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How expensive should CO_2 be? Fuel for the debate on optimal climate policy*

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Abstract

Most people are convinced that climate change is a threat and that it should somehow be dealt with. It is also clear that CO2 emissions are still too cheap and must be priced higher to sufficiently curtail emissions. Yet how high should a carbon tax be? Answering this question requires scientific insights on the costs and benefits of a carbon tax but also ethical – and thus political – judgements on how we value the damages from climate change that will happen in the near and in the far future. This paper reviews the evidence on the social cost of carbon and discusses global and unilateral policy options. It finds that a price of $77 per metric ton of carbon is defensible *if* we give 95% weight to damages occurring two generations (or 50 years) from now but *higher if* we want to further reduce the risk of catastrophic change. It is best implemented as part of trade agreements and in combination with R&D investment.

Keywords: climate change, carbon tax, discounting, policy.
JEL classifications: Q54, Q38, H20, O44.

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1. Introduction

Most people are convinced that climate change is a threat and that it should somehow be dealt with. It is also clear that CO_2 emissions are still too cheap and must be priced higher to sufficiently curtail emissions. Yet how high should a carbon tax be? Answering this question requires scientific insights on the costs and benefits of a carbon tax but also ethical judgements on how we value the damages from climate change that will happen in the near and in the far future. A target of limiting warming to 2 degrees Celsius determines a budget of cumulative emissions, but the target itself is not necessarily optimal from a welfare perspective. This review paper makes the impact of these choices clear and thus provides fuel for the debate on setting and implementing optimal climate policy.

The paper is organized as follows. Section 2 discusses the reasons for restricting the emission of greenhouse gases. Section 3 reviews the key parameters that yield an estimate of the social cost of carbon. Section 4 discusses the scope for unilateral climate policy, while Section 5 discusses the need for subsidies in addition to a tax. Section 6 concludes.

2. Why should we tax CO_2?

The goal of a CO_2 tax is to reduce global warming. Often, a target of 2°C is mentioned, which corresponds with the target set at the Paris accord in 2015, and represents the 'acceptable' level of global warming above that of pre-industrial times, and most likely implies an average sea level rise of one meter (Vermeer and Rahmstorf, 2009). Acceptable means that the world is willing to sustain damages at this level of warming but not more, and is thus willing to curb carbon emissions today and in the near future to slow further warming (which includes limiting the emission of other greenhouse gases).

The more we tax CO_2, the more likely it is that we will reach this goal. The reason is that climate change is a global externality: overall a loss of welfare that is not taken into account by the individual emitters of carbon. The market price for carbon is thus nearly zero and too low from a welfare perspective. As with any externality, its effect will only be internalized by individual emitters once it is priced, through a tax or a competitive emissions market. A carbon tax has the effect of increasing the cost of emitting carbon and thus of reducing the use of oil, natural gas, and coal, and leaving reserves in the ground. Moreover, it increases the profitability of renewable sources of energy. Without a tax on carbon (or a subsidy on renewables), renewable sources tend to be uncompetitive. Both effects reduce carbon emissions.

The limit of 2 degrees reflects the fact that this is a level of temperature rise beyond which there is no historical human experience (Nordhaus, 1977; Hansen, 1988; Rijsberman and Swart, 1990; WBGU, 1995). Accepting a higher temperature goal requires a relatively lower tax.

The temperature goal is closely related to our assessment of the damages of climate change. Sea levels will rise and extreme weather events will be more common. To illustrate some of the direct costs: a sea level rise of only 23 cm above 2010 levels by 2050 translates into an adjustment cost of dams and dykes in the Netherlands (of which two thirds of its area is vulnerable to flooding) of $ 15-20 billion (Deltares, 2011). Currently, the Dutch government spends $ 1 billion annually on water management through the Delta program. Some regions may also benefit in the sense that some regions will become more agriculturally productive. The economic damages depend on where, how intense, and how quickly these changes take place, and on our ability to adapt to the new circumstances, which in turn depends on our resources, technology and the quality of governance. Poorer countries will find it in general more difficult to adapt due to lack of capital. Some estimates put a business-as-usual warming of 3.5 degrees at a cost of 1.8 percent of GDP in the EU in 2080 (Ciscar et al., 2014). A survey by Tol (2009) estimates the damages at 1.5 percent of global GDP for a 2.5 degree warming, and 1-5 percent of global GDP for four degrees warming.

Modest as this may seem, an additional reason to tax CO2 is that as temperature increases the probability of 'catastrophic' and irreversible change increases as well, perhaps non-linearly so. The most important so-called 'tipping points' are:

- melting of the permafrost and retreating land ice (which raises sea levels, and increases the rate at which temperature rises for a given stock of carbon in the atmosphere and thus accelerates warming) (15 percent loss of GDP);

- weakening of the Atlantic conveyor belt (the Gulf stream, which would start an ice age in Europe and increase the damages from a given temperature rise) (15 percent loss of GDP);
- dieback of the Amazon rain forest (which also decreases carbon absorption) (5 percent loss of GDP);
- a more persistent El Niño regime (which translates into more extreme weather events) (10 percent loss of GDP).

The amount of economic damage as a percentage of GDP is listed in brackets, but these numbers are highly uncertain due to the unprecedented nature of these events. Their probability distribution and transition periods come from a survey of experts (Cai et al., 2016). If we are averse to risk then we should avoid at least some of these events (given limited resources to avoid them), especially if one considers that other catastrophes may also happen (such as disease pandemics), see Martin and Pindyck (2015). Additional taxation to take this into account is valuable because it prevents some of these risks and acts as a hedge against potential catastrophe (Weitzman, 2014). The required tax would then be four times higher.

3. How high is the optimal carbon tax?

The optimal price of carbon should be set to its social (welfare) costs, which is equal to the current consumption value of the change in the discounted value of utility of consumption per unit of additional emissions. The intertemporal trade-off is that we can achieve more consumption today by allowing additional emissions, but this also raises future marginal damages to aggregate production and consumption caused by climate change. Because the marginal damages increase over time as the global economy grows and natural absorption of atmospheric CO2 by saturating oceans slows down, the social cost of carbon – and thus the optimal tax – increases over time.

The optimal level of the carbon tax should be set *higher*:

- if we value the future more and thus use a lower discount rate. Table 1 provides an example (US Government, 2013). If we place a weight of 95 percent to damages occurring two generations (or 50 years) from now when translating future costs to the equivalent of present-day costs, we should use a pure rate of time preference of 0.1 percent (and a discount rate of 2.5% following Stern (2007)) and price carbon at 50 dollars per metric ton of carbon dioxide equivalent (tCO2e). The reason is that we then want to avoid those costs even if they are far into the future. If we only give a weight of 48 percent to damages occurring 50 years from now, then the rate of time preference is 1.5 percent (and the discount rate is close to 5 percent, following Nordhaus (2014), which reflects opportunity costs in financial markets) and the optimal price is only 11 dollars per ton of carbon;

- if we place a higher probability on the event of tipping points, because then the future damages will be higher;
- if we assume lower economic productivity growth, because then future generations are not much better off to deal with climate change on their own. Moreover, for a given level of intergenerational inequality aversion, lower growth implies less incentive to reduce such inequality by emitting more today and thus less incentive to lower the tax (Karp, 2016);
- if the sensitivity of the global surface temperature to the stock of carbon is higher than is currently thought. The shorter the delay between the current stock of carbon and temperature rises, the less we discount those damages (because they are less far into the future) and the more we need to curb emissions today.

Table 1. Example: the optimal carbon tax as a function of the discount rate

Social cost of carbon today (2007, $/tCO2e)	Social cost of carbon in 2050 ($/tCO2e)	Tipping points modeled?	Discount rate
11	27	No	5
33	71	No	3
50	98	No	2.5

Source: US Government (2013)

To find the optimal carbon tax I draw on two recent studies, one that does not take into account catastrophe (Nordhaus, 2014) and one that does (Cai et al., 2016), see Table 2. Again, the discount rate is very influential, raising the present day optimal tax from 30 to 109 dollars per tCO2e when the Stern (2007) recommendation is implemented: a more than three-fold increase.

Note that here the discount rate slowly declines over time because future discount rates (set by future generations) are uncertain, and because future economic productivity growth may decline. For example, the expected net present value (NPV) of receiving $1,000 with two equally likely uncertain rates (say 1 percent and 7 percent) evaluated in 100 years is $184.40 = $1000*(exp(-1) + exp(-7))/2. An NPV of receiving $184.40 in 100 years with certainty suggests a discount rate of only 1.7%. The discount rate declines under uncertainty and declines over time (Arrow et al., 2013). Recently, estimates of actual discount rates at horizons beyond 100 years were estimated to be 2.6% (Giglio et al., 2015).

Taking expected catastrophes into account for a given high discount rate, we find an optimal tax of 126 $/tCO2e: an eight-fold increase over the baseline of 16 $/tCO2e in the same model. In that case, the cumulative probability of one or more tipping points occurring by 2100 is only 11 percent, while it is 46 percent for a carbon tax of only 16 $/tCO2e (Cai et al., 2016, p522). A lower discount rate would increase the optimum even more, to roughly 460 $/tCO2e (not shown in the table). Table 2 also shows that more risk aversion raises the level from 126 to 159 $/tCO2e, while raising the degree of aversion to intergenerational inequality from 1.5 to 2 raises the optimal tax from 126 to 164 $/tCO2e.

Table 2: Scenarios for the optimal carbon tax

Social cost of carbon		Tipping points modeled?	Discount rate	Reference	Pure rate of time preference	Risk aversion	Inter-generational inequality aversion	Degree warming by 2050	Zero emission by 2050?
Today	In 2015								
30	107	No	5-4.5	Nordhaus, 2014	1.5		1.45	2	Yes
109	231	No	3-2	Idem	0.1		1.45	1.5	Yes
16	65	No	5-4.5	Cai et al., 2016	1.5	1.45	0.7	1.4-2	No
126	272	Yes	5-4.5	idem	1.5	3	1.5	1.4	Yes
159	348	Yes	5-4.5	idem	1.5	10	1.5	<1.4	Yes
164	359	Yes	5-4.5	idem	1.5	3	2.0	<1.4	Yes

Note: all units expressed as $ per ton of CO2-equivalent using the 2015 US price level.
Source: US Government (2013) and Cai et al. (2016)

The US government provides some guidance on how high the discount rate should be. It uses a constant discount rate of one to three percent for intergenerational social cost-benefit analyses

(U.S. Office of Management and Budget, 2013). However, the Trump administration has proposed to adjust this upwards to three to seven percent (U.S. Environmental Protection Agency, 2017), which would result in a much lower social cost of carbon. Despite the recommendations of Arrow et al. (2013) the rate used is constant. Other governments make other assumptions. For example, the UK and France use a declining rate (Arrow et al., 2013), while The Netherlands uses a constant rate of three percent in (Ministerie van Financiën, 2015).

Based on the Nordhaus (2014) model and its assumptions, the goal to reach the Paris limit of no more than two degree warming by 2050 on average could be achieved by a carbon price of $30 per ton, rising to $107 per ton in 2050, assuming a discount rate of about 4.5 percent. A lower (constant) discount rate of 2.5 percent is more prudent because it raises the social cost and the optimal tax of carbon to $70 per ton in 2015 and will also limit warming by more. This translates to about $77 per ton of carbon in 2018, expressed in dollars of 2015, rising to $198 by 2050. This contrast starkly with the current EU Emission Trading System (ETS) price of little over six $/tCO2e. A carbon tax of $77 per ton of carbon, if fully passed on to consumers, translates into an additional 68 dollar cents per gallon of gasoline, a price increase of about 28%. The equivalent in euros is a carbon tax of €67 per ton of carbon. For example, if fully passed on to consumers in the Netherlands this translates into 180 euros per average annual natural gas bill of 1.500 m3 per household, increasing the bill by about 20%. It translates into an additional 16 euro cents per liter of gasoline, a price increase of about 10% (Source: Wikipedia).

Clearly, the more weight we give to future generations, the more we are willing to incur costs today.

4. Does unilateral carbon policy make sense?

What if the US cares more about the future than other countries? It would be globally inefficient to raise a CO2 tax in the United States only, although it may have local benefits by lowering related air pollution. This may raise costs relative to production costs abroad and increase the incentive to move production abroad to avoid the tax. This raises two issues: First, even if we do not mind that the dirtiest CO2-intensive industries move abroad and we still impose a US carbon tax, then we may not be helping the environment, because global CO2 emissions will not be reduced (they may even go up if foreign emission standards are lower). Second, through trade, consumers may choose to import cheaper foreign alternatives to domestic goods that are now more expensive due to the tax. These imports will increase foreign production which may also result in no net reduction of global emissions. However, a CO2 tax is only a fraction of total business costs, and businesses also care about other taxes, the local quality of labor, infrastructure, governance, etcetera, so the issue should not be overstated.

Part of the economy already pays a (low) price for CO2 though emission trading schemes such as the ETS in Europe and the Regional Greenhouse Gas Initiative in northeastern states of the US (Newell et al., 2013). In theory, an optimal CO2 tax is equivalent to an optimal quota of tradeable permits. In the latter case the government sets the quantity of permits (which may decline over time as under the ETS) such that private demand for emissions will result in a market price. The benefit of using the ETS to further increase the price of carbon is that it does not require new (international) legislation, but the resulting carbon price can fluctuate heavily due to economic cycles and clean-tech adoption. Instead, a carbon tax has the advantage that the resulting carbon price is much more stable and predictable such that businesses will find it easier to plan ahead and make decisions and investments with a long-term view. Moreover, it is transparent and potentially less susceptible to lobbying for the allocation of permits. For example, under the ETS many CO2-intensive firms receive free permits.

Evaluations of the ETS suggest that it has reduced the emission intensity of affected firms while there are only modest negative effects on competitiveness because higher costs could be passed on to consumers. More research is needed before strong conclusions can be drawn, however (Martin et al., 2016). Recent empirical research suggests that countries that ratified ‘Kyoto’ saw imports rise from countries that did not ratify by 8 percent, resulting in a 3 percent increase in carbon intensity of total imports (Aichele and Felbermayr, 2015). To prevent such ‘leakage’, the tax should be harmonized with main trade partners, such as within NAFTA to create economic zones that harmonize both trade and climate policies (Nordhaus, 2015), or the World Trade Organization would have to be reformed to allow import tariffs based on the carbon emitted in the production of the imports (although these pose significant informational problems (Mattoo and Subramanian, 2013)). Using the carbon tax to reduce other general taxes may help to rebalance the overall competitiveness of the economy on global markets, but will not eliminate the issue of leakage completely because the CO2 tax burden will still be higher for carbon-intensive industries, even if all firms pay lower corporate taxes. The adoption of a carbon tax in developing countries may be sped up through side payments such as through the UN's Green Climate Fund.

The current ETS-quota system is not socially optimal, because it only applies to large companies and many greenhouse gas intensive industries have received free permits. A CO2 tax should never overlap with a quota-based system. The reduction in emissions achieved by a firm that pays the CO2 tax would lead to less demand for permits, lowering the CO2 price for other firms under the quota system. Other firms would then have fewer incentives to reduce emissions such that the total amount of emissions may not be lower than before the tax was implemented. Both systems can only coexist if they apply to different sectors, unless double taxed firms receive rebates or if excess emission rights are taken out of the market. This would however needlessly complicate the system.

5. Are additional subsidies also necessary?

A tax on CO2 reduces emissions because cleaner alternative technologies become relatively cheaper. However, it will probably be increasingly costly to reduce emissions in ever cleaner technologies in order to reach zero emissions by 2050. Continued reliance on dirty energy – in combination with carbon capture and storage technology – is also necessary to deal with weather-related sudden drops in renewable energy supply, until large scale storage of electricity becomes possible (Sinn, 2016). However, because of the relatively large amount of carbon embodied in coal, we need smaller and nimbler natural gas fired power plants to fulfill this function rather than the existing large and unwieldy coal plants. The former could charge a premium in exchange for reliably energy supply.

R&D subsidies targeted to the development of new technologies will be useful to speed up the transition. The revenue of the CO2 tax could be earmarked to finance these. Because governments may not be able to choose winning technologies before they exist, such subsidies should be general and targeted to financing prototypes by start-ups and universities. Early stage subsidies have a large positive effect on patenting and revenue, especially for small financially constrained firms (*Howell, 2017*). Recent research based on patent citations suggests that clean-tech innovations lead to more technological innovation in other sectors, than do dirty-sector innovations (Dechezleprêtre et al., 2013). Subsidizing green technology creates a global positive externality such that it leads to faster technology adoption elsewhere. If successful, it reduces the demand for CO2 emissions and thus reduces the need to tax CO2 intensively. The CO2 tax then does not have to rise as fast as without green tech subsidies (Acemoglu et al., 2012).

6. Conclusion

The social cost of carbon and the optimal tax of carbon are strongly influenced by our assessment of future damages but also on how we much we care today about the loss of welfare that will happen in the future. A price of $77 per ton of carbon is defensible but is best implemented as part of trade agreements and in combination with R&D investment.

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