30.3	56%	12.9	48%	11.0	0.43
US	0.30	5%	11.0	20%	5.8	22%	19.6	0.53
Germany	0.08	1.3%	2.2	4%	0.8	3.0%	9.9	0.37
China	1.30	20%	7.8	14%	5.1	19%	3.9	0.65
India	1.10	17%	3.4	6%	1.1	4%	1.0	0.34
World	**6.43**	**100%**	**54.6**	**100%**	**27.1**	**100%**	**4.2**	**0.50**

Table 1 World CO_2 emissions in 2005 from fuel use

Table 2[lviii] shows how different sectors and fuels contribute to U.S. carbon dioxide emissions. Our electricity consumption is split about evenly between residential, commercial and industrial uses.

Sector and Fuel	**billion metric ton CO_2 per year**	**Percent**
Coal electricity	1.9	32%
Other electricity	0.4	7%
Transport gasoline	1.2	20%
Transport Diesel	0.4	7%
Transport Jet fuel	0.2	4%
Transport other	0.1	2%
Industrial non-electricity	1.1	18%
Residential non-electricity	0.4	6%
Commercial non-electricity	0.2	4%
Total	5.9	100%

Table 2 US CO_2 emissions by sector and fuel

Endnotes

[i] National Academy of Science. Understanding and responding to climate change. March 2006 Edition. http://dels.nas.edu/basc/Climate-HIGH.pdf . Figure 8 page 11.
[ii] Congressional Budget Office. The Economics of Climate Change: A Primer. April 2003. http://www.cbo.gov/showdoc.cfm?index=4171&sequence=0 page 40
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[vi]If you only want to read a few pages, I recommend the National Academies Summary for the science and the conclusions of Congressional Budget Office studies cited previously. For a longer version of the science, see Intergovernmental Panel on Climate Change. Climate Change 2001. http://www.grida.no/climate/ipcc_tar/. For more in-depth economics and policy options, read CBO's Climate Change Primer and the Stern review. If you really want to understand environmental economics, read a textbook such as Barry Field's *Environmental Economics – an introduction.* I also highly recommend William Nurhaus's *"To Tax or Not to Tax: Alternative Approaches to Slowing Global Warming,"* volume 1, issue 1, winter *Review of Environmental Economics and Policy,* 2007, pp. 26–44 http://www.econ.yale.edu/~nordhaus/homepage/nordhaus_carbontax_reep.pdf.
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