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Carbon Taxes in Theory and Practice

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Abstract

As of 2020, carbon taxes were in effect in 30 jurisdictions around the world. This article provides a theoretical overview of carbon taxes along with some empirical evidence on the macroeconomic impacts of existing taxes, including emission reductions. It compares and contrasts carbon taxes with other policy instruments to reduce emissions. It also highlights issues that have recently attracted the attention of researchers on which additional research would be beneficial. Those include (*a*) the role of border adjustments in a unilaterally imposed carbon tax, (*b*) hybrid carbon tax systems that increase the likelihood of hitting desired emission reduction targets, (*c*) the optimal price path for a carbon tax, and (*d*) the growing empirical literature on the economic impact of carbon taxes.

1. INTRODUCTION

Among economists, a carbon tax has long been a favorite policy tool to reduce greenhouse gas (GHG) emissions and so reduce the impacts of climate change. This review article provides an overview of the literature, with attention paid to recent developments in the study of carbon taxation and other policy instruments to reduce emissions.[1] Section 1 provides an overview of climate change. The following section reviews the basic economic theory of pollution control and assesses various policy instruments to reduce emissions. I then provide a brief review of the use of carbon taxes globally along with a review of the empirical evidence to date on economic impacts. Section 4 surveys key design considerations. A brief conclusion follows.

2. CLIMATE CHANGE

Climate change refers to the climatic impacts arising from accumulations of GHGs in the Earth's atmosphere. The most prominent GHG is carbon dioxide (CO_2), which accounts for three-quarters of global emissions. Methane is the second most prominent GHG, accounting for a further 18% of global emissions. Nitrous oxides (N_2O) and other gases account for the remaining roughly 8% of GHG emissions. **Table 1** reports the breakdown of GHG emissions for 2016, excluding Land Use Change and Forestry (LUCF) emissions for various countries along with the global breakdown.[2] CO_2 emissions are a higher share of total emissions in the United States, European Union, and China than the world average. In India, methane is a larger share of emissions than the global average, a not surprising fact given the role of agriculture in the economy. In all countries, methane and CO_2 account for roughly 90% of emissions (using a 100-year global warming potential to compare the different GHGs).

Energy-related CO_2 emissions account for roughly 70% of global GHG emissions. **Table 2** gives a breakdown of these emissions in 2018 by sector for the world and several large emitting countries. Globally, electricity production accounts for just over 40% of energy-related CO_2 emissions followed by transportation and industry at roughly one-quarter each. Residential, commercial, and agricultural sectors account for a final 10%. The distribution of emissions differs between developed and less-developed countries. For the European Union and United States, electricity, and transportation vie for the top emitting sectors; industrial emissions are approximately one-half of all emissions in each of the top two sectors. For China and India, electricity accounts for over one-half of each country's emissions, with industry following at between one-quarter and one-third. The difference in importance of the electricity sector for emissions is driven in large

Table 1 Greenhouse gas emissions, 2016

Source	World	China	EU-28	India	United States
Carbon dioxide	74%	83%	80%	70%	83%
Methane	18%	11%	11%	21%	10%
Nitrous oxides	6%	5%	6%	8%	4%
Fluorinated gases	2%	2%	3%	1%	3%

Data from the World Resources Institute CAIT at **https://www.climatewatchdata.org**. Cell entries are the share of total emissions excluding land-use change and forestry emissions.

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[1] This review draws on papers by Metcalf (2019a,b).

[2] Data are the World Resources Institute CAIT data set from **https://www.climatewatchdata.org**. The data collection methodology is described at **https://www.climatewatchdata.org/about/faq/ghg**.

Table 2 Energy-related CO_2 emissions by sector, 2018

Sector	World	China	EU-28	India	United States
Residential	6%	4%	12%	4%	7%
Commercial	3%	2%	5%	1%	5%
Industry	23%	32%	18%	28%	14%
Transportation	25%	10%	30%	13%	36%
Electricity	42%	52%	33%	52%	38%
Agriculture	1%	1%	2%	1%	1%

Data from Int. Energy Agency (2020). Cell entries are the share of total energy-related CO_2 emissions in each sector.

Table 3 Energy-related CO_2 emissions by source, 2018

Source	World	China	EU-28	India	United States
Coal	44%	80%	28%	71%	26%
Natural gas	34%	14%	42%	26%	41%
Oil	21%	5%	28%	3%	33%
Other	1%	1%	2%	0%	0%

Data from Int. Energy Agency (2020). Cell entries are the share of total energy-related CO_2 emissions by source. Other includes industrial and municipal waste.

measure by the heavy reliance on coal in China and India relative to the European Union and United States (see **Table 3**).[3]

The damage from GHG emissions stems from the stock of these gases in the atmosphere. Just as the glass roof of a greenhouse traps solar radiation and raises the temperature inside the greenhouse, CO_2 and other GHGs trap solar radiation in our atmosphere and raise the planet's temperature, which explains the reference to "greenhouse gases" and the greenhouse effect of climate change. How fast the temperature rises in response to an increase in the stock of GHGs in the long run depends on the climate sensitivity parameter, i.e., the rise in temperature due to a doubling of GHG concentrations in the atmosphere.[4] According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, equilibrium climate sensitivity (ECS) is "likely in the range of 1.5°C to 4.5°C" (IPCC 2014, p. 62). A recent analysis by Sherwood et al. (2020) finds it "extremely unlikely" that ECS is less than 2°C and "not likely" to be above 4.5°C.

Pre–industrial era concentrations of CO_2 in the atmosphere are typically pegged at 280 ppm, though air samples taken from Antarctic ice cores make clear that concentrations have ranged between 180 and 300 ppm over the past 400,000 years. Current measurements of CO_2 have been taken on a continuous basis in Hawaii starting in 1958, when Charles Keeling installed monitoring equipment on the upper slopes of the Mauna Loa volcano just over 11,000 feet above sea level. **Figure 1** combines data from the Antarctic ice cores and the Mauna Loa monitor to show atmospheric CO_2 concentrations over the past 400,000 years. There is clear historic variation in

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[3] According to International Energy Agency (IEA) data, coal accounted for 96% of India's electricity and heat-related CO_2 emissions in 2018. China's coal share is even higher. In contrast, comparable shares for the European Union (EU-28) and the United States are 68% and 59%, respectively.

[4] Equilibrium climate sensitivity measures the long-run equilibrium response. Transient climate response measures the temperature response over a shorter period.

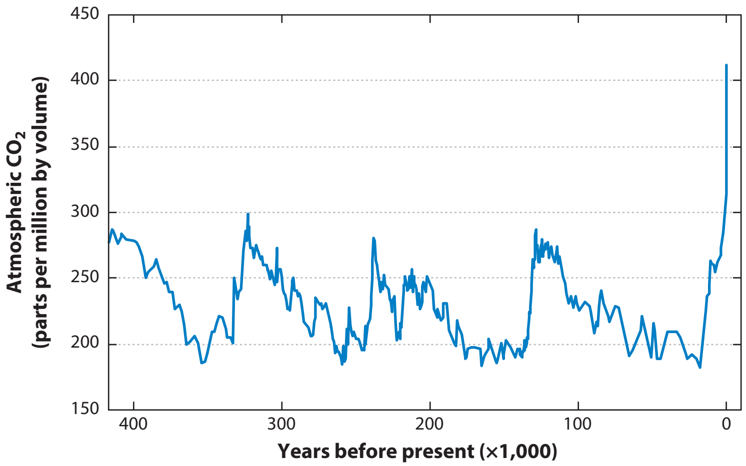

Figure 1

Atmospheric concentrations of carbon dioxide based on combined data sets from Antarctic ice core carbon dioxide concentrations (Petit et al. 1999) and Mauna Loa Observatory air readings (Keeling et al. 2001; **http://scrippsco2.ucsd.edu/data/atmospheric_co2/mlo.html**).

concentrations over the preindustrial era; what is striking is the sharp rise in concentrations since the 1850s and especially since 1960.[5]

Failing to act to reduce emissions is costly. The 2018 IPCC Special Report (IPCC 2018) on the impacts of global warming of 1.5°C lists a number of key natural and human systems impacted by climate change (see **Figure 2**). These systems are impacted by more frequent durations of hotter weather, heavier precipitation, and increased likelihood of drought conditions (IPCC 2018). As one illustration of the increased prevalence of more extreme weather, consider the US National Oceanic and Atmospheric Administration (NOAA) Climate Extremes Index. This index summarizes extreme temperatures (high and low), precipitation, droughts, and tropical storm intensity for the United States, with data going back to 1910. Six of the top 10 extreme climate years have occurred since 2005.[6] This index highlights the fact that climate change is as much (if not more) about climate variability than it is about warming.

Hsiang et al. (2017) construct detailed estimates of the damage from climate change in the United States at the county level, and they find that the combined market and nonmarket damages for a 1°C increase in temperature is on the order of 1.2% of GDP. Damages are unequally distributed, with higher damages in southern areas. By the end of this century, they estimate that the poorest third of US counties have a 90% chance of experiencing damage between 2% and 20% of county income in a business-as-usual scenario with no action to reduce emissions. Hsiang et al.'s study highlights the geographic variation in projected damages for the United States. This

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[5] Ice core data give a CO_2 concentration of 285 ppm in the time of Alexander the Great (340 BCE). By 1960, they had risen to 320 ppm. Concentrations as of late 2020 now exceed 410 ppm, according to NOAA (**https://climate.nasa.gov/vital-signs/carbon-dioxide/**).

[6] Data from NOAA's Climate Extremes Index for the contiguous United States published at **https://www.ncdc.noaa.gov/extremes/cei/graph/us/cei/01-12**, accessed September 25, 2020.

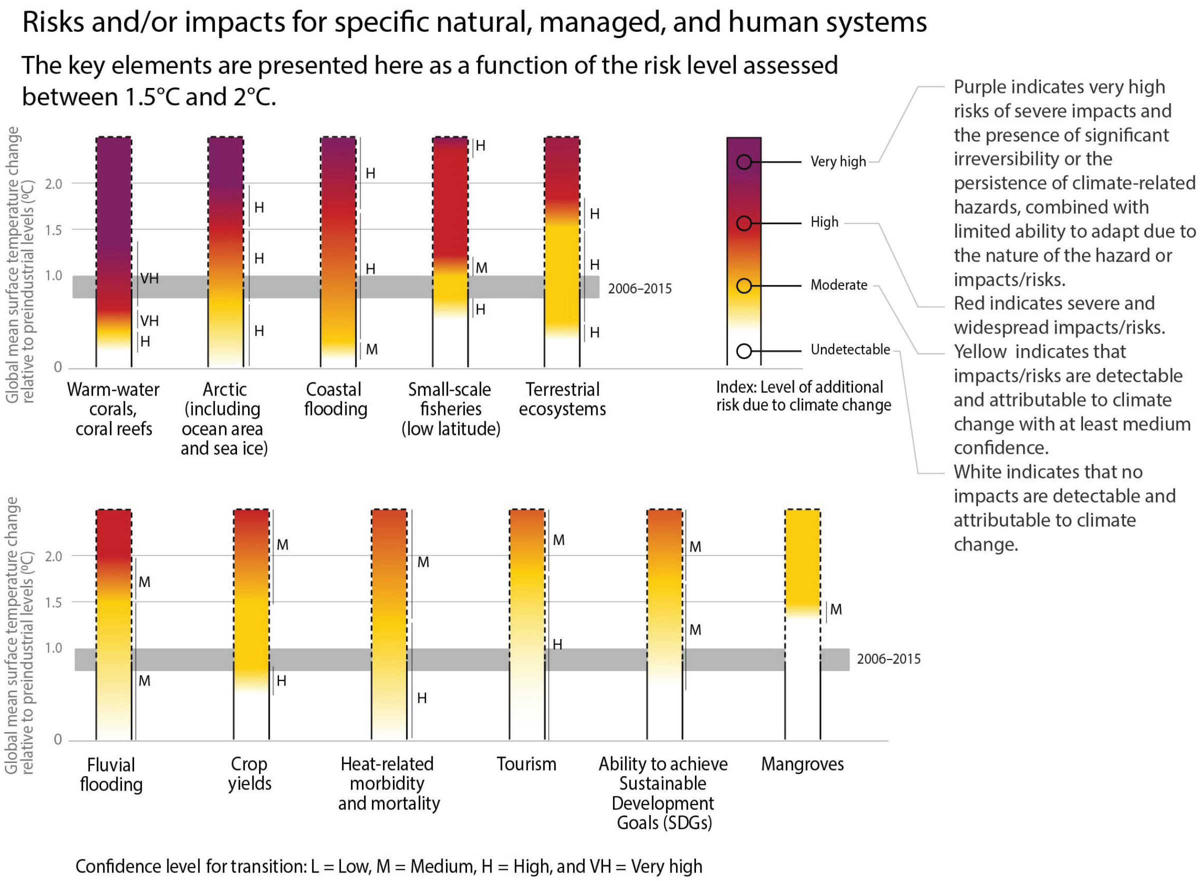

Figure 2

Risks and impacts of higher temperatures for specific natural, managed, and human systems, as summarized in Hoegh-Guldberg et al. (2018). Adapted from the original Figure 3.20 from Hoegh-Guldberg et al. (2018), with permission from the IPCC (**https://www.ipcc.ch/site/assets/uploads/sites/2/2018/11/figure-3.20.jpg**).

variation is a global property of climate change, as detailed in, among other places, the Synthesis Report from the IPCC's Fifth Assessment Report (IPCC 2014).[7]

The cost of climate change includes both damages and the costs of adaptation. As temperatures increase, we can expect to see greater penetration and use of air conditioners—a form of adaptation. Infrastructure investments to cope with more frequent and severe storms are also forms of adaptation. Adaptations, of course, come with their own costs. The International Energy Agency (Int. Energy Agency 2018) estimates that household ownership of air conditioners will rise from 1.1 billion units in 2016 to over 4 billion units by 2050. The electricity needed to power those new air conditioners exceeds the current electricity consumption in Germany and the United States.

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[7] See also Burke et al. (2015), highlighting differential impacts of temperature increases on GDP globally, with disproportionately adverse impacts on poorer countries, as well as Kalkuhl & Wenz (2020), who find that heterogeneous productivity declines with temperature increases, with larger declines in tropical and low-income regions.

3. THEORY OF PIGOUVIAN TAXATION

Pollution is a problem arising from the failure of firms or individuals to account for the damages from pollution that are borne by others in their decision making. Put simply, the market failure from pollution arises from the failure to fully price the resources used in production or consumption. Given the divergence between the private and social costs of a good owing to pollution, with the divergence equal to the marginal damage from the pollution, Pigou (1920) argued that taxing the pollution at its social marginal damage would equate private and social marginal costs and ensure an efficient market outcome.

A Pigouvian tax is especially easy to apply in the case of energy-related CO_2 emissions. The amount of CO_2 associated with burning a ton of coal, a gallon of gasoline, or a therm of natural gas is constant.[8] Changes in industrial processes may affect the amount of fossil fuel burned but not the emissions per unit of fuel input.[9] Given this fact, taxing fossil fuels on their carbon content is a straightforward application of Pigouvian pricing.

A Pigouvian tax is especially attractive in a situation where it is (relatively) easy to measure the marginal damages from the pollutant but where it is difficult to identify the individuals suffering the damages from pollution. In such an instance, Coasian bargaining between the polluter and those affected by pollution cannot substitute for government intervention. Coase (1960, p. 18) understood this: "In the standard case of a smoke nuisance, which may affect a vast number of people engaged in a wide variety of activities, the administrative costs might well be so high as to make any attempt to deal with the problem within the confines of a single firm impossible. An alternative solution is direct government regulation." Coasian bargaining requires reasonably low transaction costs (along with clear property rights) for private bargaining to substitute for government intervention. The ability to bargain to a Coasian equilibrium is especially difficult (if not impossible) given the number of people affected, both across countries and across time.

3.1. Putting a Price on Pollution: Alternative Approaches

A Pigouvian tax is a market-based instrument to control pollution, in that it allows the market to operate once prices have been adjusted through the use of a Pigouvian tax. A cap-and-trade system is an alternative market-based instrument to set a price on pollution. Whereas a carbon tax puts a price on CO_2 pollution and lets the market determine the amount of pollution, a cap-and-trade system puts a cap on pollution and lets a market operate in the buying and selling of rights to pollute (subject to the cap) and so determine a market clearing price. See Metcalf (2019a) for a more detailed discussion of cap-and-trade programs. Here, I simply point out three factors that favor carbon taxes over cap-and-trade systems.[10] First, a cap-and-trade system fixes emissions but allows prices to vary as market conditions change. This can lead to price volatility

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[8] Different grades of coal release different amounts of CO_2 per ton burned. However, the differences are well understood and limited in number, making it straightforward to apply a carbon tax to coal either at the mine mouth or at the site where burned—or anywhere in between.

[9] The one major exception is carbon capture and storage, where CO_2 is captured when the fuel is burned and permanently stored to prevent its release into the atmosphere. Any emissions captured and safely stored should be excluded from the carbon tax base.

[10] I elaborate on these issues in Metcalf (2019b). Goulder & Schein (2013) have a similar list. I do not consider the economic efficiency arguments for price versus quantity instruments as per the seminal paper by Weitzman (1974) and the very large literature his article spawned. While that literature tends to favor putting a price on GHG emissions rather than a cap, the efficiency arguments that literature focuses on are, in my opinion, of a lower degree of practical relevance than the issues discussed here.

and uncertainty for firms planning long-lived, capital-intensive projects. The US Environmental Protection Agency (EPA) Acid Rain Program illustrates the potential for price volatility. Allowance prices fluctuated anywhere from zero to US$1,200 in the five years between 2005 and 2010.[11]

The second difference between the two policy instruments is in administrative complexity. All developed countries—and many developing countries—have robust tax collection systems, including the capacity to collect taxes on most fossil fuels. A cap-and-trade system, in contrast, requires an entirely new administrative structure to create allowances, track them, hold auctions or otherwise distribute them, and develop rules to avoid fraud and abuse.

The final difference between a carbon tax and a cap-and-trade system is the potential for adverse policy interactions that can work against the goal of reducing emissions. Any additional policies enacted to reduce emissions in sectors covered by the cap-and-trade program (for example, low carbon fuel standards or renewable portfolio standards) will do nothing to reduce overall emissions but can only undermine allowance prices in the program. Any emission reductions in these supplementary programs will simply be offset by increases in emissions elsewhere, assuming the cap is binding. The only effect of the additional policies is to drive down allowance prices in the cap-and-trade system and drive up the economic costs of reducing emissions.[12]

That allowance prices in cap-and-trade programs tend toward low levels is borne out in the real world. The World Bank Group (2020) annual review of carbon pricing tracks carbon pricing in 61 countries, cities, states, and regions around the world. The highest carbon price among the cap-and-trade systems surveyed in the review is about $33 a ton. In contrast, five countries have carbon tax rates of at least $50 a ton, with Sweden leading the group at about $112.

Two arguments favor cap-and-trade programs over carbon taxes. First, allowance prices are not set directly by politicians, and so political distance is created for risk-averse policy makers. Second, allowances created in a cap-and-trade program are valuable assets that policy makers can distribute in ways to reduce political opposition. It is hard for an economist to opine on the value of political distance. What is clear, however, is that giving allowances to polluting firms for free to build political support for pricing pollution raises important distributional questions. Freely allocated allowances provide a windfall for shareholders—profits and share prices go up. This is what happened in Europe when the European Union set up its CO_2 cap-and-trade program and gave allowances to the firms that were subject to the cap.[13,14] Whether this is fair is a matter of debate. However, the very complexity of the cap-and-trade approach means that the public likely did not really understand the massive transfer taking place in the European Union's emissions trading system (EU ETS).

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[11] See Schmalensee & Stavins (2013, figure 2).

[12] Economic costs are driven up because lower cost emission reductions in the cap-and-trade program are replaced with higher cost reductions in the other programs. See the discussion of generally low allowance prices in Burtraw & Keyes (2018). Adverse policy interactions are one contributing factor for low allowance prices. A lack of political will can also certainly contribute to low prices. Which factor is more important for explaining low prices is beyond the scope of this review.

[13] Smale et al. (2006) examine five energy-intensive sectors in the United Kingdom and conclude that profits in most of the sectors rose following the imposition of a cap-and-trade system with free allowance allocation.

[14] While the EU ETS initially distributed allowances for free to covered firms, they have gradually moved to auctioning as the default as of Phase III (2013–2020). According to the European Commission, power generators must (with the exception of some countries) purchase all allowances, while manufacturing firms must purchase 70% of auctioned allowances (other than firms in sectors deemed at risk for carbon leakage). In all, some 57% of allowances are to be auctioned in Phase IV (2021–2030). See **https://ec.europa.eu/clima/policies/ets/auctioning_en**, accessed September 25, 2020.

3.2. Alternatives to Pricing Pollution

Historically, most of the policies to address climate change rely on various forms of regulation, subsidies, and voluntary actions or information. Given the importance of transportation (primarily motor vehicle) and electricity emissions (see **Table 2**), these sources have been a primary focus of regulators in many countries. For transportation, fuel economy standards are a common form of regulation and are found in more than 20 countries around the world, including such major countries as the Unites States, Germany, France, China, Brazil, and Mexico (Int. Energy Agency 2019).

Numerous articles have been written on the relative inefficiency of fuel economy regulation relative to a Pigouvian tax—see, for example, the recent review by Anderson & Sallee (2016). Taxes on emissions—in transportation, this can be translated into a tax on gasoline use—create incentives for consumers to purchase more fuel-efficient vehicles, drive fewer miles in the aggregate, and scrap fuel-inefficient vehicles sooner. A fuel economy standard mandating that an automaker's vehicle fleet meet minimum fuel economy standards in toto also incentivizes the purchase of more fuel-efficient vehicles. The higher fuel economy standard, however, drives down the cost of driving per mile and thus can lead to more driving, a phenomenon known as the rebound effect. Moreover, fuel economy standards only apply to new vehicles. This increases the value of fuel-inefficient vehicles already on the road and delays their eventual scrappage, an effect first pointed out by Gruenspecht (1982). All in all, these factors lead to fuel economy standards being less cost-effective than an emissions tax for achieving given emission reductions. Jacobsen (2013), for example, finds that the cost of fuel economy standards per ton of CO_2 avoided is a little over three times the cost of a comparable gasoline tax.

Subsidizing activities that compete with the polluting activity can reduce pollution and is particularly attractive to politicians. After all, subsidies generally lower costs for their constituents. An immediate problem, however, is that someone has to pay for the subsidy. These costs, in general, are spread across many people; while the aggregate cost of the subsidy might be large, the cost to any individual may be too small to notice.

Renewable portfolio standards (RPSs) are common policies in many European countries and in many US states. RPS programs are a blend of regulation and subsidy mandating that a certain fraction of the electricity sold must come from a designated renewable source, such as wind or solar. Renewable suppliers are incentivized to increase supply by payments that come from local distribution companies (and ultimately ratepayers).

Although the RPS costs get passed on to ratepayers, the cost increase is blunted to some extent by the fact that wind and solar power have very low (essentially zero) operating costs. As a result, electricity prices do not go up as much as when a tax is imposed.[15] Keeping prices down discourages firms and individuals from investing in energy efficiency to reduce consumption. Blunting the price signal raises the cost of RPS emission reductions relative to a carbon tax. Reguant (2018) finds that the cost of cutting carbon emissions in the electricity sector by 10% was over six times higher with an RPS program than with a carbon tax applied to fuels used to generate electricity.

Rather than have the ratepayer pay for the subsidy, as in RPS programs, taxpayers could finance it. Since the first energy crisis back in the 1970s, the US tax code, for example, has provided tax breaks to encourage various energy technologies, including breaks for developing and using

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[15] Fischer (2010) has shown that RPS programs can actually reduce electricity prices because the price of wind or solar at the margin is zero in contrast to natural gas which, while cleaner than coal, still has a cost at the margin.

renewable technologies.[16] Subsidies to clean energy are problematic. The first and most obvious problem is that subsidies lower the end-user price of energy rather than raise it. In Texas, a wind-rich area with much installed wind capacity, generators have willingly accepted a negative price for their electricity when demand was very low, say, in the middle of the night. This is because the wind generators have next-to-zero operating costs and can collect 2.3 cents in production tax credits for every kilowatt hour they sell. Even if they have to pay a penny to provide electricity, they are still earning 1.3 cents on each kilowatt hour sold after cashing in on the production tax credit.[17]

Lowering consumer prices encourages more energy use. It also means that consumers buy fewer energy-efficient appliances and that factory owners invest less in energy-efficient equipment than is optimal even if we ignore the pollution-related damages associated with fossil fuel use. Subsidies are also expensive per ton of CO_2 reduced. This follows, in part, because a significant share of the subsidy goes to inframarginal purchasers of the capital asset. Estimates of the proportion of tax subsidies going to inframarginal investment vary, but studies suggest the proportion could be as high as 80%.[18]

In addition, energy subsidies disproportionately accrue to high-income households. A 2016 analysis of US tax returns shows that 10% of energy tax credits go to the bottom 60% of the income distribution, while nearly two-thirds go to households in the top 20%.[19]

4. ECONOMIC IMPACTS OF CARBON TAXES

Carbon taxes have been used by countries and subnational governments for more than 25 years. As of 2020, 30 national or subnational carbon taxes were currently in effect or in the process of implementation.[20] There have been two waves of carbon tax enactments. In the early 1990s, carbon taxes were enacted in Denmark, Finland, Norway, and Sweden, among other countries. By 2000, seven countries had a carbon tax. A second wave in the mid-2000s saw carbon taxes enacted in Switzerland, Iceland, Ireland, Japan, Mexico, and Portugal. In addition, the Canadian provinces of British Columbia and Alberta enacted carbon taxes. Globally, tax rates range widely, from Poland's carbon tax rate of less than $1 per ton of CO_2 to as much as $112 per ton for Sweden. A total of 11 subnational or national governments have carbon tax rates of at least $25 per ton, and five have rates of at least $50 per ton.[21] We now have enough experience with carbon taxes around the world that we can begin to make an empirical assessment of their impact. I review that literature here.

4.1. Emissions

The first, and perhaps most important, question is whether carbon taxes reduce emissions. One analysis by Lin & Li (2011) runs difference-in-difference regressions of the log difference in

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[16] Since the inception of the tax code, there have been large tax breaks for domestic oil and gas drilling. Metcalf (2018) shows that these incentives have had modest effects on domestic oil and gas production but are costly to the US Department of the Treasury.

[17] See Wald (2012). The problem is not unique to Texas. Wald reports that in 2010 the Chicago area experienced negative pricing 3% of the time.

[18] Houde & Aldy (2017) find that 70% of consumers claiming rebates for an energy-efficient appliance would have bought it anyway, and another 15–20% simply delayed their purchase by a couple of weeks to become eligible for the rebate. Other research showing a high fraction of purchases that benefit from but are not influenced by a subsidy include studies by Chandra et al. (2010) and Boomhower & Davis (2014).

[19] This study was done by Borenstein & Davis (2016). Some tax credits are more regressive than others. The researchers document that 90% of the credits for electric vehicles go to households in the top 20% of the income distribution.

[20] Existing and planned carbon tax regimes are summarized by the World Bank Group (2020).

[21] Rates are as of April 1, 2020, as reported by the World Bank Group (2020).

emissions in various European countries. Regressions are run for each country individually that imposed carbon taxes in the 1990s—Finland, the Netherlands, Norway, Denmark, and Sweden—with 13 European countries selected as controls. Regressions are run over the 1981–2008 time frame. In 4 of the 5 countries, the growth rate of emissions fell by between 0.5 and 1.7 (based on the estimated coefficient of the interaction variable).[22] Only the estimate for Finland is statistically significant at the 10% level, with the coefficient suggesting a drop in the growth rate of emissions of 1.7%. The coefficient for Norway is positive but trivially small and statistically insignificant at the 10% level. These researchers argue that the larger effect for Finland reflects the smaller number of exemptions from the tax than in other countries.

Martin et al. (2014) consider the impact of the United Kingdom's Climate Change Levy (CCL) on various manufacturing firms' energy and emissions indicators. Adopted in 2001, the CCL is a per-unit tax on fuel consumption by industrial and commercial firms. Unlike a carbon tax, the rate per ton of carbon emissions varies across fuels, from a low of £16 per ton for industrial coal use to a high of £30 (natural gas) and £31 (electricity), as reported in Martin et al. (2014, table 1). They find that CO_2 emissions fall by 8.4%, albeit imprecisely estimated (i.e., large standard errors). Given the differential carbon tax rates on electricity (£31 per ton) and coal (£16 per ton), we cannot rule out the possibility that the CCL has led to fuel substitution away from electricity and toward coal.[23]

Rivers & Schaufele (2015) consider the impact of British Columbia's carbon tax on the demand for gasoline in the province using data at the province-month level between January 1990 through December 2011. The authors regress log consumption on a carbon tax exclusive of the price of gasoline and a price on the carbon contained in gasoline. Although an increase of 1 cent per liter in the price of gasoline depresses gasoline consumption in the province by 0.41%, an increase of 1 cent per liter in the carbon tax reduces demand by 1.7%—a fourfold increase. The authors attribute the difference to the high salience of the carbon tax.

Metcalf (2019a) reports regressions on provincial data in Canada over a 27-year period to investigate the impact of the British Columbia carbon tax. He finds that it has reduced emissions on the order of 5–8%. In contrast, Prettis (2019) employs a structural break model and finds no statistically significant reduction in aggregate emissions but does find a 5% reduction in transport-related emissions. Metcalf & Stock (2020) carry out an analysis of the 31 countries in Europe that are part of the EU ETS. While all of these countries price a portion of their emissions through this cap-and-trade system, 15 of them also impose a carbon tax, mostly on emissions not covered by the EU ETS. By limiting their analysis to countries that are part of the EU ETS, the authors identify the incremental impact of carbon taxes on emissions, output, and employment by leveraging the variation in carbon tax systems within this group of countries. Based on their regression estimates, they find cumulative emission reductions on the order of 4–6% for a tax of \$40 per ton of CO_2 covering 30% of emissions. They argue that this is likely to be a lower bound on reductions for a broad-based carbon tax because European carbon taxes do not include in the tax base those sectors with the lowest marginal costs of carbon pollution abatement. European carbon taxes generally exclude the electricity sector and carbon-intensive industries, as those emissions are covered under the EU ETS.

Within Europe, Andersson (2019) investigates the impact of Sweden's carbon tax on transportation emissions, the most-impacted sector. He finds an emissions reduction on the order of

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[22] The regressions take as a treatment the imposition of a tax but not the magnitude or coverage.

[23] The coefficient on the treatment variable in a regression with a measure of solid fuel use (coal and coke) as the dependent variable is positive but not statistically significant.

11%. While this might appear modest given that Sweden has the highest carbon tax in the world, most analysts argue that the transportation sector is the most difficult sector to decarbonize given the efficiency of the internal combustion engine.

In summary, the evidence suggests that carbon taxes have been effective at reducing emissions. It is also fair to say, however, that few, if any, countries have implemented broad-based carbon taxes at sufficiently high rates to effect substantial emission reductions.

4.2. Macroeconomic Outcomes

One concern with climate policy has been the potential for job losses and higher unemployment. This concern stems in large part from the obvious job losses that will come about with a high carbon price in industries such as coal mining. What is often overlooked, however, is the potential for job creation in new industries and sectors. As a simple example, although there are roughly 50,000 coal miners in the United States whose jobs would be put at risk with ambitious climate policy, a report from the Energy Fut. Init./Natl. Assoc. State Energy Off. (2019) notes that some 335,000 employees worked full- or part-time in the solar industry in 2018 and another 111,000 workers were employed in the wind industry. Presumably these numbers would rise with ambitious national climate policy.

As part of their analysis of the United Kingdom's CCL, Martin et al. (2014) find that the climate levy was associated with an increase in employment, though it was imprecisely estimated. They conclude that a factor substitution effect (labor for energy) was driving the employment increase in UK manufacturing.

Yamazaki (2017) constructs employment data on 68 industries across Canadian provinces and territories for the years 2001–2013 to investigate the impact of British Columbia's carbon tax on employment. In the aggregate, he finds a modest positive and statistically significant impact on employment, on the order of 0.75% annually. Jobs are shifting, however, from carbon- and trade-sensitive sectors to sectors that are less carbon and trade sensitive. Chemical manufacturing, for example, has the largest decline in employment, while health care has the largest increase.

Yamazaki's findings are corroborated by Metcalf & Stock (2020). Using the same set of countries discussed above, they find no impact of carbon taxes on EU country total employment growth rates or on manufacturing growth rates.

In summary, the evidence suggests there would be significant job shifting in response to a carbon tax, but overall employment is likely to be relatively unchanged and could, in fact, rise.[24] This is a point worth stressing given political concerns around the economic and job impacts of carbon pricing in general and carbon taxes in particular.

Another concern is the impact of a carbon tax on economic growth. Metcalf (2019a) runs Canadian province–level difference-in-difference regressions over the 1990–2016 time period on GDP as a function of various covariates, including controls for the British Columbia carbon tax. Regressions show a positive impact on GDP on the order of 4–8%, though it is not statistically significant in all regressions. The British Columbia carbon tax revenue was recycled through lump-sum grants and reduced income tax rates with some revenue specifically earmarked for lower-income households that are likely to have higher marginal propensities to consume out of income. He also ran regressions on GDP in the EU countries using variation in the use of carbon taxes to reduce emissions in sectors not part of the EU ETS. Estimated coefficients are positive, albeit not

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[24] This empirical evidence is supported by modeling results reported by Hafstead & Williams (2018).

statistically significant. The evidence from British Columbia and the European Union may not demonstrate a large positive impact of a revenue-neutral carbon tax on GDP, but it also does not support claims that a carbon tax will significantly reduce economic activity in a country. Metcalf & Stock (2020) find a similar result looking at the EU countries with carbon taxes in place. Their approach identifies the tax impact by focusing on the response to tax changes not predicted by previous tax changes or growth rates of GDP (or employment). Unlike difference-in-difference regressions, their approach does not rely on identifying an exogenous control set or an assumption of preexisting parallel trends.

4.3. Distributional Considerations

A common concern with a carbon tax is that it will adversely impact low-income households. This is based on the fact that energy is a necessary good and comprises a higher share of household budgets for low-income households than for high-income households. Early work that focused on consumer spending patterns (a use side analysis) buttressed this view (e.g., Metcalf 1999, Grainger & Kolstad 2010, among others). This literature missed two important elements of the distributional impacts of the tax. First, the tax will affect factor prices as well as consumer prices. If returns to capital fall more than wages, then the carbon tax will have a progressive aspect on the sources side. Another factor contributing to progressivity on the sources side is the existence of indexed transfers that are disproportionately important for lower-income households. Goulder et al. (2019) show in a computable general equilibrium analysis that the source side effects fully offset the use side effects, so that the carbon tax, even when ignoring the use of revenue, is distributionally neutral to slightly progressive. This progressive sources side impact was first identified by Rausch et al. (2011a), while Fullerton et al. (2011) highlighted the importance of transfers.

Metcalf (1999), among others, has argued that one should focus on the distributional effects of carbon tax reform, by which I mean the package of a carbon tax and the use of the proceeds, whether it be new spending, tax cuts, or cash grants to households. Distribution of the carbon revenue through an equal per capita cash grant—as proposed by, for example, the Climate Leadership Council—would be highly progressive. Distributional tables from a US Department of the Treasury research article (Horowitz et al. 2017) illustrate this. **Figure 3** shows the carbon tax ignoring the use of revenue. The Treasury's analysis finds it is progressive up through the seventh and eighth deciles. It then turns regressive in the top deciles. With the equal per capita rebate, shown in **Figure 4**, the tax reform is sharply progressive. In fact, households up through the 70th percentile are better off, in the sense of receiving more in the rebate than the effects on disposable income through source and use side effects. Note, however, that these graphs are showing average distributional effects at each decile. Various researchers have noted that there can be considerable heterogeneity within a decile (Rausch et al. 2011a, Cronin et al. 2019). Given the variation in mix of fuels for electricity generation as well as driving patterns across the country, there is also considerable geographic heterogeneity in impacts (e.g., Hassett et al. 2009, Rausch et al. 2011a,b).

5. DESIGN CONSIDERATIONS

Numerous publications describe how to design a carbon tax in practice. See, for example, those by Metcalf & Weisbach (2009), Horowitz et al. (2017), and Metcalf (2017, 2019b). Because a carbon tax is an excise tax on coal, natural gas, and petroleum products, it can piggyback on existing fuel excise taxes (for petroleum and coal). The tax on the carbon content of natural gas could be easily levied on major consumers of natural gas (electric power plants, large industrial users,

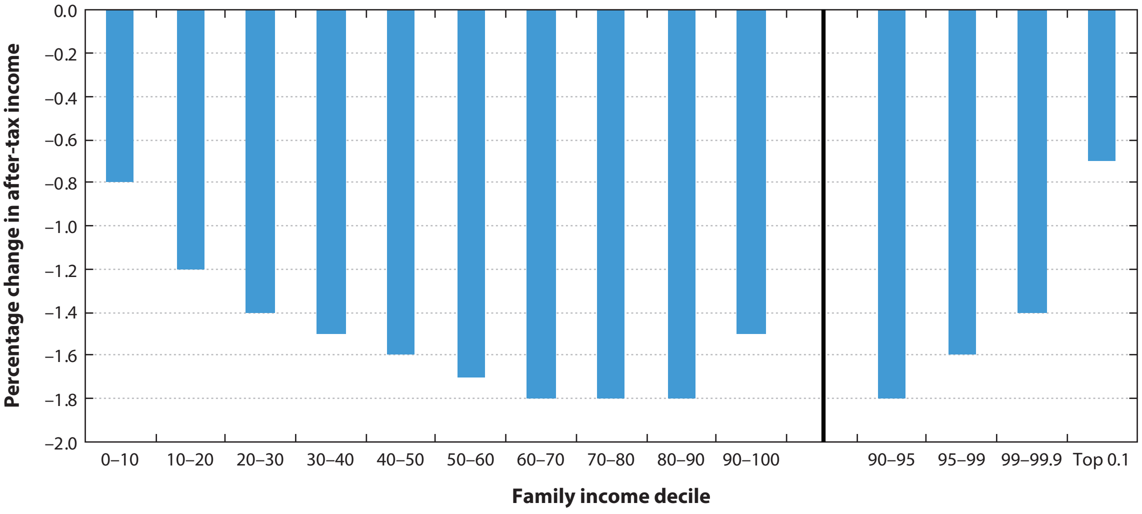

Figure 3

Carbon tax burden, ignoring the use of revenue. Families are sorted into deciles by family cash income. Readers are referred to Horowitz et al. (2017) for more information on income distribution. Underlying data come from the US Treasury Distribution Model, as reported by Horowitz et al. (2017, table 5).

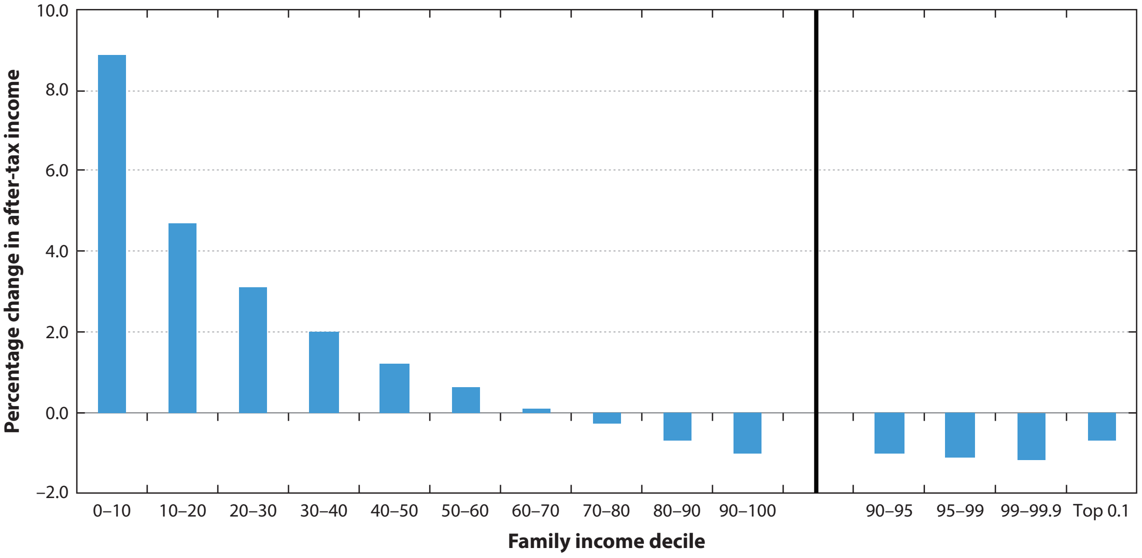

Figure 4

Carbon tax burden, with revenue recycling through equal per capita rebates. Families are sorted into deciles by family cash income. Readers are referred to Horowitz et al. (2017) for more information on income distribution. Underlying data come from the US Treasury Distribution Model, as reported by Horowitz et al. (2017, table 6).

and local natural gas distribution companies). Based on the analysis carried out by Metcalf & Weisbach (2009) for the United States, additional process emissions could be included in the tax base such that roughly 85% of US GHG emissions (excluding forestry and land-use changes) could be covered by a carbon tax.

Any tax collected on fossil fuels burned in a facility that captures the CO_2 and stores it in an approved manner should be exempt from the tax (if the facility is legally responsible for paying the tax) or should be able to claim a refundable credit (if the facility purchases fossil fuels on which a tax was levied prior to purchase by the facility). Similarly, CO_2 removed from the atmosphere through direct air capture should be eligible for a subsidy equal to the carbon tax rate. Keith et al. (2018) estimate the technology could be profitable at a price per ton of CO_2 between $94 and $232.[25]

5.1. Setting the Tax Rate

Given the range in carbon tax rates around the world, how should a country set the tax rate if it implements a carbon tax? Pigouvian theory suggests the tax on carbon pollution should be set equal to the marginal damage from one more ton of CO_2 emissions.

In a world with preexisting market distortions, economists have argued that the optimal tax on pollution (of any type) will typically be less than the marginal damage.[26] Specifically, the optimal tax equals the marginal damage of pollution divided by the marginal cost of public funds. The larger are the tax distortions, the larger is the marginal cost of public funds and the smaller is the optimal tax relative to marginal damage.[27]

Whether one uses a first- or second-best Pigouvian approach, policy makers need an estimate of the marginal damage from CO_2 emissions. They could base their estimate on some estimate of the analyses of the social cost of carbon as done using one or more integrated assessment models.[28] Although useful, these models suffer from our imperfect state of knowledge about the full range of damage and risks of catastrophic events—events with a high impact but low probability.[29] With

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[25] Lemoine (2020) notes that with large amounts of negative emissions, the payment outflows could overwhelm carbon tax collections. He proposes a tradable bond called a carbon share that prices carbon and addresses this problem.

[26] The first articles to make this point were those by Bovenberg & de Mooij (1994) and Parry (1995).

[27] See Bovenberg & Goulder's (2002) review of the literature on second-best environmental taxation and, in particular, section I. As a central case, Bovenberg & Goulder (1996) estimate the marginal cost of public funds to equal 1.25, which suggests that the optimal tax on pollution should be 20% lower than social marginal damage. The first-best rule that sets the tax on pollution equal to social marginal damage can be recovered if households have identical tastes, leisure is weakly separable from pollution and private goods, and a nonlinear income tax can be imposed such that the benefits of the pollution tax are exactly offset by the income tax to achieve distributional neutrality. See, for example, Kaplow (1996) and Pirttila & Tuomala (1997). As Bovenberg & Goulder (2002) point out, these conditions—especially the last—are unlikely to be met.

[28] In the United States, the Interagency Work. Group Soc. Cost Carbon (2010) developed a methodology for including the costs of GHG emissions in regulatory analysis; see also Natl. Acad. Sci. Eng. Med. (2017). Addicott et al. (2019) develop a model that calculates an optimal global carbon price while allowing for long-term social discount rates to differ across countries.

[29] Much has been written on the implications of high-impact, low-probability events—sometimes referred to as fat-tail events. See Wagner & Weitzman (2015) for a lively summary of the literature and a clear statement of the view that climate policy should be viewed as an insurance policy rather than as a Pigouvian price adjustment.

this caveat in mind, a tax rate based on the social cost of carbon would be roughly \$50 per metric ton of CO_2 in 2020.[30,31]

A second approach would be to set a tax rate to hit a revenue target over a 10-year budget window. The US Treasury study projects that a carbon tax starting at \$49 a metric ton in 2019, and rising at 2% (real) annually, would raise \$2.2 trillion in net revenue over the 10-year budget window (Horowitz et al. 2017). This is net of reductions in other tax collections due to the carbon tax.

Alternatively, a sequence of tax rates could be set over time to achieve a given reduction in emissions by some date. International climate negotiators have historically focused on a global goal of reducing emissions by 80% relative to 2005 by 2050. The United States set this as an aspirational goal in the promises it made in 2015 as part of the international climate negotiations that led to the Paris Agreement. Economic and engineering analyses suggest that an 80% reduction by 2050 is possible but would require significant advances in technology along with strong political will.[32] More recently, climate groups have focused on a goal of net-zero emissions by 2050.[33] Whether policy makers settle on an 80% reduction by 2050 or some other target, a carbon tax will likely be designed with some emissions reduction target in mind. I discuss emission reduction targets further in Section 5.4.

5.2. International Trade

A major objection to a unilaterally imposed carbon tax is that it would simply lead firms to relocate carbon-intensive activities abroad to countries with lower or zero prices on CO_2 emissions. This suggests the need for some form of border tax adjustment for imports and exports. Ideally, a country would tax the carbon content of all imports and exempt from taxation the carbon content of all exports. Doing so would tax emissions associated with domestic consumption. Taxing fossil fuel imports (and rebating the tax on exports) is straightforward and should be part of the tax design. Taxing the embedded CO_2 in imported goods and services is more difficult. Looking at the United States, Gray and Metcalf (2017) document that roughly 95% of the value of manufacturing shipments has very low carbon content. We need only concern ourselves with a handful of carbon-intensive intermediate and final goods. Determining the carbon content of selected imports is a nontrivial task, and Metcalf & Weisbach (2009) propose setting the tax on the basis of the emissions content of similar domestically produced carbon-intensive goods.

Kortum & Weisbach (2017, p. 440) argue that implementing border tax adjustments will be a "daunting prospect" and that there needs to be a very strong rationale for their use before relying

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[30] The \$50 figure is based on the estimate by the Interagency Work. Group Soc. Cost Carbon (2016) for 2020 equal to \$42 in 2007 dollars. I have converted the estimate to 2020 dollars using the Consumer Price Index deflator. Pindyck (2017) is a prominent critic of using integrated assessment models to set the tax rate on carbon dioxide.

[31] Daniel et al. (2019) argue for a high initial price on emissions that declines over time. The initially high price is to provide insurance against high-cost damages initially, and the declining price reflects the benefits from technological advances that reduce mitigation costs.

[32] Heal (2017) argues that an 80% reduction by 2050 could be achieved at a reasonable cost. His scenario, however, requires strong financial incentives and political support along with significant reductions in the cost of renewables and battery storage.

[33] See, for example, the European Climate Foundation's Net-Zero 2050 initiative at **https://europeanclimate.org/net-zero-2050/**.

on them (a rationale they find lacking). In particular, they point out that the decisions of which goods, which emissions, and which countries to include in border adjustments each involve difficult problems of administration that significantly complicate any practical application of border adjustments if one actually cares that ensuring the emissions associated with imported goods are actually taxed.

Cicala et al. (2021) address this problem by proposing a mechanism that incentivizes foreign firms to self-disclose the carbon content of the goods exported to carbon pricing countries as a form of "virtuous adverse selection." Initially, the least carbon-intensive firms have an incentive to self-disclose to obtain a lower tax rate on goods imported into carbon taxing countries. The border adjustment for that country is then adjusted upward by subtracting those certifying firms from the calculation of the border adjustment. This incentivizes more firms to self-disclose, leading to an increase in the border adjustment for remaining noncertifying firms, and so on. In the limit, all firms would self-disclose and verify their emissions.

As an alternative to a border tax adjustment, Nordhaus (2015) has put forward the idea of a "climate club." Developed countries (or any group of major countries, for that matter) that have enacted carbon pricing rules (either through a tax or cap-and-trade system) with a price above a given floor could band together and impose trade sanctions on countries that do not take effective action to reduce emissions.[34]

5.3. Other Policies

A carbon tax is an essential policy tool for reducing GHG emissions. Additional policies, however, will be needed as part of an efficient policy portfolio. First, regulations will be required to reduce emissions from GHG sources that are not easily covered by a carbon tax. This includes certain agricultural and other land-use activities and certain production activities including, for example, methane emissions from oil and gas production.

In addition, various regulatory and other institutional barriers impede the transition to a zero-carbon economy. This can be especially important in countries with federal systems of government that share governance between national and subnational governments. In the United States, for example, resistance by states to interstate transmission lines passing through their state can limit the use of zero-carbon electricity (e.g., wind from the Midwest and hydropower from Canada).[35] The lack of clear legal and financial liability rules for carbon capture and sequestration will also impede the growth of this technology when and if it becomes cost-competitive.[36]

Finally, a country's transition to a zero-carbon economy will require new inventions and production processes. Research and development will be key to the successful diffusion of these technologies. Information and new knowledge are pure public goods that are underprovided in a market economy. A carbon tax should be complemented with a major increase in zero-carbon energy research to help develop cost-effective replacements for fossil fuels.[37]

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[34] Nordhaus (2015) argues that nonparticipating countries could be punished with carbon tariffs or a uniform tariff on all imported goods to club members. He finds that a modest uniform tariff is more effective at promoting club membership than a carbon tariff. How Nordhaus's club idea would dovetail with the existing international trade order overseen by the World Trade Organization is unclear.

[35] Joskow & Tirole (2005) point out other barriers and market failures that lead to suboptimal investment in transmission lines.

[36] The Natl. Acad. Sci. Eng. Med. (2019) lays out a research agenda to address the various barriers and high costs of carbon capture and storage.

[37] At the same time, other policies can be eliminated, as discussed by Williams (2019).

5.4. Emission Reduction Goals

A reasonable concern with a carbon tax is that it does not provide any assurance that a desired emission reductions target will be achieved. An extreme view is that the tax simply allows firms to pay to continue polluting (Sandel 1997). While the extreme view fails to recognize the role that price signals can play in reducing emissions, it is true that a carbon tax does not directly limit emissions. Metcalf (2020) has proposed a simple mechanism to increase the likelihood that a given emission reduction target will be met over some control period (e.g., 15 years). His emission assurance mechanism (EAM) proposal would include in any carbon tax legislation a clear and transparent rule for adjusting the tax rate over time to hit emission reduction benchmarks, as also set out in the legislation. This would provide greater assurance that the United States would hit desired emission reduction targets while still providing the price predictability that the business community needs.[38] In effect, an EAM incorporates the targeting properties of a cap-and-trade program in a carbon tax, thereby creating a hybrid carbon tax.[39]

Other approaches include the structured discretion approach of Aldy (2019). Aldy proposes a streamlined legislative approach to reduce the risk of political obstacles to revising the tax rate in response to new information. Murray et al. (2017) note that tax adjustments, regulatory flexibility, and/or revenue spending flexibility to purchase additional emission reductions are all approaches that could be used to provide greater emissions reduction certainty with a carbon tax.

6. CONCLUSION

A carbon tax is a key element in a cost-effective suite of policies to reduce a country's GHG emissions. Implementation, administration, and compliance costs are significantly lower than alternative policies to reduce emissions. This review highlights issues that have recently attracted the attention of researchers on which additional research would be beneficial. Those include (*a*) the role of border adjustments in a unilaterally imposed carbon tax, (*b*) hybrid carbon tax systems that increase the likelihood of hitting desired emission reduction targets, (*c*) the optimal price path for a carbon tax, and (*d*) the growing empirical literature on the economic impact of carbon taxes.

With 30 carbon taxes in place around the world, a carbon tax is moving from a theoretical construct to a political reality. Although a carbon tax will entail costs to the economy, the evidence to date indicates that a carbon tax need not impose large costs on an economy and that the costs of inaction far outweigh the costs of effective climate policy.

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The author is not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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[38] Metcalf's proposal builds on work by Metcalf (2009) and Hafstead et al. (2017).

[39] The Climate Leadership Council includes an EAM in one of its four pillars of their carbon tax and dividend plan. See **https://www.clcouncil.org/our-plan/**.

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