RFF REPORT

Implementing a Carbon Tax

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Abstract

This report updates earlier work by Metcalf and Weisbach (2009) on design considerations for a national carbon tax. It maintains that 75 to 85 percent of US greenhouse gas emissions could reasonably be covered by a carbon tax. In contrast to the earlier paper, it argues that natural gas should be taxed downstream, given the large fraction of marketed gas that does not go through processing plants. The report also describes various approaches to setting the tax rate on emissions and suggests that a Pigouvian approach where the tax rate is periodically updated to reflect new estimates of the social cost of carbon (and other greenhouse gases) reasonably approximates the optimal nonlinear carbon tax. Finally, it discusses the interplay between federal and state carbon pricing policies.

Key Words: carbon tax, climate change, fiscal policy

JEL Codes: H23, Q48, Q58

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Contents

1. Introduction

A considerable body of literature has been written on the benefits of pricing carbon. Generally speaking, the focus has been on cap-and-trade schemes and carbon taxes. A prominent example of the former is the American Clean Energy and Security (ACES) Act (better known as the Waxman-Markey Bill), which passed the House of Representatives in 2009 but failed to pass in the Senate. Less detailed design work has been done on implementing a carbon tax. A few papers have addressed this topic, most notably Metcalf and Weisbach (2009). This current report updates the Metcalf and Weisbach analysis, taking advantage of more recent data and covering some additional topics that were not included in that earlier paper.

This report makes the following points. First, setting the tax rate according to Pigouvian principles is feasible. With periodic updating of the tax rate based on the best estimates of the social cost of carbon and other greenhouse gases (GHGs), moreover, the tax would approximate the optimal nonlinear tax on GHG emissions. Second, the tax rate could also be set to achieve either targeted emissions reductions or revenue goals. The ability to design the tax to automatically adjust to hit emissions targets erodes the distinction between “price” instruments (e.g., a carbon tax) and “quantity” instruments (e.g., cap-and-trade programs). Third, in contrast to the recommendations of Metcalf and Weisbach (2009), downstream taxation of natural gas at the level of local distribution or the final consumer (for gas purchased directly from suppliers) covers a higher share of natural gas at a likely lower administrative cost than if the tax were administered at the processor level.

Fourth, energy-related carbon dioxide emissions constitute three-quarters of US GHG emissions. A tax on these emissions is reasonably straightforward to administer. Including other emissions is challenging, but it is possible that another 10 percent of GHGs could be taxed, bringing coverage up to 85 percent of total emissions. It is worth exploring whether there are cost-effective offset opportunities for the remaining noncovered emissions to effect further emissions reductions. Fifth, border adjustments for imported or exported fossil fuels are relatively straightforward. Capturing the emissions embodied in energy-intensive intermediate and final goods imported to the United States would be much more challenging. As in Metcalf and Weisbach (2009), I argue that border adjustments on goods from a select subset of energy-intensive trade-exposed sectors would be the way to proceed with the tax based on domestic emissions shares for like products.

Next, enacting a carbon tax would allow for the elimination of considerable burdensome regulation and contribute to the Trump administration’s goal of reducing regulatory burden. It would also raise revenue both directly from the tax and through the opportunity to eliminate a wide array of energy-related tax expenditures for both fossil and renewable energy sources. Finally, economic theory does not provide guidance on how federal and state carbon pricing programs should interact. An argument can be made for federal preemption of state-level carbon pricing programs on the grounds of the global nature of the pollutant and a view that the carbon price should not vary within the country. On the other hand, our federal structure allows for state-level variation in tastes for taxation, as well as multiple taxation of the same base at the state and federal levels.

2. Emissions by Source and Sector: Trends over the Past Decade

The United States provides an annual inventory of greenhouse gas emissions as part of its reporting obligations under the United Nations Framework Convention on Climate Change (UNFCCC). Conducted by the US Environmental Protection Agency (EPA), it is the most comprehensive analysis of US emissions available.[1] Total emissions in 2014, the most recent year available, were 6,870 million metric tons (MMT) of carbon dioxide equivalent (CO_2e).[2] Carbon dioxide emissions account for four-fifths of total GHG emissions, with methane and nitrous oxide accounting for an additional 15 percent. The other gases reported in the table have very high global warming potentials but are released in very small amounts and account for less than 3 percent of total emissions in carbon dioxide equivalents.

Total emissions have fallen by 6 percent between 2006 and 2014, with the largest drop in carbon dioxide.[3] Offsetting declines in emissions from carbon dioxide, nitrous oxide, PFCs, and sulfur hexafluoride are increases in methane and hydrofluorocarbon (HFC) emissions, the latter growing by one-third over this period. Methane emissions grew in part with the increase in domestic oil production arising with the fracking boom. While methane emissions from oil production rose, methane emissions from domestic natural gas production and distribution fell, in large part due to declines in emissions in distribution at the final stage of the natural gas chain from field to final consumer.

The share of carbon dioxide in total emissions is 4 percentage points lower in Table 1 than that reported in Metcalf and Weisbach (2009). The decline is for two reasons. First, updating the global warming potential (GWP) from the values used in the IPCC Second Assessment Report to those of the Fourth Assessment Report increased the importance of methane and HFCs in overall emissions. Reporting 2006 emissions using the updated GWP reduces carbon dioxide's share of overall emissions by 2 percentage points from the share reported by Metcalf and Weisbach (84.8 to 82.6 percent). Second, greater progress has been made in reducing carbon dioxide emissions than other emissions such that carbon dioxide's share fell to 80.9

[1] The Energy Information Administration (EIA) tracks energy-related fossil fuel carbon dioxide emissions on a monthly basis and updates the information more rapidly than EPA's data. EIA reports 5,406 MMT of CO_2 for 2014. This compares with 5,208 MMT of CO_2 reported by EPA. The difference has to do with the treatment of fossil fuel consumption by US territories (excluded by EIA but included by EPA), international bunker fuels (included by EIA but excluded by EPA), and a number of other measurement issues in the conversion from fuel units to GHG emissions units. See EPA (2016), Annex 4, for more information on the differences.

[2] Gases other than carbon dioxide are converted to an equivalent amount of carbon dioxide using the 100-year global warming potential (GWP), the amount of carbon dioxide that leads to the same increase in radiative forcing as one unit of the gas in question. EPA uses GWP values from the IPCC Fourth Assessment Report as per UNFCCC reporting rules.

[3] I focus on 2014 emissions relative to 2006 emissions, since Metcalf and Weisbach (2009) discussed how to implement a carbon tax based on emissions in 2006. This allows me to decompose any recommendations on tax design into components based on how emissions have changed in the eight-year period and on changes in technology or feasibility that might suggest a different approach than was proposed in the earlier paper. It is worth noting that the Obama administration committed at the Cancun climate negotiations in 2009 to reduce emissions "in the range" of 17 percent below 2005 levels by 2020. Emissions have fallen by 7 percent between 2005 and 2014.

percent in 2014 from its 2006 share of 82.6 percent.

Energy-related carbon dioxide emissions account for nearly 95 percent of CO_2 emissions and three-quarters of total emissions. Table 2 shows the sources of emissions and users of energy in 2014 for energy-related CO_2 emissions. Coal accounted for nearly one-third of energy-related carbon dioxide emissions in 2014. Over 95 percent of coal-related emissions occurred from the use of coal to produce electricity. Nearly all remaining coal-related emissions came from the industrial sector. As a share of total GHG emissions, coal's share has dropped from 29 percent in 2006 to 24 percent in 2014, reflecting in part the drop in energy-related CO_2 emissions as a share of total emissions. The other reason for the drop in coal's share of total emissions is the growing share of energy-related natural gas CO_2 emissions. The share of total GHG emissions from natural gas has risen from 16 percent in 2006 to nearly 21 percent in 2014. Petroleum's energy-related CO_2 share has also declined since 2006, falling from 34 percent to 30 percent in 2016. Petroleum continues to be the leading source of energy-related CO_2 emissions, with transportation accounting for 80 percent of these emissions.

The use of fossil fuels for electricity generation continues to be the single largest sectoral source of emissions, accounting for nearly 30 percent of total GHG emissions in 2014, down from 34 percent in 2006. Coal continues to be the major source of emissions for electricity, given its high carbon content per Btu of energy. While coal accounts for over three-quarters of energy-related CO_2 emissions, it accounted for less than 40 percent of electricity generation in 2014; natural gas, in contrast, accounted for 28 percent of generation but only 22 percent of energy-related CO_2 emissions.[4] This reflects the fact that coal has, on average, nearly twice the carbon dioxide emissions per million Btus of energy as natural gas: 210 pounds per million Btus versus 117.[5]

Transportation is the second-largest sectoral source of energy-related CO_2 emissions, accounting for one-third of energy-related CO_2 emissions and one-quarter of total GHG emissions. Petroleum accounts for over 97 percent of transportation emissions. Passenger cars and light-duty trucks account for 60 percent of transportation-related CO_2 emissions, with medium- and heavy-duty trucks and buses accounting for another 24 percent. These shares are unchanged since 2006.

Industrial CO_2 emissions account for one-sixth of energy-related CO_2 emissions and just over 10 percent of total GHG emissions, with natural gas responsible for over half of these emissions. Residential and commercial make up the remainder, accounting for less than 10 percent of total US GHG emissions. Natural gas is the predominant source of emissions from the residential and commercial sectors (80 percent of energy-related CO_2 emissions). Residential and commercial emissions are small shares of total emissions in large part because the bulk of energy consumption for these two sectors is in the form of electricity. If electricity-related emissions are allocated to the four final use sectors (residential,

[4] Nuclear power accounted for 20 percent of utility-scale generation, hydroelectric for 6 percent, and other renewables for 7 percent. Data are from Table 1.1 of EIA's Electric Power Monthly available at https://www.eia.gov/electricity/monthly/index.cfm and accessed on January 17, 2017.

[5] Emissions coefficients reported at http://www.eia.gov/environment/emissions/co2_vol_mass.cfm (accessed January 17, 2017).

commercial, industrial, and transportation), then residential and commercial emissions now account for roughly 15 percent of total GHG emissions. Industry's share of total GHG emissions grows from 12 to 20 percent, while transport's sector is unchanged at 25 percent.

The composition of energy-related CO_2 emissions depicted in Table 2 illustrates how sectoral climate policy in the Obama administration has managed to target the major emissions sources. Corporate Average Fuel Economy (CAFE) standards for cars and light trucks were extended out to model year 2025, and average new car and light truck fuel economy standards have been doubled, with average fuel economy targeted greenhouse gas reductions equivalent to a fuel economy goal of 54.5 miles per gallon by 2025. And for the first time, standards for heavy-duty trucks and buses were set, starting in model year 2014. This ensured that the bulk of emissions from transportation are subject to regulation and emissions curtailment.[6]

The Obama administration also released final rules in 2015 for carbon emissions from existing electric power generation through its Clean Power Plan. Implementation of the plan, which was designed to reduce emissions from the electricity sector by 32 percent relative to 2005 by 2030, was stayed by the US Supreme Court in early 2016 pending resolution of challenges to the rules in the Federal Court of Appeals. It is unclear what the fate of the Clean Power Plan (or CAFE, for that matter) will be under the Trump administration. Even if the Clean Power Plan is withdrawn or ruled unconstitutional, the Supreme Court has ruled that EPA has the authority to regulate carbon dioxide as a criteria pollutant under the Clean Air Act and directed the agency to revisit its previous ruling that EPA need not regulate carbon dioxide. Upon review, EPA decided that carbon dioxide should be subject to regulations and began a process that led, among other things, to the Clean Power Plan. Unless the law is changed or the agency determination that carbon dioxide must be subject to regulation is withdrawn, EPA continues to operate under the mandate to promulgate rules to limit carbon dioxide emissions.

The Obama administration's focus on the Clean Power Plan and enhanced and expanded CAFE rules meant that nearly three-quarters of energy-related carbon dioxide emissions would be subject to regulation. Accounting for other emissions, this works out to over half of total US greenhouse gas emissions. As detailed in *The President's Climate Action Plan*, released in June 2013, the Clean Power Plan and CAFE were just two of a number of initiatives to reduce greenhouse gas emissions (Executive Office of the President 2013). Other initiatives included promoting renewable energy investment and production through tax and cash incentives, loan guarantees, and energy efficiency programs; investment in research and development for new clean energy technologies; EPA's Significant New Alternatives Policy (SNAP), a program to identify alternatives for more

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6 Bunker fuels (fuels used in international travel by sea and air) continue to be unregulated. Emissions from these fuels total nearly 6 percent of transportation emissions. Note that bunker fuel emissions are not included in Table 2. The United States has participated in talks within the UN International Civil Aviation Organization (ICAO), which led to a 2016 agreement to implement a carbon reduction and offsetting mechanism to achieve carbon neutral growth from 2020 onward. See ICAO resolution and information at http://www.icao.int/environmental-protection/Pages/market-based-measures.aspx (accessed January 17, 2017).

hazardous chemicals; and initiatives to reduce methane and HFC emissions.[7]

Table 3 shows the top 15 emitting sources of greenhouse gases in 2014. The major energy-related CO_2 sources that account for 75 percent of total emissions have been discussed already. The remaining sources in the top 15 account for an additional 20 percent of emissions, for a cumulative share of 95 percent. Agricultural activities (soil management, enteric fermentation, and manure management) account for 8 percent of total emissions. Nitrogen naturally occurs in soils and is added through fertilization and decomposition of residual plant materials. It is released to the atmosphere in the process of farming, as well as through water runoff into nearly bodies of water. Emissions from nitrogen release through agricultural soil activities has increased by 2.8 percent since 2006. Enteric fermentation is methane release occurring as a natural part of the digestion process for certain livestock (e.g., cattle, sheep, and goats).

Non-energy-related industrial activity is responsible for 3 percent of total emissions. While not large, the emissions of HFCs as part of the substitution away from ozone-depleting substances has grown by one-half since 2006. In contrast, CO_2 process emissions from iron and steel production have declined by 20 percent over that period, in large measure due to the decreased domestic production of iron and steel.

Methane emissions also occur in the production of natural gas, petroleum, and coal, with the largest emissions occurring from natural gas. Despite the substantial growth in natural gas production in the United States, methane emissions associated with its production, transmission, and distribution have declined by 2 percent between 2006 and 2014. In contrast, the emissions from petroleum systems have grown by 36 percent over that period and now outstrip methane emissions from coal mining, which have grown by only 3 percent.

The list of the top greenhouse gas emitting activities is similar to the list for 2006 reported in Metcalf and Weisbach (2009). Cement manufacturing has dropped out of the top 15, as have N_2O emissions from mobile combustion. Emissions from cement manufacturing have declined by 17 percent between 2006 and 2014, in part due to a slowdown in construction following the Great Recession. Nitrous oxide emissions from mobile sources have been cut in half, in large part due to a tightening of pollution regulations for on-road vehicles over this time.

Not all fossil fuel consumption results in GHG emissions. Natural gas in particular and other fossil fuels less extensively are used as feedstocks in the production of various chemicals (see Table 4). Two-thirds of the carbon dioxide equivalent in fossil fuels used as feedstocks is not released to the atmosphere but rather permanently stored. For heavy oils and other residual petroleum used to make asphalt and road oil, nearly all the carbon dioxide is stored and not released. Feedstocks and asphalt/road oil are two uses of fossil fuels with significant storage. Roughly one-tenth of the greenhouse gases contained in fuels used as lubricants is also stored, while other products (coke, waxes, and other miscellaneous products) store modest amounts of carbon dioxide or other GHGs. Below, I discuss how to design the tax to ensure that stored carbon is excluded from the tax base.

Summing up, GHG emissions have fallen in the United States between 2006 and 2014.

[7] In October 2016, the United States, for example, joined 170 other countries in agreeing to amend the Montreal Protocol on Ozone Depleting Substances to phase out the production and use of nearly all HFCs, as reported by Vidal (2016).

Overall emissions have declined by 6 percent while carbon dioxide emissions have declined by 8 percent. The share of non–carbon dioxide emissions in total emissions has risen by 1.7 percentage points (17.4 to 19.1 percent), primarily due to a modest rise in methane emissions over that eight-year period, as well as a large rise in HFC emissions (though this is less significant, since HFC emissions account for only 2 percent of total emissions).

3. Setting the Tax Rate

A key question for policymakers is what the tax rate on carbon emissions should be and how it should adjust over time. The textbook answer is clear: The rate should be set equal to the social marginal damages from pollution (subject to a caveat in a world of second-best policy). This is the appropriate rate if the goal is to maximize economic efficiency. While I discuss that approach below, I also discuss other approaches to setting the tax rate that reflect the fact that the impetus to enact a carbon tax may be as much fiscal as environmental. If the policy goal underlying a carbon tax is to develop a revenue stream that can be used to finance new spending initiatives or replace existing revenue streams, then we may come to a different conclusion about the appropriate time profile of carbon tax rates.

Given the tension among environmental, fiscal, and political considerations, four different approaches could be taken to set the tax on emissions. The fourth approach is a balancing act among the first three approaches.

3.1. Pigouvian Approach

In the presence of an environmental externality, one approach to attain an efficient outcome is to set a price on pollution equal to the social marginal damages of pollution. This approach was first articulated by Arthur C. Pigou in his 1920 book *The Economics of Welfare*. Pigou advocated setting the tax rate on a pollutant equal to the incremental damage to society from one more unit of pollution. In the climate context, the incremental damage from one more ton of carbon dioxide emissions is called the social cost of carbon (SCC). In a world with no market failures or other economic distortions, Pigou's recommendation leads to the socially efficient level of greenhouse gas emissions where the incremental benefits of burning fossil fuels are exactly balanced against their incremental costs.

In a second-best world with preexisting distortions, the policy prescription is less straightforward. Papers by Bovenberg and de Mooij (1994) and Parry (1995) argue that in the presence of market distortions (e.g., preexisting taxes on income), the optimal tax on pollution should be less than the social marginal damage from pollution, with results from models using environmental tax revenue to lower income taxes suggesting the optimal rate is less than social marginal damages by 20 percent or more (see, e.g., Bovenberg and Goulder 2002 and the discussion in Congressional Budget Office (2013a)).

Kaplow (2012) argues that even in a second-best world with existing income taxes, the optimal tax on pollution should equal the social marginal damages from pollution.[8] Deviations of the environmental tax from social marginal damages, Kaplow maintains, result from income redistribution that is embedded in the environmental tax reform. To show this, Kaplow conceptually decomposes the imposition of an environmental tax into a

[8] Kaplow assumes that utility is weakly separable in labor and that there is no heterogeneity of preferences across individuals. Individuals, rather, differ only in wage rates. These are assumptions typically made in the literature on second-best environmental taxation.

two-step reform. Consider an equilibrium in which environmental taxes are not equal to social marginal damages.[9] In the first step, the environmental tax is imposed at a rate equal to social marginal damages. At the same time, the income tax is adjusted such that every individual's utility is unchanged compared with utility before the reform is undertaken. Assuming weak separability of labor supply, Kaplow argues that labor supply will not change and that this new equilibrium is a Pareto improvement over the initial equilibrium without Pigouvian taxation.

The second step of Kaplow's approach is to adjust the income tax from the hypothetical tax that was set to keep utility unchanged to the actual tax that is the outcome of whatever environmental tax reform is under consideration. This step will redistribute income among agents and create distortions on the labor supply dimension. The resulting deadweight loss implies that the optimal environmental tax should be reduced (to mitigate the distributional distortions) and thus leads to the result that the optimal tax falls below social marginal damages. Kaplow illustrates this point with an example from Goulder, Parry, Williams and Burtraw (1999), who consider an environmental tax reform where proceeds are distributed to maintain the real value of transfers in the tax and transfer system. Since transfers are disproportionately received by poorer households, this approach implicitly redistributes away from the rich and contributes to a labor supply distortion that leads to the optimal environmental tax rate being less than social marginal damages.

Kaplow's result on the optimal second-best environmental tax problem follows from the flexibility he has assumed in the change to the income tax system to hold utility constant with the first-best environmental tax. Practically speaking, where political constraints preclude any number of tax reforms and limit us to certain types of reforms (e.g., rate reduction, base broadening), the fact remains that the optimal environmental tax is likely to fall below social marginal damages. Kaplow's point is that the deviation of the tax rate from its Pigouvian prescription follows not from the distortionary aspect of the environmental tax itself (what Goulder 1995 has called the "tax interaction effect"), but rather from the implicit redistribution built into the tax reform under consideration.[10]

Where does that leave us? One possible approach is to compute the optimal carbon tax rate conditional on the specific tax and spending reform under consideration, recognizing that the optimal rate will deviate from social marginal damages in some fashion based on the nature of underlying redistributions. A second approach would be simply to ignore the complicating redistributional implications of the tax reform, noting that all tax reforms entail some amount of redistribution, and focus on setting the tax rate equal to social marginal damages. But that leads naturally to the next difficult question: What is the social marginal damage from GHG emissions?

Estimating the social marginal damages from GHG emissions is extraordinarily complicated. Carbon dioxide, for example, can persist in the atmosphere for hundreds of years. Thus any effort to measure the marginal

[9] This could be either because there are no environmental taxes or because they have been set at rates not equal to social marginal damages.

[10] The Congressional Budget Office (2013a) analysis of carbon taxation also notes that carbon leakage and any nonclimate benefits from the tax (e.g., local pollution impacts) will affect the optimal tax rate.

impact of a release of carbon dioxide today (otherwise known as the social cost of carbon) requires measuring damages far into the future and choosing the appropriate discount rate to convert all future damages into today's dollars. To measure damages from GHG emissions requires complex modeling that can track GHGs in the atmosphere and ocean, translate increased atmospheric concentrations of the gases into temperature increases, trace through other climatic impacts of higher temperature, and then measure damages from those changed climate conditions.

In 2009, the Obama administration's Council of Economic Advisers and Office of Management and Budget convened an Interagency Working Group on Social Cost of Carbon (2010) to develop an official social cost of carbon (SCC) for US regulatory impact analysis. The IWG chose three well-known integrated assessment models (DICE, FUND, and PAGE) and ran Monte Carlo simulations to address various uncertainties and to model different economic scenarios.

A key parameter linking atmospheric greenhouse gas concentrations to temperature increase is equilibrium climate sensitivity (ECS), which measures the long-run temperature increase from preindustrial age levels that would occur with a doubling of the concentration of atmospheric greenhouse gases from preindustrial levels. Based on its reading of the literature, the IWG selected a distribution for the ECS parameter and took random draws of this parameter. Then it added one ton of additional carbon dioxide into the model in a given year, tracked it over time, and measured the incremental damages under various assumptions about the future economy. Damages in the future were discounted back to the present using one of three discount rates (2.5, 3, or 5 percent real). For each discount rate and each of five economic scenarios, 10,000 draws of the ECS parameter were selected. For each assumed discount rate, each model was run 50,000 times (10,000 draws × 5 economic scenarios) for each year in which an additional ton of carbon dioxide was emitted. Results from the 150,000 runs for the three models were averaged, and mean social costs of carbon were reported for each year (as well as the 95th percentile value for the runs using a 3 percent discount rate).

Setting the tax equal to the social cost of carbon that has been constructed as described above is not, strictly speaking, the optimal Pigouvian tax. The IWG constructed estimates of the SCC under one of five different economic scenarios used in a Stanford University Energy Modeling Forum modeling exercise. The scenarios made projections about economic and population growth as well as emissions trajectories that were fed into the three integrated assessment models (IAMs) used by the Interagency Working Group for its calculations. Four of the five scenarios were "business-as-usual" scenarios that were projected to lead to atmospheric carbon dioxide concentrations of 612 to 889 parts per million (ppm) by 2100. The fifth scenario assumed lower emissions, targeting 425 to 484 ppm of CO_2 by 2100 (and an overall CO_2e concentration of 500 ppm).

Pigou's analysis suggests setting a tax on pollution equal to its social marginal damages at the optimal level of pollution. The SCC as constructed by the IWG is a measure of social marginal damages neither at current emissions trajectories nor at the socially optimal trajectory. Rather, it is a measure of some average of business-as-usual trajectories and some reduced—though not necessarily socially optimal—trajectory. It may well be that setting the tax equal to a measure of the SCC where the social cost is based on business-as-usual emissions (conditional on policies in place at the time the SCC is computed) and then periodically updating the tax based on the most current estimates of the

SCC will eventually lead to Pigou's desired outcome, where the tax is equal to social marginal damages at the optimal level of emissions. But it is not clear how long that would take and what the losses along the transition path would be (relative to the optimal tax rate trajectory). Despite this, I will refer to an approach that sets the tax equal to the SCC as constructed in a process similar to that of the IWG as a Pigouvian tax rate.

Table 5 shows estimates of the SCC from the 2016 update. The table reports the IWG's estimates of the social cost of carbon in various years. Focusing on the 3 percent discount case (the discount rate that the IWG advises using as a central case for regulatory impact analysis), the average value of damages of an additional ton of CO_2 emissions across the various models and scenarios is $42 in 2020, rising to $69 in 2050. Using a 5 percent discount rate rather than 3 percent reduces the estimate of the SCC by 60 to 70 percent. Lowering the discount rate from 3 to 2.5 percent raises the SCC by 40 to 50 percent. The final column reports the 95th percentile value of the SCC from the 3 percent discount rate scenario. Reporting this value is an effort to characterize potential "worst-case" scenarios, though it should be clear that reporting a 95th percentile value is not a proxy for high-damage catastrophic outcomes.

Metcalf and Stock (forthcoming) provide an assessment of the approach and note three critical aspects of the measurement of the SCC. First, the science on climate sensitivity is quite uncertain, with little progress having been made in the past 30 years in narrowing the range of uncertainty over the parameter's value (Weitzman 2015). Second, the scientific underpinnings of the functions relating temperature increases to losses in welfare (damage functions) are rudimentary and make heroic assumptions in places. Moreover, very low-probability but high-damage events (catastrophes) are poorly modeled in a Monte Carlo scenario. By definition, a catastrophic event happens with such low probability that sampling approaches cannot properly account for them.

Third, the present value of cumulative future damages is highly sensitive to the choice of discount rate, given the long-lived nature of climate pollutants. Economists use one of two approaches for selecting an appropriate discount rate: positive approach based on observation of market interest rates and a normative approach based on the cross-generational valuation of consumption from Ramsey-style growth models. Unfortunately, the two approaches give very different discount rates that can lead to very different estimates of the social cost of carbon.

Given these difficulties with constructing estimates of the social cost of carbon from integrated assessment models, Pindyck has argued that IAMs are "of little or no value for evaluating alternative climate change policies and estimating the SCC" and that the models suggest "a level of knowledge and precision that is nonexistent, and allows the modeler to obtain almost any desired result because key inputs can be chosen arbitrarily" (2013, 870).

Because of the complexity involved in estimating the social cost of carbon or any greenhouse gas, the IWG asked that the National Academies of Sciences (NAS) convene a committee to assess and make recommendations for improving the process for developing an official SCC. The NAS committee was tasked with making specific recommendations "on potential approaches that warrant consideration in future updates of the SCC estimates, as well as research recommendations based on their review that would advance the science in areas that are particularly useful for estimating the SCC" (NAS 2017, 35–36).

The committee recommended that a single model be used for estimating the SCC, rather than averaging results from multiple models. It went further to suggest that the IWG should support a process to develop a scientifically sound and transparent approach to modeling the SCC that can account for important uncertainties in our scientific understanding of key parameters. Further, the committee recommended that a modular approach to modeling the SCC be taken and specifically that four modules be developed that would be used to estimating the SCC: (1) a socioeconomic module to project population and gross domestic product (GDP) that would serve as inputs for estimating emissions; (2) a climate module to take GHGs from the socioeconomic module and project climate impacts including temperature changes; (3) a damages module to project and, where possible, monetize damages; and (4) a discounting module to convert a stream of future monetized damage estimates into a present value from which an SCC could be constructed.[11] Finally, the committee recommended a regular updating process that would review and update modules periodically and provide new and updated estimates of the SCC on a roughly five-year basis.

Recognizing that the approach taken by the IWG to estimate an SCC was based on projected emissions pathways (as opposed to the optimal pathway), the NAS committee stressed that the SCC constructed based on the NAS committee's approach is designed specifically for use in regulatory impact analysis and not as an approach for setting an optimal tax rate in a carbon tax.[12] While this is an important caveat to keep in mind, it is very likely that any government estimate of the SCC will factor heavily in any carbon tax proposal that is setting tax rates to correspond (albeit roughly) to the damages from emissions.[13] And to be clear, the modeling approach for estimating an SCC could be adapted to estimate the optimal tax rate on carbon subject to all the uncertainties that go into estimating the SCC. Given those uncertainties and the likely improvement in our understanding of the various factors that go into estimating the social marginal damages from GHG emissions, any process that sets a carbon tax based on estimates of the social marginal damages of emissions should include a regular and institutionalized updating process that is both transparent and scientifically sound.

However a carbon tax rate is set, the tax itself would be levied on fossil fuels in a similar manner as existing excise taxes on fossil fuels. The tax therefore would have to be converted from a tax per ton of carbon dioxide to a tax per unit of each fossil fuel. Fortunately, the amount of carbon dioxide emitted when fossil fuels are burned is straightforward to calculate and does not vary appreciably for given fossil fuels. Table 6 shows the carbon dioxide content and the carbon tax rate converted to units of fuel for

[11] While I refer to a social cost of *carbon* here, the committee had in mind estimating social costs of all important GHGs. In fact, the IWG changed its name to become the Interagency Working Group on the Social Cost of Greenhouse Gases in 2016.

[12] It also noted that the probability-based approach to estimating an SCC is better suited to regulatory impact analysis than to optimal tax design.

[13] Senators Whitehouse (D-RI) and Schatz (D-HI) cosponsored the American Opportunity Carbon Fee Act (S. 1548) in June 2015 and proposed to start the fee at the administration's central estimate of the social cost of carbon. See press announcement at https://www.whitehouse.senate.gov/news/release/sens-whitehouse-and-schatz-unveil-carbon-fee-proposal-at-american-enterprise-institute.

various fossil fuels for a carbon tax set at $40 a metric ton.

3.2. Environmental Targeting Approach

A second possible approach sets tax rates to achieve a given reduction in emissions (relative to a baseline) or cap on emissions in one or several years. One possible cap in the near term could be the Obama administration's pledge in the Paris Climate Agreement to reduce emissions "by 26–28 percent below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%." Another, far more ambitious pledge would be an 80 percent reduction in emissions by 2050 below 2005 levels. This latter target is often cited as necessary to avoid temperature increases of 2 degrees C over this century and was put forward as a goal for developed countries at the 2009 Group of Eight (G8) summit in L'Aquila, Italy.

To operationalize this approach, Congress could set a schedule of tax rates that are consistent with consensus modeling results that show tax rate trajectories leading to the desired emissions reductions. Some preliminary work by Yuan, Metcalf, Reilly and Paltsev (unpublished manuscript) suggests that a policy designed to achieve the reduction pledged by the Obama administration for 2025 combined with an 80 percent reduction by 2050 would require a tax rate that initially grew rapidly from a low level (in the neighborhood of $8 a metric ton) until 2025, and then grew at an annual rate in the range of 9 percent. Yuan et al. note that the tax rate trajectory depends importantly on advances in abatement technology between now and 2050. It is important to stress, however, that there is considerable uncertainty as to the required tax rate trajectory that would be required for an ambitious and long-range goal such as an 80 percent reduction in emissions by 2050. The work by Yuan et al. is preliminary, and it is likely that different models will come to possibly very different tax rate trajectories for such a goal. Thus one should be cautious before signing on to a tax rate path to address distant or highly ambitious emissions reduction goals.

3.3. Revenue Targeting Approach

A third possible approach would set a revenue target for the carbon tax, perhaps over a 10-year budget window. The revenue could be an element, for example, of a broad-based tax reform where carbon tax revenue is used to help pay for tax reductions elsewhere in the tax code. In its 2013 report on budget options for reducing the federal deficit, the Congressional Budget Office (2013b) estimated that a carbon tax starting at $25 per ton in 2014 and growing at an annual real rate of 4 percent would net just over $1 trillion over the 2014–2023 budget window. A more recent US Treasury study by Horowitz, Cronin, Hawkins, Konda and Yuskavage (2017) estimates that a carbon tax starting at $49 a ton in 2019 and rising at a real growth rate of 2 percent annually could raise $2.2 trillion in net revenue (net of reductions in other tax collections due to the carbon tax).

A revenue targeting approach highlights the fiscal benefits of a carbon tax. In other words, the carbon tax provides a source of revenue that can be used to address other fiscal needs, whether it be reducing the federal budget deficit—the subject of the 2013 CBO report—or paying for reductions in tax rates in the personal or corporate income tax.

An obvious question is how high a carbon tax rate can be set before carbon tax revenues begin to decline. This is reminiscent of the famous Laffer curve for income taxes. During a 1974 lunchtime discussion, Arthur Laffer reportedly sketched a curve on a cocktail napkin that showed income tax revenues growing from zero as the tax rate is raised from zero and eventually peaking at some tax rate. Past that rate, revenues begin to fall until at some very high tax rate, revenues go to zero as taxpayers find ways to avoid (or evade!) income taxes. The idea is uncontroversial. At a zero tax rate, a tax collects zero revenue. And at a sufficiently high rate, revenues would also be zero (imagine an income tax rate of 200 percent, for example, where taxpayers are required to pay twice their income in taxes). What is less clear is where the revenue peak occurs. While Laffer argued that the US tax code was to the right of the revenue peak in the mid-1970s, subsequent research suggests that we are well to the left of the peak (e.g., Fullerton 1982).

Just as there is a Laffer curve for income taxes, there is also one for carbon. Given existing technologies, the peak of the carbon Laffer curve is quite high—perhaps over $500 a ton (Yuan et al.). The revenue-maximizing carbon tax rate can be defined in terms of carbon tax revenue alone or in terms of total tax revenue. As the carbon tax rate grows, income and payroll tax revenues would be affected so that the revenue-maximizing carbon tax rate—when defined in terms of total tax revenue—could be considerably lower than the carbon tax revenue-maximizing rate. Initial results from modeling by Yuan et al. suggest that a carbon tax that starts at $20 a ton in 2015 and grows at an annual rate of 5 percent (real) would increase total tax collections over the first half of this century. The caveat above to be cautious in accepting results from modeling of ambitious policy far into the future applies here as well.

In addition, constructing a carbon Laffer curve is made more complicated by the uncertain way that carbon prices will interact with technological development. At high carbon prices, firms have incentives to develop carbon-free energy technologies. The process by which high energy prices spur research and development that leads to new inventions, processes, and technologies that make carbon-free technologies cost-effective is known as induced innovation. While economists do not doubt the existence of induced innovation, all agree that one cannot predict when breakthrough zero-carbon technologies will occur.

The sudden emergence of a breakthrough technology would lead to an abrupt drop in carbon tax revenue as the new technology supplants fossil fuels. This is not the Laffer curve of the income tax, where a gradual increase in income tax rates leads to a revenue plateau after which revenues fall. Rather, this would be a sudden collapse of the carbon Laffer curve, as carbon tax revenues go to zero for any positive carbon tax rate.[14]

Of course, a dramatic technological innovation that moves us to a carbon-free world is what we ultimately need if we are to solve the climate problem. But a carbon tax motivated by revenue considerations needs to take into account that this *is* the ultimate goal. So while we can certainly make a case for a carbon tax on revenue grounds, we should recognize its limitations as a long-term revenue source. Carbon revenues can likely contribute substantially to the federal budget for several decades, but we need to plan for the day when the carbon tax will no longer be a meaningful revenue source. When will that day come? It depends on how quickly we ramp up the carbon tax rate as well as spending on carbon-free energy research and development. With a robust climate policy, we might expect that day to come somewhere in the latter half of this century.

[14] Any loss in carbon tax revenues would be offset to a degree by increases in income tax revenues, given the sudden drop in the after-tax cost of energy to firms.

3.4. Environmental and Revenue Balancing Approach

In the end, Congress will set rates through some combination of competing goals and political forces. To build a coalition to get a carbon tax through Congress, a balancing of environmental, fiscal, and economic considerations needs to take place. This might lead, for example, to an initial carbon tax rate at a modest level motivated by a need for revenue for fundamental tax reform, to pick one example. Such an approach would hardly be embraced by environmental groups that support the Clean Power Plan's emissions reduction targets. One way to square this circle is through the inclusion of a mechanism to adjust the carbon tax rate automatically in response to observed emissions reductions. Such a mechanism would allow for adjustment of the tax rate in some fashion to achieve a given long-run target.[15]

This mechanism could take a number of forms. Hafstead, Metcalf and Williams (2016) describe a mechanism they call a Tax Adjustment Mechanism for Policy Pre-Commitment (TAMPP). A TAMPP is a provision in a carbon tax that automatically adjusts the tax rate to achieve a given long-run target. If emissions are on track to exceed some long-run emissions target, the tax rate automatically increases to increase the chances of meeting the long-run target. Building on the work of Metcalf (2009), a TAMPP would do the following:[16]

- set an initial tax rate and standard rate of growth for the tax at the outset;
- put forward benchmark targets for cumulative emissions for a control period, which could be 1, 5, or 10 years or some other time interval; and
- adjust the tax rate upward in a predetermined fashion if cumulative emissions exceed the benchmark targets (or cumulative abatement falls short of the target) at the specified benchmark date, or adjust the tax rate downward if emissions reductions exceed the targeted emissions reductions by the benchmark date.

Figure 1 shows the timing process for a TAMPP mechanism. At time zero, when the tax is enacted, a target for overall emissions (or emissions reduction relative to some benchmark, such as emissions in 2005) in a given year is put forward. This final target year might be 20 to 30 years in the future. Hafstead et al. (2016) caution against setting a final target too far into the future, given the inherent uncertainties of making commitments in the distant future and the credibility of achieving what would likely be very ambitious long-range targets (e.g., 80 percent emissions reduction by 2050).

The frequency of adjustment at interim benchmarks would depend on the type of adjustment that is built into the TAMPP process. More frequent adjustments would likely reduce the cost, since smaller adjustments would likely be needed. But it may be impractical to have overly frequent adjustments. Hafstead et al. (2016) discuss this in greater detail.

The Swiss carbon tax is an example of a TAMPP mechanism. Initially enacted in 1999, the law established a tax rate on emissions from electricity and heating and mandated that if emissions in a benchmark year exceeded a target (a given reduction in emissions relative to 1990 emissions), then the tax rate would rise in a preordained way. For example, if

[15] The idea of a self-adjusting carbon tax to hit long-run targets was first proposed by Metcalf (2009).

[16] This description draws on Hafstead, Metcalf and Williams (2016).

emissions exceeded 70 percent of 1990 emissions in 2012, the tax rate would automatically rise from 36 Swiss francs (CHF) to 60 CHF at the beginning of 2014. Interim targets were also set for 2014 and 2016 that would trigger tax rate increases in 2016 and 2018, respectively (Hafstead et al. 2016). The tax is currently 84 CHF and is scheduled to rise to either 96 or 120 CHF in 2018, once emissions levels relative to the benchmark for 2016 are known.[17]

Murray, Pizer and Reichert (2016) discuss additional ways in which greater emissions certainty could be built into a carbon tax. One approach would be to mandate a regulatory program as a backup should emissions reductions miss specified targets. For example, if a carbon tax were put in place to replace regulation under the Clean Power Plan, the authors note that the tax could include a trigger provision that would delegate to EPA authority to reinstate the Clean Power Plan if emissions reduction targets were not met. Another possible option the authors discuss is the use of some revenues from the carbon tax to pay for emissions reductions in noncovered sectors if emissions exceed specified targets.

Aldy (2017) describes another possible approach to updating a carbon tax in a predictable fashion through a process similar to the expedited regulatory process under the Congressional Review Act, among other precedents. Every five years, the president would recommend changes to the carbon tax based on a review process undertaken by the Departments of Treasury and State, as well as EPA. Congress would then take an up or down vote on the recommendation, with no filibuster or amendments allowed. Aldy argues that this approach balances the predictability of the price signal from the carbon tax against the need to incorporate new information about climate damages and costs of mitigation as it emerges. He also notes that his approach could complement the TAMPP-type approach discussed above.

The various approaches described above are efforts to address the uncertainties about ultimate emissions reductions, since a carbon tax sets a price on emissions but has no direct control over emissions. Just as safety valves and price floors limit price volatility in cap-and-trade programs and turn the cap-and-trade instrument into a hybrid of cap-and-trade and tax instruments, a TAMPP-type mechanism would add some emissions certainty to a tax and create another type of hybrid price-quantity instrument. Besides potential efficiency gains from such an approach, this hybrid approach within a carbon tax framework might help diminish concerns among some climate policy advocates that a carbon tax will not achieve desired emissions reduction targets.[18]

The discussion about a Pigouvian tax-setting approach above has focused on a linear tax system where the tax rate is set equal to social marginal damages of pollution. When there is no uncertainty in measuring marginal abatement costs or marginal damages, the Pigouvian approach with the tax rate equal to τ^* is economically equivalent to a cap-and-trade system where the allowance cap is set such that the clearing price for allowances

[17] See http://lenews.ch/2015/12/29/big-rises-in-swiss-carbon-tax-from-1-january-2016/ (accessed January 30, 2017).

[18] Hafstead et al. (2016) critique this view, pointing out, among other things, that a "pure" cap-and-trade program has an implicit safety valve built into it in the sense that if allowance prices rise to politically unacceptable levels, Congress could always act to issue more allowances and thus bring the price down.

equals τ^*. Weitzman (1974) shows that when there is uncertainty in measuring marginal abatement costs, the two instruments are no longer equivalent, and he derives conditions under which one of the instruments provides higher expected welfare on an ex ante basis. Studies typically find that a carbon tax provides higher expected welfare than a cap-and-trade system.[19]

Kaplow and Shavell (2002) show that once one allows for a nonlinear tax system, a cap-and-trade system can never provide higher expected net benefits than a carbon tax. The result is straightforward to show. Let q_t be emissions abatement in period *t* and $B(q_t, \eta_t)$ be the benefit function for abatement. The function *B* implicitly measures damages from GHG emissions, since a reduction in emissions ($q_t > 0$) reduces damages (a benefit). The term η_t is an unobserved shock to the benefit function. Abatement is costly and given by the function $C(q_t, \theta_t)$, where θ_t is an unobserved shock to the cost function. If the social planner could observe the cost shock before setting policy, she would choose a level of abatement (q_t) to maximize

(1) $$E_t\{B(q_t, \eta_t)\} - C(q_t, \theta_t),$$

where the expectation is taken over the unknown benefit shock variable. The Weitzman model assumes that the social planner must set policy (the level of q_t) before the cost shock is observed. Firms, on the other hand, will observe the cost shock before they choose their level of abatement. It can easily be shown that a nonlinear fee schedule of the form

(2) $$F(q_t) = E_t\{B(q_t, \eta_t)\}$$

will be socially optimal. This follows from the fact that a firm that observes the cost shock will choose q_t to maximize

(3) $$F(q_t) - C(q_t, \theta_t) = E_t\{B(q_t, \eta_t)\} - C(q_t, \theta_t).$$

The fee schedule has been designed such that the firm's profit maximization problem is the same as the social planner's problem.

What are the possible objections to a nonlinear fee schedule? One possible objection is perceived taxpayer complexity from having to confront a nonlinear tax schedule. By point of comparison, the personal income tax is a nonlinear tax over taxable income. The income tax deals with this by providing tax tables to determine a taxpayer's tax once taxable income is computed. While there is considerable complexity in the income tax, the complexity does not arise from the fact that we use tax tables to calculate our tax bill.

A second objection is that there are high information requirements to construct a tax schedule rather than a tax rate. The latter requires knowing only the social marginal damages from emissions in the neighborhood of current emissions. A schedule, on the other hand, requires knowing damages at all possible emissions levels. Here, the stock nature of the pollutant works to our advantage. To see this, it is helpful to define a fee schedule in terms of emissions (e) rather than abatement (q). Damages from GHGs are a function of the stock of GHGs in the atmosphere (S), and a fee schedule for firm *i* with emissions in year *t* equal to (e_{it}) would take the form

(4) $$F(e_{it}) = E\{D(S_{t-1} + e_{it}, \eta_t) - D(S_{t-1}, \eta_t)\}.$$

[19] Studies include Hoel and Karp (2002), Newell and Pizer (2003), and Karp and Zhang (2005). Pizer and Prest (2016) find that with banking and borrowing, cap-and-trade systems can, in certain circumstances, provide higher welfare than a tax, since banking and borrowing serves as a vehicle for future price expectations to influence current price, something that a tax cannot do.

Assuming emissions are small relative to the stock of gases in the atmosphere, we can approximate the fee by

(5) $F(e_{it}) = E\{MD(S_{t-1},\eta_t)\}e_{it} = G(S_{t-1},X_{t-1})e_{it}$

where the vector X contains information that helps determine the shape and location of the marginal damage function.

While interesting, it is not clear that a nonlinear carbon tax provides significant efficiency gains over a linear tax where the rate is set equal to social marginal damages. The key variables that would determine the value of the *G* function in equation (5) above (variables such as world GDP and atmospheric GHG concentrations, among others) change slowly over time, so there would not likely be much variation in the emissions multiplier, *G*, especially if the social cost of carbon (and other GHGs) were updated on a regular basis, as recommended by the 2017 National Academies of Sciences panel on climate damages. In effect, regular updating of the social cost of carbon would mean we are pricing carbon dioxide as if we had an optimal nonlinear carbon tax.

4. The Tax Base and Point of Implementation

Metcalf and Weisbach (2009) put forward a theory of the optimal tax base for a carbon tax where a balance is struck between the marginal benefits of expanding the base and the marginal cost of including harder-to-tax greenhouse gas sources. Their analysis suggests that roughly 90 percent of greenhouse gas emissions (exclusive of land use, land use changes, and forestry) could be covered at reasonable administrative cost. I revisit that analysis based on current emissions patterns, along with the question of the point of implementation of the tax.

4.1. Energy Related Emissions

Energy-related emissions in 2014 totaled 5,746 MMT and accounted for 84 percent of total US greenhouse gas emissions in that year. The bulk of that (91 percent) is carbon dioxide emissions from fossil fuel combustion. Methane emissions from natural gas and petroleum systems is a distant runner-up, accounting for 4 percent of energy-related emissions. Let me first consider carbon dioxide emissions from each of the fossil fuels in turn.

4.1.1. Petroleum

Carbon dioxide emissions from petroleum combustion accounted for nearly one-third of total US GHG emissions in 2014.[20] Theoretically, petroleum could be taxed at one of four logical points in the production and distribution chain: wellhead, refinery, terminal rack, or point of final sale.[21] Logically, the refinery or terminal rack is the practical point of taxation. Taxing oil at the wellhead is impractical, given the large number of active oil wells in the United States.[22] Similarly, the large number of retail gas stations, oil dealers, and other sellers of petroleum products makes taxing petroleum at the final point of sale cumbersome.[23] Taxing petroleum at the refinery is more practical. In 2016, there were

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[20] US Environmental Protection Agency (2016), Table 3-5.

[21] Under a wellhead approach, imported crude oil would be taxed on import. Under the refinery approach, imported refined products would also be taxed on import.

[22] *World Oil* magazine estimated over 600,000 active oil wells in the United States in 2014. See Abraham (2015).

[23] The 2014 Survey of US Businesses counts over 111,000 retail gasoline stations in the United States. See data at https://www.census.gov/programs-surveys/susb.html (accessed January 23, 2017).

139 operating refineries in the United States. As noted by Horowitz, Cronin, Hawkins, Konda and Yuskavage (2017), refineries are already responsible for remitting a tax on crude oil received at the refinery for the Oil Spill Liability Trust Fund (OSLTF) under Section 4611 of the Internal Revenue Code, so guidance on how to implement the tax is in place by simply applying the guidance for the OSLTF tax. If taxed at the refinery level, the tax would also need to be imposed on imports of refined products that enter the country and are not processed further by refineries. In addition, downstream firms that use refined products should receive credits for fuels burned where emissions are captured and stored. In addition, the tax should be rebated on exported fuels.

Alternatively, the tax could be imposed at the wholesale rack, the wholesale terminal that receives refined products from a refinery and dispenses them to trucks for sale to retail operations. This would be consistent with the tax administration of the federal motor vehicles excise tax and other excise taxes on refined products; taxes are generally paid by the wholesale rack facility upon sale of the fuel.[24] The advantage of a more upstream collection of the tax (at the refinery) is that it would tax petroleum used at the refinery for refinery operations. The disadvantage of taxing at the refinery is that a crediting mechanism would be needed to rebate the tax for GHGs that are permanently stored in various feedstock uses (see below), as well as for exported refined products.

[24] For guidance on excise taxes including all excise taxes on fuels, see IRS Publication 510, https://www.irs.gov/publications/p510/.

4.1.2. Natural Gas

Unlike petroleum and petroleum products, natural gas is not currently subject to a federal excise tax. As with petroleum, there are thousands of operating natural gas wells. While a small number of operators are responsible for a large share of natural gas production, it would be administratively burdensome to levy the tax on operators.[25] If not taxed at wellhead, the feasible options for point of taxation would be processing plants (upstream implementation) and local distribution companies (downstream implementation).

Natural gas is typically processed to remove impurities, water, and other liquids before it enters the pipeline network. As of 2014, there were 551 processing plants in the United States, according to data collected by EIA.[26] Imposing the tax on natural gas processers would be a plausible upstream option. However, while the amount of natural gas that is processed equals over three-quarters of marketed dry natural gas, not all processed gas is marketed. In particular, nearly all Alaskan natural gas is associated with oil production. It is processed in Alaska and then reinjected into oil fields, given the limited ability to transport and market this gas. After subtracting Alaskan processed gas from the US totals, only two-thirds of dry natural gas has gone through a processing facility. Figure 2 shows the trend since 1991 in the share of dry gas that has been processed. The

[25] Ernst and Young Global (2015) report that the top 50 companies produced 13.5 trillion cubic feet of natural gas in the United States in 2015. This represents just over 40 percent of gross withdrawals in that year.

[26] EIA collects data on the capacity, status, and operations of all natural gas processing plants on Form 757 every three years. The most recent survey was in 2014. See http://www.eia.gov/survey/#eia-757 for information on the survey.

share has fallen from a high of about 80 percent in the early 1990s to a low of 60 percent in 2011, before rebounding to 66 percent in 2015.

If processing plants were the point of taxation, it would be necessary to tax imported processed natural gas, as well as domestic gas that enters the pipeline without being processed. Taxing imports is straightforward to do, since there are a limited number of international pipeline entry points (23 from Canada and 3 from Mexico) and LNG import facilities (14), according to data from Energy Information Administration (2016). Taxing nonprocessed gas would be more difficult but not impossible. Either well operators or pipeline operators could be the point of taxation for natural gas that enters the pipeline network directly without processing.

The other option for the point of taxation would be farther downstream: The tax could be imposed on local distribution companies (LDCs) along with final users that purchase gas directly from suppliers rather than from LDCs. There are roughly 1,300 LDCs that sell gas directly to final consumers. LDCs (e.g., natural gas utilities) are typically subject to state regulation and provide both gas and local distribution services either by selling natural gas directly to customers or by acting as the distributors of gas that customers purchase from pipelines or other owners of gas. According to data from the American Gas Association, LDCs provide nearly all the natural gas consumed by residential and commercial customers, about half the natural gas consumed by industrial users, and just over one-quarter of the natural gas consumed by electricity generators.[27] Downstream implementation of the tax, therefore, could be on LDCs for its sales; on companies that operate natural gas electric generating plants that did not purchase gas from an LDC; and on industrial users that purchase natural gas directly from suppliers other than LDCs. No tax would be required on imports, nor would there need to be a tax rebate on exports or a credit for sequestered carbon in feedstocks with pricing at the LDC level.

4.1.3. Coal

As noted above, coal is primarily used for electricity generation, and 95 percent of energy-related coal emissions come from electricity generation. A tax on coal could easily be implemented at the mine mouth or at electricity generating plants, along with the small number of industrial coal users. According to EIA, 1,109 mines were active or temporarily closed in 2015. Of those mines, 775 were actively producing coal that year.[28] If a tax were levied at the mine mouth, a border adjustment could rebate the tax on exports and collect the tax on the modest amount of coal imported into the United States. Horowitz et al. (2017) note that taxing coal at the mine mouth could easily build on the existing tax guidance for the coal excise

27 The shares are for 2015 and were calculated from data at the American Gas Association website, https://www.aga.org/annual-statistics/energy-consumption (accessed January 18, 2017).

28 Data from EIA Form 7A and the US Mine Safety and Health Administration available at http://www.eia.gov/coal/data.php#coalplants (accessed on January 25, 2017).

tax imposed on the first sale of coal in the United States.[29]

If levied on coal use, the tax could be levied on coal-fired electricity power plants and industrial users. In 2015, there were 427 operable coal-fired power plants totaling 968 units in the United States, numbers considerably lower than documented in Metcalf and Weisbach (2009). The low price of natural gas and increased regulation of pollutants from coal plants have led to the retirement of a number of coal plants. Since 2010, 294 plants were retired, and few coal plants are being proposed.[30] While there are no existing excise taxes on coal levied on electric power generators and industrial users, GHG accounting procedures are in place under EPA's Greenhouse Gas Reporting Program, so it would not be administratively burdensome to coal users to comply with the tax.

4.1.4. Other Energy Related Emissions

Methane releases from natural gas and petroleum systems are the second-largest source of energy-related emissions, after CO_2 emissions from fossil fuel combustion, and account for 4 percent of energy-related emissions. Nearly all methane emissions in petroleum systems come from production field operations, including vented methane from wells and fugitive emissions from equipment or storage tanks. Petroleum-related methane emissions are roughly one-third the emissions from natural gas systems. As with petroleum systems, the bulk of methane emissions occur at the production stage (including gathering). Unlike petroleum, there is a significant share of emissions at the processing, transmission, and distribution stages—roughly 40 percent of total natural gas system methane emissions. It is not clear how one would bring petroleum and natural gas emissions into the tax base or whether the benefits of including them in the base would exceed the costs when compared with alternative ways of addressing these emissions (e.g., regulation).

If natural gas were taxed at the processor or wellhead stage, one possible way to address methane emissions in transmission, storage, and distribution would be to employ a deposit-refund scheme where natural gas would be taxed as it enters the pipeline system according to its methane content. Final users (LDCs and large industrial and electricity customers that purchase directly from the pipeline rather than LDCs) would receive a rebate equal to the difference between the methane and carbon dioxide rates. As an example, consider a processor that sells 1,000 thousand cubic feet (Mcf) of natural gas. Assuming a tax rate of $40 per metric ton of CO_2, the tax rate per Mcf of natural gas, assuming it is burned, would be $2.12. If released as methane, the rate would be approximately $61.48 per Mcf.[31] The processor would pay a tax of $61,480 on the 1,000 Mcf of natural gas sold. For purposes of illustration, assume 1 Mcf of natural gas leaks in transmission between the processor and an LDC. An LDC that sells 999 Mcf of natural gas would be eligible for a rebate of (61.48 – 2.12) 999 = $59,300.64. On net, $2,179.36 in taxes would be collected. This corresponds to

[29] The coal excise tax does not apply to sales of lignite or imported coal. The tax guidance on covered coal could easily be extended to these currently noncovered types of coal. Note that the tax would vary depending on the type of coal, as indicated in Table 6.

[30] Data from EIA Form 860 available at http://www.eia.gov/coal/data.php#summary (accessed January 25, 2017).

[31] This calculation uses the ratio of the social cost of carbon and the social cost of methane for a 3 percent discount rate, as provided in Table 6 of Marten, Kopits, Griffiths, Newbold and Wolverton (2015).

the tax on carbon emissions of $2.12*999 = $2,117.88 and the tax on the 1 Mcf of methane of 61.48.

A deposit-refund approach would address only those methane emissions in transmission. These emissions account for less than 20 percent of methane emissions from natural gas systems. While it may be technically feasible to use a deposit-refund system to address a portion of natural gas–related methane emissions, the benefits appear small relative to the costs of setting up such a system.

The next category of energy-related emissions (as categorized by EPA's Inventory of Greenhouse Gases) is nonenergy fuel use. This accounts for 2 percent of energy-related emissions in 2014. These emissions are associated with the use of fossil fuels in feedstocks and other uses that store some portion of the GHGs in the product. Table 4 provides information on stored emissions, and actual emissions of these products.

Fossil fuels are used as feedstocks in the production of plastics, rubber, synthetics, and other products, as well as in ammonia production. Roughly two-thirds of potential emissions are stored. Asphalt is the second-largest source of sequestered greenhouse gases, with nearly all of it stored. Sequestered greenhouse gases in lubricants and a few other assorted uses (e.g., waxes) make up the rest. Overall, nearly two-thirds of potential emissions from these nonenergy fuel uses are stored, and a carbon tax levied at the refinery level (for petroleum) or processor level (for natural gas) would need to allow a credit for sequestered gases in these products. If the tax were levied downstream (at the terminal rack and LDC, for example), then firms in these sectors would be responsible for paying the tax on their nonstored emissions (assuming they are purchasing directly from suppliers rather than from LDCs). Alternatively, it might be more practical from an administrative point of view to exempt nonenergy fuel use from taxation, given the very low amount of emissions in these uses (less than 2 percent of total emissions in 2014).

The emissions discussed above constitute 97 percent of energy-related emissions in 2014. The remaining emissions include nitrous oxide emissions from stationary and mobile sources and assorted other methane emissions (mainly from coal mines). Nitrous oxide emissions from combustion can be best addressed through continued improvements in combustion technologies and emissions testing programs. Methane emissions from coal mines are most prevalent among underground mines where methane is released as a result of ventilation and degasification systems. Some of this methane could be captured and sold. It is not clear that these emissions could easily be brought into the tax base. Alternatively, coal mines could receive a credit for methane emissions that are captured and permanently stored underground.[32]

4.2. Industrial Emissions

Industrial process and product use emissions account for 6 percent of total greenhouse gas emissions. Nearly half of these emissions are carbon dioxide emissions. The iron and steel, cement, petrochemical, and lime sectors account for three-quarters of CO_2 process emissions. Taxing industrial process

[32] Presumably, coal mines have an incentive to capture and sell methane if the capture cost is not too high and it is easy to move the captured gas into the natural gas pipeline system. Coal-sourced methane would be treated no differently than other natural gas that enters the pipeline system for eventual sale. Providing a tax credit for otherwise stranded methane that is permanently stored would incentivize some methane capture. A partial credit (for the difference between the tax on methane and the tax on carbon dioxide) could be provided for methane that is flared.

emissions would require further study to determine whether the benefits of including these emissions in the tax base would outweigh the costs of administering the tax on these emissions.

It would, however, be reasonably straightforward to include some industrial process emissions. Emissions from the production of cement is one example. Carbon dioxide emissions from cement manufacture occur during the production of clinker, an intermediate product. The EPA Inventory of Greenhouse Gases notes a constant share of carbon dioxide emissions per ton of clinker produced. Clinker is produced at 104 cement plants in the United States.[33] Although there are no existing taxes on clinker that would provide guidance for administering the tax, it would be straightforward to include clinker production in a carbon tax base.

The other half of industrial process emissions are primarily HFCs from the production of substitutes for ozone-depleting substances and nitrous oxides released in the production of nitric and adipic acids. HFC emissions predominantly occur in refrigeration and air conditioning, where these chemicals have replaced ozone-depleting substances phased out by the Montreal Protocol. Emissions occur during manufacture, as well as over the life of appliances due to equipment failure. Metcalf and Weisbach (2009) recommend a deposit-refund system to incentivize the capture of these chemicals when appliances are scrapped. Given the very high global warming potential of these chemicals, financial incentives to recover the chemicals at scrappage would be high.

4.3. Agriculture

Agricultural emissions account for just over 8 percent of total greenhouse gas emissions. Methane emissions from manure management and enteric fermentation, an aspect of the digestive process of ruminant animals (most notably cattle), account for 40 percent of total agricultural emissions. Metcalf and Weisbach (2009) note that steps can be taken to reduce emissions from these two sources; study on a case-by-case basis would be required to determine whether taxing these emissions is cost-effective relative to regulation or some crediting approach to reducing emissions from these sources.

The release of nitrous oxides from agricultural soil management accounts for a further 55 percent of agricultural greenhouse gas emissions. Much of the N_2O emissions are related to fertilizer activity crop residue. The complexity of agricultural N_2O release makes it extremely difficult to arrive at a clear recommendation for taxing agricultural soil management activities.

4.4. Waste

Methane release from landfills constitutes the third-largest source of methane emissions in the United States, with the vast bulk coming from municipal solid waste landfills. Methane release from landfills depends on the characteristics of landfilled materials and the landfill covering, among other things. Large municipal solid waste landfills are already required to collect and burn landfill methane. Given the small share of landfill methane in total GHG emissions (2 percent), it is doubtful that including waste-related methane in the tax base would be cost-effective.

[33] Data on cement plants from http://www.cement.org/docs/default-source/GA-Pdfs/cement-industry-by-state-2015/usa.pdf?sfvrsn=2 (accessed January 26, 2017).

4.5. Summary

If carbon dioxide emissions from fossil fuel combustion were the only greenhouse gases included in the carbon tax base, the tax would cover 76 percent of emissions (using 2014 emissions data). A conservative estimate of the additional gases that could be brought into the tax base (methane taxation from large underground mines, CO_2 emissions from clinker production, some taxation of HFCs) would bring the tax base up to 78 percent of total emissions. Even with more optimistic assumptions about the inclusion of more process, agricultural, and waste emissions in the tax base, the taxable share rises only to 85 percent. A reasonable starting point for a carbon tax would be to tax carbon dioxide emissions from fossil fuel combustion.

Table 7 summarizes the possible points of taxation for fossil fuels and industrial emissions. Stages of production go from upstream at the left to downstream at the right. Consider domestically produced oil. After extraction from an oil well, it is sent by pipeline or rail to a refinery for processing. From the refinery, it is sent by pipeline or rail to a terminal rack. From there, it is sold to final consumers. For each row, I have boldfaced stages where the tax could reasonably be imposed. For oil, the two logical points of implementation are at the refinery (either a tax on crude entering the refinery or a tax on refined products leaving the refinery) and at the terminal rack. If taxed at the refinery, imported finished products would need to be taxed at import, whereas if taxed at the rack, there would be no need to tax at import. The advantage of taxing crude oil as it enters the refinery is that refinery emissions would be included in the tax, whereas taxing refined product either would not tax refinery emissions or (preferably) would require the refinery to pay taxes on its consumed oil. On the other hand, taxing petroleum products on exit from the refinery or at the terminal rack may make it easier to avoid taxing petroleum products that end up as feedstocks or in asphalt and that should not be subject to a carbon tax.

For natural gas, the processing plant and final consumer (either LDC or final consumers purchasing directly from the pipeline) are the logical points of taxation. Because of the large share of natural gas not going through processing plants (see Figure 2), taxing at the LDC and final consumption stage is likely to be administratively less burdensome for a given level of coverage. Although coal could be taxed at the mine or at the point of consumption, taxing at final consumption would treat electric generators consistently if natural gas were taxed at the final consumer stage, since the bulk of natural gas consumed by electric utilities does not go through LDCs and thus would be taxed at its point of use.

Finally, those industrial process emissions that are included in the tax would need to be taxed at the firm level where emissions occur. The same would be true for agricultural emissions covered by a carbon tax.

5. Leakage and Competition

In a perfect world, carbon emissions would be taxed worldwide where emissions occur. Restricting our attention to carbon dioxide emissions from fossil fuels, we could also tax fossil fuels upon extraction, since the emissions that will result from the use of those fuels are known.34 In the real world, carbon emissions are taxed at different rates or not subject to a meaningful price in different

[34] This ignores carbon capture and sequestration. If fossil fuels were taxed on extraction, a credit should be allowed for downstream activities that permanently capture and sequester emissions, as well as for fuels that are exported.

countries. This gives rise to leakage and competitiveness issues. Leakage refers to the shifting of production activities from countries that price emissions to those that do not. As Kortum and Weisbach (forthcoming) point out, leakage reduces global welfare to the extent that production location decisions are distorted by the differential carbon pricing. It also leads to incomplete internalization of the greenhouse gas externality.

Border adjustments apply a carbon tax to imported carbon and rebate the tax on exported carbon. The use of border adjustments shifts the tax from the location of the production of the fossil fuels to the location of the consumption of the goods and services on the basis of the carbon embodied in those goods and services. Perfectly applied border adjustments would eliminate leakage concerns.

Kortum and Weisbach (forthcoming) distinguish between leakage and competitiveness concerns. Competitiveness concerns are often raised with respect to firms in energy-intensive, trade-exposed (EITE) sectors. While a unilateral carbon tax without any border adjustments reduces the competitiveness of EITE firms, Kortum and Weisbach note that the tax increases the competitiveness of firms in non-energy-intensive sectors such that the overall competitiveness of firms in a country with a carbon tax is unaffected.

Whether competitiveness has welfare implications or not, it clearly has political implications.35 Adverse impacts will be concentrated on a few industries, while any competitiveness gains will be small for any given industry and spread over large portions of the economy. Thus we can expect calls for some form of border adjustment with a carbon tax. Kortum and Weisbach (forthcoming) provide information on the source of imports for selected EITE sectors (see Table 8). The table illustrates that the leakage and competitiveness concern is not entirely clear-cut. First, it shows that for several of these key EITE sectors, the major sources of imported goods are countries that have or are likely to have carbon pricing schemes in place (EU, Canada among the developed countries, and China, Korea, and Mexico among developing countries). Even if one discounts carbon pricing in developing countries on the grounds that whatever price they set will be well below whatever the United States might impose, the EU and Canada still are, in most cases, the dominant sources of imports in these EITE categories.

The table also illustrates, in comparison with the corresponding table in Metcalf and Weisbach (2009), that imports in these sectors from developing countries are growing in importance. China, for example, was not among the top-five sources of imported aluminum in 2005 but jumped to second place by 2015. Mexico’s import share for paper has tripled over the decade.

If one decides that border adjustments are worthwhile, the practical question of how to apply them arises. Taxing the embodied carbon in fossil fuel imports is straightforward, as is the tax rebate for exported fossil fuels. Taxing the carbon contained in steel, aluminum, chemicals, and other energy-intensive products is extremely difficult to do accurately. Ideally, we would levy the tax based on the increased emissions associated with the production of the imported goods.36 But how do we measure those

[35] Also see Aldy (forthcoming) on this point.

[36] See Kortum and Weisbach (forthcoming) for a fuller discussion of this point.

emissions? Using the average emissions intensity for Chinese aluminum is not appropriate, since marginal emissions can differ substantially from average emissions. Asking Chinese firms that export to the United States to source their electricity also is problematic. Exporting firms would have incentives to report that their electricity comes from hydroelectric projects despite the impossibility of determining which fuel is marginal for the aluminum produced for export to the United States. Levying an import tax on the basis of the production process also raises serious World Trade Organization (WTO) legal concerns, as discussed by Trachtman (forthcoming). One suggestion explored by Metcalf and Weisbach (2009) is to levy the tax based on the carbon content of similar US products.37 Although this does not provide the correct incentive for carbon emissions reductions in the exporting countries, it does level the playing field between domestic and imported manufacturers to a large extent. It is also less likely to run afoul of WTO rules on border adjustments.

6. Treatment of Existing Greenhouse Gas Mitigation Policies

Climate policy at the federal level is a mix of incentives for clean energy production and regulatory initiatives. The two most significant policy initiatives under the Obama administration were the tightening of fuel economy standards under the Department of Transportation and EPA's Corporate Average Fuel Economy (CAFE) rules and EPA's Clean Power Plan (CPP). Fleet fuel economy standards for cars and light trucks were tightened in 2010 so that the fleet would achieve an average fuel economy of 54.5 miles per gallon by 2025. In addition, standards for heavy trucks and buses were set for the first time to go into effect beginning in model year 2014.[38]

Meanwhile, the Obama administration released the final rules for the CPP in 2015 to reduce greenhouse gas emissions from existing coal and natural gas electric generating units. Litigation immediately ensued, and in a highly unusual move, the US Supreme Court issued a stay in February 2016 on implementation of the CPP pending arguments before the DC Circuit Court of Appeals and the Supreme Court, as discussed in Linn, Burtraw and McCormack (2016).

With the Supreme Court stay on the implementation of EPA's CPP and President Trump's avowed plan to roll back environmental regulation, prospects for the CPP are dim. Although the CPP has gone through final rulemaking, the Trump administration has a number of options to kill the measure, ranging from refusing to appeal the various court challenges seeking to rule the CPP unconstitutional to amending the Clean Air Act to remove carbon dioxide as a criteria pollutant subject to regulation under that act.[39]

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37 Gray and Metcalf (forthcoming) take an entirely different approach by using some of the revenue from a carbon tax to pay for a tax credit for carbon tax payments based on best practices within a sector. Depending on the design of the credit, it could cost anywhere from $4 billion to $9 billion in lost tax revenues. This is in contrast to the roughly $11 billion collected from these EITE firms from the corporate income tax.

38 See Klier and Linn (2011) for a discussion of CAFE standards in general and Harrington and Krupnick (2012) for a discussion of the new heavy-duty vehicle rules.

39 For a discussion of the various options available to Trump, see Nathan Richardson's RFF blog posting at http://www.rff.org/blog/2016/trump-administration-and-climate (accessed January 27, 2017).

Meanwhile, California's cap-and-trade program for carbon dioxide emissions continues, as do various state-level policies to encourage clean energy deployment, most notably the use of renewable portfolio standards in 29 states (as of August 2016). States also have a variety of regulatory initiatives in place (e.g., net metering rules) to support clean energy deployment.

Enacting a sufficiently stringent federal carbon tax would make regulation under the CPP unnecessary and contribute to the Trump administration's goal to reduce regulatory burden. There could be a straight swap of a carbon tax enactment coupled with repeal of the CPP. Aldy (2016) describes other preemptive approaches, including keeping the CPP on the books but as a backstop in case the carbon tax is not set at a level sufficiently stringent to achieve desired emissions reductions. Whether the CPP is explicitly repealed or kept as a backstop, regulatory burden on states and on firms would be significantly reduced, as there would be no need to develop state implementation plans or otherwise take steps to comply with CPP regulations.

A carbon tax would also raise revenue that could help finance initiatives being discussed in Washington, including tax reform and infrastructure spending. At the same time, a substantive carbon tax would allow the repeal of various clean energy incentives in the tax code, including the production and investment tax credits for clean energy production. These have a 10-year tax expenditure estimate of $28 billion, according to the FY 2017 budget submitted by the president. Removing clean energy tax expenditures could be paired with the removal of all energy-related tax preferences in the tax code. Metcalf (2016) provides an assessment of the three largest oil- and gas-related tax preferences and argues that removing them would have little impact on oil and gas prices or the oil import share, while saving $40 billion in lost tax revenue over a 10-year budget window.

Theory provides no guidance on whether subnational carbon pricing programs such as California's cap-and-trade program or the Regional Greenhouse Gas Initiative should be preempted by federal legislation. On the one hand, having a single carbon price would be appealing to firms operating in multiple states. On the other hand, we have broad experience in our federal system with multiple layers of taxation. Forty-three states have an individual income tax, for example, with considerable variation across states in the tax base and rate structure.[40] Moreover, states that have incorporated carbon revenues in their budgets would need to cut spending or raise other taxes in response to federal preemption of subnational carbon pricing programs.

Legislation enacting a federal carbon tax could address existing cap-and-trade programs (e.g., California, RGGI) and any state-level carbon taxes that might be enacted prior to federal enactment in a number of ways. One approach would be to prohibit state or regional carbon pricing and thereby force the shutdown of existing cap-and-trade programs (and any state-level carbon taxes that might have been enacted). Whether this would be constitutional is a question for lawyers. But states do have considerable latitude to set taxes within their jurisdiction, so this option would not seem likely to prevail if challenged in court.

A second option would be to exempt from federal taxation any emissions covered by a state-level carbon pricing program or provide a federal tax credit for state-level carbon tax payments. Allowing a federal tax credit for

[40] For a summary and overview, see https://taxfoundation.org/state-individual-income-tax-rates-and-brackets-2016 (accessed January 28, 2017).

surrendered allowances in a cap-and-trade program would require clear tax guidance for valuing the surrendered allowances, since the allowances might be purchased at different times and prices.

A third approach would be simply to allow both programs to operate. This approach would be consistent with the taxation of income at both the federal and the state levels in most states. For states with a carbon tax, this option permits different states to have different carbon prices, reflecting varying state views on the appropriate price of carbon. The situation is very different for states with cap-and-trade programs. Unless the programs tightened their caps (or put in place price floors, as is the case in California), the equilibrium allowance price would fall by the full amount of the federal tax (or go to zero if the allowance price is less than the federal tax rate). Recent allowance auctions in California have settled at the auction reserve price ($12.73 per metric ton in the November 2016 auction).[41] If prices are bounded below at a reserve price, then the system is effectively acting as a tax, so state-level revenues would be unaffected by the federal tax except to the extent that the higher overall carbon price induces lower emissions, as would be expected to occur.

In summary, enacting a federal carbon tax would allow considerable regulatory streamlining at the federal level. It would also allow the removal of a number of costly tax subsidies for all types of energy that could free up roughly $7 billion a year for other uses. Federal policymakers would have to decide how to mesh a federal carbon tax with state-level carbon pricing programs that exist when the federal tax is enacted. Since greenhouse gases are a global pollutant, it is harder to rationalize differential carbon pricing across states than it is to rationalize differential taxation of income across states. A carbon tax rate that exceeds all existing state-level prices would be both reasonable and consistent with the greater efficiency of pricing carbon at a national level than at a state level. To the extent that state revenues fall upon enactment of a federal tax, Congress will have to decide whether states should receive some offsetting federal aid for some period of time.

7. Conclusion

In this report, I have reviewed and considered how thinking has changed in the years since Metcalf and Weisbach (2009) provided a detailed analysis of how best to design and implement a carbon tax. Much remains unchanged from that analysis. But this report provides some new thinking on design issues. Several findings stand out. First, setting the tax rate according to Pigouvian principles is feasible. With periodic updating of the tax rate based on the best estimates of the social cost of carbon and other greenhouse gases, moreover, the tax would approximate the optimal nonlinear tax on greenhouse gas emissions.

Second, the tax rate could also be set to achieve either targeted emissions reductions or revenue goals. The ability to design the tax to automatically adjust to hit emissions targets erodes the distinction between “price” instruments (e.g., a carbon tax) and “quantity” instruments (e.g., cap-and-trade programs). Third, in contrast to the recommendations of Metcalf and Weisbach (2009), downstream taxation of natural gas at the local distribution level or final consumer (for gas purchased directly from suppliers) covers a higher share of natural gas at a likely lower administrative cost.

41 See auction results at https://www.arb.ca.gov/cc/capandtrade/auction/auction.htm (accessed January 28, 2017).

Fourth, energy-related carbon dioxide emissions constitute three-quarters of US greenhouse gas emissions. A tax on these emissions is reasonably straightforward to administer. Including other emissions is challenging, but it is possible that another 10 percent of greenhouse gases could be taxed, bringing coverage up to 85 percent of total emissions. It is worth exploring whether there are cost-effective offset opportunities for the remaining noncovered emissions to effect further emissions reductions. Fifth, border adjustments for imported or exported fossil fuels are relatively straightforward. Capturing the emissions embodied in energy-intensive intermediate and final goods imported to the United States would be much more challenging. As in Metcalf and Weisbach (2009), I argue that border adjustments on goods from a select subset of energy-intensive trade-exposed sectors would be the way to proceed, with the tax based on domestic emissions shares for like products.

Next, enacting a carbon tax would allow for the elimination of considerable burdensome regulation and contribute to the Trump administration's goal of reducing regulatory burden. It would also raise revenue both directly from the tax and through the opportunity to eliminate a wide array of energy-related tax expenditures both for fossil and renewable energy sources. Finally, economic theory does not provide guidance on how federal and state carbon pricing programs should interact. An argument can be made for federal preemption of state-level carbon pricing programs on the grounds of the global nature of the pollutant and a view that the carbon price should not vary within the country. On the other hand, our federal structure allows for state-level variation in tastes for taxation, as well as taxation of the same base at the state and federal levels.

Given the current political environment, where regulatory approaches to addressing greenhouse gas pollution have fallen out of favor, understanding how to implement a carbon tax in an efficient and administratively straightforward way is more important than ever. In the end, congressional interest in a carbon tax may be driven as much by a need for revenue as by environmental considerations, if not more. Even if that is the case, it still behooves us to design a tax that is comprehensive and avoids subjecting taxpayers to needlessly burdensome compliance rules.

Tables and Figures

TABLE 1. US GREENHOUSE GAS EMISSIONS IN 2014

Greenhouse Gas	*Amount (MMT)*	*Share*	*Change: 2006 - 2014*
Carbon Dioxide	5,556.0	80.9%	-8.0%
Methane	730.8	10.6%	1.5%
Nitrous Oxide	403.5	5.9%	-1.6%
Hydroflourocarbons (HFC's)	166.7	2.4%	34.4%
Perfluorocarbons (PFC's)	5.6	0.1%	-6.7%
Sulfur Hexaflouride (SF_6)	7.3	0.1%	-43.8%
Nitrogen Triflouride (NF_3)	0.5	0.0%	-28.6%
Total	6,870.5	100%	-6.1%

Source: US Environmental Protection Agency (2016).

TABLE 2. ENERGY-RELATED CARBON DIOXIDE EMISSIONS IN 2014

	Coal	*Natural Gas*	*Petroleum*	*Total*
Residential	0.0%	5.4%	1.3%	**6.7%**
Commercial	0.1%	3.7%	0.7%	**4.5%**
Industrial	1.5%	9.0%	5.3%	**15.7%**
Transportation	0.0%	0.9%	32.7%	**33.6%**
Electricity	30.4%	8.6%	0.5%	**39.5%**
Total	**31.9%**	**27.6%**	**40.5%**	

Source: US Environmental Protection Agency (2016).

TABLE 3. MAJOR US SOURCES OF GREENHOUSE GASES IN 2014

Gas	*Source*	*MMT of CO_2e*	*Share*
CO_2	Electricity generation	2,039.3	29.7%
CO_2	Transportation	1,737.6	25.3%
CO_2	Industrial	813.3	11.8%
CO_2	Residential	345.1	5.0%
N_2O	Agricultural soil management	318.4	4.6%
CO_2	Commercial	231.9	3.4%
CH_4	Natural gas systems	176.1	2.6%
CH_4	Enteric fermentation	164.3	2.4%
HFCs	Substitution of ozone depleting substances	161.2	2.3%
CH_4	Landfills	148.0	2.2%
CO_2	Nonenergy use of fuels	114.3	1.7%
CH_4	Petroleum systems	68.1	1.0%
CH_4	Coal mining	67.6	1.0%
CH_4	Manure management	61.2	0.9%
CO_2	Iron and steel production & metallurgical coke production	55.4	0.8%

Source: US Environmental Protection Agency (2016).
Notes: Methane (CH4), nitrous oxide (N2O), and hydrofluorocarbons (HFCs) are reported in units of carbon dioxide equivalents (CO2e) using the IPCC Fourth Assessment Report global warming potentials used in the EPA report. The share column reports the source as a percentage of total greenhouse gas emissions in 2014.

TABLE 4. SEQUESTERED CARBON DIOXIDE

Table 4. Sequestered Carbon Dioxide			
Source	*Emissions (MMT CO_2e)*	*Stored (MMT CO_2e)*	*Percentage Stored*
Feedstocks	75.0	142.3	65
Asphalt	0.3	59.4	99
Lubricants	18.9	2.2	10
Other	20.2	1.8	8
Total	114.4	205.7	64

Source: US Environmental Protection Agency (2016).

TABLE 5. ESTIMATES OF THE SOCIAL COST OF CARBON

	Discount Rate			
Year	5%	3%	2.5%	3% High Impact
2020	$12	$42	$62	$123
2030	$16	$50	$73	$152
2040	$21	$60	$84	$183
2050	$26	$69	$95	$212

Source: US Interagency Working Group on the Social Cost of Carbon (2016).
Notes: This table reports the social cost of carbon in year 2007 dollars per metric ton of carbon dioxide. The first three columns report average values for all modeled estimates for the given discount rate. The last column reports the value for a 3 percent discount rate that is in top 95th percentile.

TABLE 6. CARBON TAX RATE FOR VARIOUS FOSSIL FUELS: $40 PER METRIC TON CO2 TAX RATE

	CO_2 Content		*Tax Rate*		*Energy Price ($/unit)*	*Tax as Share of Price*
Fuel	*Amount (kg)*	*Units*	*Rate ($)*	*Unit*		
Crude Oil	432	barrel	$17.28	barrel	52.33	33%
Home Heating and Diesel Fuel (Distillate)	10.16	gallon	$0.41	gallon	2.57	16%
Gasoline	8.89	gallon	$0.36	gallon	2.44	15%
Natural Gas	53.12	Mcf	$2.12	Mcf	3.24	66%
Anthracite	2578.68	short ton	$103.15	short ton	97.91	105%
Bituminous	2236.80	short ton	$89.47	short ton	51.57	173%
Subbituminous	1685.51	short ton	$67.42	short ton	14.63	461%
Lignite	1266.25	short ton	$50.65	short ton	22.36	227%
Coal (all types	2100.82	short ton	$84.03	short ton	31.83	264%

Source: http://www.eia.gov/environment/emissions/co2_vol_mass.cfm. Value for crude oil from https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references.
Notes: Energy prices as of week ending January 20, 2017. Crude oil price is WTI spot price. Coal is price as of 2015. Others are national averages from EIA.gov. Natural gas price is price for NG used for electricity generation.

TABLE 7. POSSIBLE POINTS OF TAXATION

Fuel	*Production Stage*				
Oil	Well	Pipeline/Rail	**Refineries**	**Rack**	Consumers
Natural Gas	Well	**Processing Plant**	Pipeline		**LDC and Major Consumers**
Coal	Mine	[Transport (rail)]			**Final Consumers**
Industrial Emissions	**Firms**				

Notes: This table shows the stages of production and distribution for domestically produced fuels. A carbon tax would also apply to imported fossil fuels as described in the report. Bold faced entries indicate points of taxation that are likely to be less administratively burdensome.

TABLE 8. US IMPORTS OF EITE GOODS BY ORIGIN, 2015

Steel		Aluminum		Chemicals		Paper		Cement	
Source	%	Source	%	Source	%	Source	%	Source	%
EU	22.3	Canada	46.7	Trinidad	31.4	Canada	39.7	Canada	39
Canada	15.3	China	12.4	Canada	21	China	19.6	EU	26.7
Korea	11.5	OPEC	9.2	Korea	10.1	EU	18	China	11.6
China	10.5	EU	9.2	EU	8.3	Mexico	6.8	Korea	7.9
Brazil	7.1	Russia	5.8	OPEC	5.3	Korea	2.9	Mexico	5
Annex I	50.4		59.4		35.5		61.7		70.3

Source: Kortum and Weisbach (forthcoming).

FIGURE 1. A TAX ADJUSTING MECHANISM FOR POLICY PRE-COMMITMENT (TAMPP)

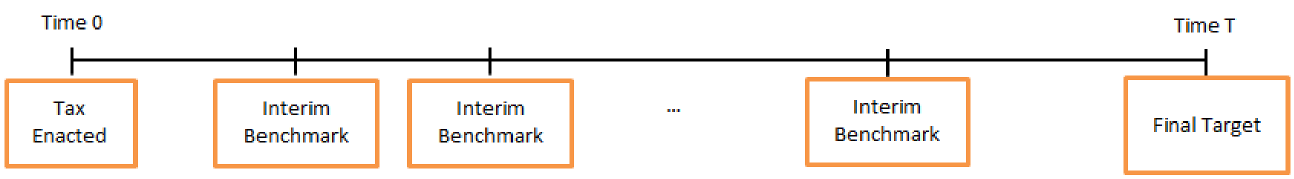
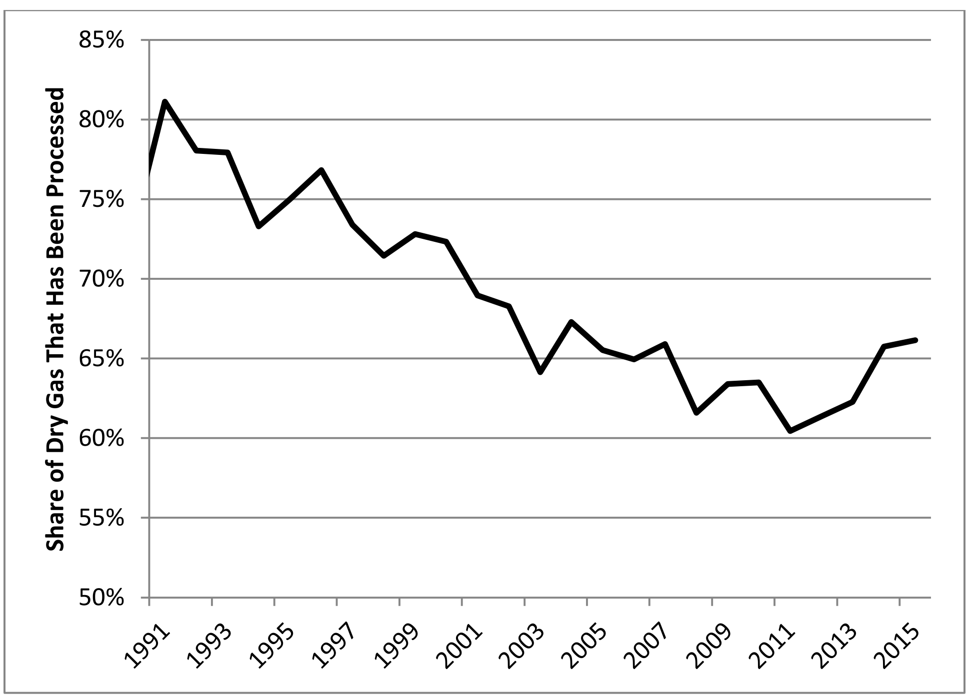


FIGURE 2. PROCESSED GAS SHARE IN DRY GAS



Source: Energy Information Administration (2016).

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