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DISCUSSION PAPER

Taxing Electricity Sector Carbon Emissions at Social Cost

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RESOURCES FOR THE FUTURE

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Abstract

Concerns about budget deficits, tax reform, and climate change are fueling discussions about taxing carbon emissions to generate revenue and reduce greenhouse gas emissions. Imposing a carbon tax on electricity production based on the social cost of carbon (SCC) could generate between $21 and $82 billion in revenues in 2020 and would have important effects on electricity markets. The sources of emissions reductions in the sector depend on the level of the tax. A carbon tax based on lower SCC estimates reduces emissions by reducing demand and through the substitution of gas for coal, whereas taxes based on higher SCC estimates induce switching to wind and nuclear generation. The slow rate of growth of the SCC estimates means that any SCC-based carbon tax trajectory provides weaker long-run incentives for expanded renewable and nuclear generation than a cap-and-trade program that achieves an equivalent level of cumulative carbon dioxide emissions reductions. Taxing carbon at the SCC is welfare enhancing, but the SCC may not be the optimal tax rate.

Key Words: carbon tax, cap and trade, social cost of carbon, electricity, energy, climate

JEL Classification Numbers: Q58, H23, H77

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Introduction

As the federal government searches for ways to address the fiscal challenges facing the nation, one option is a carbon tax that would raise government revenue to reduce the deficit or facilitate broader tax reform. Recent estimates suggest that an economy-wide $25-per-ton carbon dioxide (CO_2) tax could yield annual revenues on the order of $125 billion per year,[1] which is about 1.3 times the size of the annual savings expected from the federal budget sequestration imposed by the Budget Control Act of 2011 and modified by the American Taxpayer Relief Act of 2012. In addition to its fiscal benefits, a tax on CO_2 emissions could be a potent environmental policy that would raise the costs of fossil fuels and accelerate investment in cleaner energy sources. This combination of fiscal and environmental benefits is the outcome of taxing a negative environmental externality (Goulder 1995; Parry and Oates 2000; Goulder 2002).

The largest emitter of CO_2 in the United States is the electric power sector, which was responsible for 38 percent of total emissions in 2011 (US Environmental Protection Agency 2013). Most of the CO_2 emissions from electricity production come from coal-fired generators, which emit CO_2 at an average rate just above one short ton[2] per megawatt-hour (MWh) of electricity generated, roughly twice the emissions rate of the average natural gas–fired, combined cycle power plant, which emits just under one-half of a short ton of CO_2 per MWh. Taxing carbon from electricity production would raise the cost of coal relative to both natural gas and nonemitting power generation options; it also would raise the cost of natural gas–fired generation relative to nonemitting sources. A carbon tax would also affect the retail price of electricity paid by consumers and would, in turn, affect electricity consumption; these effects would vary

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[1] See "Considering a Carbon Tax: Frequently Asked Questions," RFF, http://www.rff.org/centers/climate_and_electricity_policy/pages/carbon_tax_faqs.aspx, accessed June 26, 2013.

[2] This paper reports carbon dioxide emissions in short tons, which is equilavent to 2,000 pounds. The Interagency Working Group reports carbon dioxide emissions in metric tons, which is equivalent to 2,204 pounds.

regionally depending on the mix of fuels used to produce electricity and how electricity prices are set.

Not only is the power sector the largest emitter of CO_2, it is also the sector that offers the cheapest potential reductions in CO_2 emissions. The Annual Energy Outlook (AEO) for 2013 (Energy Information Administration [EIA] 2013) includes three side cases that incorporate economy-wide CO_2 taxes beginning in 2014 at $10, $15, and $25 per metric ton, respectively, and rising at 5 percent per year through 2040. In every case, EIA finds that about 90 percent of economy-wide CO_2 emissions reductions induced by the tax will come from the electricity sector. This implies that a carbon tax imposed only on the power sector at a level in the neighborhood of those modeled by EIA would harvest most of the cost-effective emissions reductions available in the economy, leaving few on the table. In a strict economic efficiency sense, an economy-wide tax is superior to a tax that is limited to the power sector. However, a power sector–only tax has the advantage of being simpler to implement than an economy-wide tax; considering that it would harvest most of the cost-effective reductions available, a tax imposed only on the power sector is a potentially potent policy prescription and is the subject of this paper.

Economists have long argued that an efficient carbon tax should be set at the level of marginal damages of carbon emissions (Baumol and Oates 1988). This conclusion is based on a model of a perfectly competitive market in which prices are always equal to marginal production cost, there are no preexisting distortionary taxes, and carbon tax revenues are returned to consumers as a lump-sum payment per capita. However, in American power markets, about two-thirds of retail sales occur at a price based on cost of service, or average cost, not on marginal cost. Furthermore, virtually no customers pay prices that vary in real time with the cost of electricity production. In short, electricity prices never equal marginal cost, so taxing emissions at marginal damages may not be optimal. Tax interaction effects[3] are another consideration; through such effects, the use of tax revenue to offset preexisting distortionary taxes on capital or labor can improve the efficiency of tax policy but may cause the optimal tax rate to diverge from

[3] Because carbon taxes interact with preexisting distortionary taxes in complicated ways, the efficiency of a carbon tax will depend importantly on how the revenue is used (Bovenberg and Goulder 1997). Research has suggested that carbon taxes will be most efficient when the revenues are used to offset preexisting distortionary taxes; when this is not the case, and even when it is, the second-best optimal tax rate may differ from the social cost of carbon (Bovenberg and Goulder 2002).

marginal damages. Although a carbon tax set at marginal damages is not generally optimal for the US power market, it may nonetheless be close to the optimum.

The term "social cost of carbon" (SCC) refers to the marginal damages of a small increase in carbon emissions. The relationship among increased CO_2 emissions, changes in climate, adaptation, and economic damages is complicated. As such, assigning a value to the damages attributable to marginal changes in CO_2 emissions is fraught with uncertainties (Greenstone et al. 2013). In 2010, the Obama administration convened an Interagency Working Group (IWG) that developed a range of estimates of the SCC for use in policymaking—and, in particular, in regulatory impact analyses[4]—to assess the benefits and costs of policies with direct or indirect CO_2 emissions implications (IWG 2010). Their conclusions emphasize the uncertainties in their estimates, and they present a set of possible SCC estimates over time. Those estimates were revised upward by a subsequent IWG panel, whose report (IWG 2013) also presents a range of SCC estimates. The conclusions of these studies provide a focal point for setting a carbon tax designed to impose the SCC on the consumption of fossil fuels.

In this paper, we use the Haiku electricity market model to analyze the effects of a carbon tax imposed on electricity production based on the range of SCC estimates published in 2013 by the IWG. We examine how the taxes would affect emissions, consumption, fuel use, investment, regional electricity prices, and social welfare.[5] The time paths of the SCC estimates are approximately linear, so a carbon tax based on these estimates will unfold on a trajectory that is unlike the path of carbon allowance prices anticipated under a cap-and-trade policy on carbon emissions that allows for unlimited banking and borrowing of allowances. Cap-and-trade policies that allow banking of emissions allowances would induce an expected carbon price rising at a constant discount rate (Hotelling 1931; Cronshaw and Kruse 1996; Rubin 1996), not an approximately linear path. We compare the environmental and electricity market outcomes of the

[4] The Office of Management and Budget (2003) *Circular A-4* directs federal agencies to use constant discount rates of 3 percent and 7 percent when reporting benefit estimates in regulatatory impact analyses. However, the Office of Management and Budget allows for different discount rates to be considered when intergenerational issues arise, as is the case with the social cost of carbon.

[5] We do not explore the implications of different uses for the carbon tax revenue, such as a tax swap or reductions in the federal deficit, but instead assume that it is put to beneficial use by the government with $1 of revenue being valued by society at $1. For an analysis of the effects of different ways of using carbon tax revenue, see Carbone et al. (2013). We also do not incorporate other uses of tax revenue, such as to mitigate potential damage to electricity-intensive, trade-exposed industries or to low-income consumers.

SCC-based carbon taxes to corresponding cap-and-trade scenarios that price carbon emissions on cap-and-trade paths.

Background on the Social Cost of Carbon

The goal of the SCC estimates, as provided in the IWG's initial report (2010) and its recent update (2013), is to enable cost–benefit analyses of federal regulations to account uniformly for the marginal benefits of reducing CO_2 emissions across the analyses performed by different federal agencies. The SCC represents estimates of the value of not emitting an additional ton of CO_2. This includes, for example, the costs associated with avoiding negative impacts on agricultural productivity and human health as well as addressing increased property damage resulting from greater flood risks and changes in the value of ecosystem services due to climate change. The SCC estimates reflect global marginal damages, and this distinguishes them from damage estimates used in regulatory analyses of the benefits of reducing emissions of other pollutants, where only US impacts are considered. However, unlike other pollutants, CO_2 emissions have global impacts, and that is the rationale for valuing their marginal damages on a global basis.

The SCC estimates are highly uncertain. The components of that uncertainty include the future levels of greenhouse gas emissions, the effects of emissions on the climate system, the impact of climate changes on the environment, and how environmental impacts will translate into economic damages (IWG 2010). The working group does not select a single time path for the SCC. Instead, it provides four trajectories based on different assumptions about social discount rates. The estimates are average results of three well-known integrated assessment models—DICE (Dynamic Integrated Climate and Economy), PAGE (Policy Analysis of Greenhouse Effect), and FUND (Climate Framework for Uncertainty, Negotiation, and Distribution). The three models estimate the SCC by translating greenhouse gas emissions into changes in atmospheric greenhouse gas concentrations, changes in temperature, and economic damages.

The models are standardized on three assumptions: socioeconomic and emissions trajectories, equilibrium climate sensitivity, and social discount rates. Each model produced five sets of results for each discount rate, representing five socioeconomic scenarios. These scenarios include varying estimates of gross domestic product, population, and emissions trajectories for carbon as well as non-CO_2 greenhouse gases. Three of the final paths are average values from across the three models and five socioeconomic scenarios; one path represents the 95th percentile estimate across the models and scenarios at the 3 percent discount rate (IWG 2010).

The 2013 update uses the same methodology as the 2010 study and does not alter the socioeconomic and emissions trajectories, equilibrium climate sensitivity, and discount rates agreed upon by the 2010 working group. However, updated values do reflect numerous changes in the underlying models. For example, the DICE and PAGE models now include an explicit representation of sea level rise damages, and the FUND model now includes indirect climate effects of methane emissions.[6] As a result of these changes, the SCC estimates increased across the board. For example, the 2010 report lists the 2025 SCC estimate in the 3 percent discount rate case as $34 per short ton (2009$; IWG 2010); this increased to $55 per short ton (2009$) in the 2013 update (IWG 2013).

Table 1. Social Cost of Carbon Estimates

	2013 IWG SCC estimates (2009$ per short ton)			
	Low Case (5 percent discount rate, mean)	Medium Case (3 percent discount rate, mean)	High Case (2.5 percent discount rate, mean)	Tail Case (3 percent discount rate, 95th percentile)
2010	10	31	49	84
2015	11	36	54	102
2020	11	40	61	121
2025	13	45	66	135
2030	15	49	71	149
2035	18	53	76	165
2040	20	58	82	180
2045	23	62	86	193
2050	25	67	92	207

Source: IWG (2013) translated into 2009$ per short ton of CO_2.

[6] Further research is necessary to improve the cost estimates as new scientific information becomes available (IWG 2013).

The reports provide SCC paths at discount rates of 5 percent, 3 percent, and 2.5 percent. In an effort to capture impacts from climate change that are more extreme than expected, the reports also include results from the 95th percentile estimates across all three models at the 3 percent discount rate (IWG 2010). The estimates from the 2013 report translated into 2009 dollars per short ton of CO_2 are shown in Table 1. The 5 percent and 2.5 percent discount rates are different from the standard 3 percent and 7 percent discount rates used in regulatory impact analyses of proposed US regulations. Traditionally, 3 percent and 7 percent have been applied to benefits and costs expected to occur in the near term. However, the integrated assessment models measure damages in terms of consumption impacts; thus, the social rate of discount is more appropriate than the market rate of 7 percent that applies to changes in capital allocation over time. Also, the choice of discount rate has an important impact on the estimate of the SCC. In 2020, the SCC is $14 with a 5 percent discount rate, $49 with a 3 percent discount rate, and $74 with a 2.5 percent discount rate (IWG 2013). The estimates increase based on rates endogenously determined within the three models (IWG 2010). These paths do not rise over time at the rate of interest, a key feature that we discuss in detail below.

The SCC reports have critics. Johnson and Hope (2012) point out that the appropriate discount rate in an intergenerational context, like that of global climate change, may be much lower than even the lowest rate evaluated by the IWG, 2.5 percent, which would raise the SCC[7]. They point out also that assigning greater weight to economic damages in poorer countries (the IWG currently assigns equal weight to all countries) would push the SCC up further. They conclude that the IWG estimates of 2010 may be an order of magnitude too low. Pindyck (2013) questions the suitability of integrated assessment models for estimating the SCC because they are too assumption driven—particularly with responses to the economic damages of temperature changes and associated climate effects—and because they fail to account properly for catastrophic climate outcomes. He suggests a more back-of-the-envelope approach for catastrophic risk analysis, like that used to assess the risk of an American–Soviet thermonuclear exchange. We feel that an imperfect SCC estimate is better than none at all as certainly the SCC is not zero, and we remind the reader that the estimates are plural and uncertain.

[7] Stern (2006) also argues for a much lower discount rate to be applied in the case of climate change impacts affecting future generations.

Model and Scenarios

Haiku Electricity Market Model[8]

Haiku is a partial equilibrium model that solves for investment in and operation of the electricity system in 22 linked regions of the contiguous United States, from 2013 to 2035. Each simulation year is represented by three seasons (spring and fall are combined) and four times of day (time blocks). For each time block, demand is modeled for three customer classes (residential, industrial, and commercial) in a partial adjustment framework that captures the dynamics of the long-run demand responses to short-run price changes. Specifically, aggregate demand in each season for each customer class is a function of current electricity price and electricity price 12 months prior. This structure allows for changes in electricity consumption or investments in long-lived energy-using capital equipment to persist into the future and for consumers to respond in the short run to changes in price.

Supply is represented using 58 model plants in each region—including various types of renewable energy, nuclear, natural gas, and coal-fired power plants—and assumed levels of power imports from Mexico and Canada that are held fixed for all scenarios. In each region, 39 model plants aggregate existing capacity according to technology and fuel source from the complete set of commercial electricity generation plants in the country. The remaining 19 model plants in each region represent new capacity investments, again differentiated by technology and fuel source. Each coal model plant has a range of capacity at various heat rates, representing the range of average heat rates at the underlying constituent plants. Transmission capability for power trades among the 22 regions is parameterized based on the AEO for 2011 (EIA 2011a) and is modeled as a pipeline.

Operation of the electricity system (generator dispatch) in the model is based on the minimization of short-run variable costs of generation, and a reserve margin is enforced based on margins obtained in the AEO 2011. Fuel prices are benchmarked to the AEO 2011 forecasts for both level and supply elasticity, except for natural gas, which is benchmarked to the AEO 2013

[8] For detailed documentation of Haiku, see Paul et al. (2009).

(EIA 2013).[9] Coal is differentiated along several dimensions, including fuel quality and content and location of supply, and both coal and natural gas prices are differentiated by point of delivery. The price of biomass fuel also varies by region depending on the mix of biomass types available and delivery costs. All fuels are modeled with price-responsive supply curves. Prices for nuclear fuel and oil as well as the price of capital and labor are held constant.

Investment in new generation capacity and the retirement of existing facilities are determined endogenously[10] for an intertemporally consistent (i.e., forward-looking) equilibrium, based on the capacity-related costs of providing service in the present and into the future (going-forward costs) and the discounted value of going-forward revenue streams. Existing coal-fired facilities also have the opportunity to make endogenous investments to improve their fuel efficiency (Burtraw and Woerman 2013). Discounting for new capacity investments is based on an assumed rate of 5 percent. Investment and operation include pollution control decisions to comply with regulatory constraints for sulfur dioxide (SO_2), nitrogen oxides, mercury, hydrochloric acid, and particulate matter, including equilibria in emissions allowance markets where relevant. All currently available generation technologies, as identified in AEO 2011, are represented in the model, as are integrated-gasification combined cycle coal plants with carbon capture and storage and natural gas combined cycle plants with carbon capture and storage (EIA 2011b). Ultra-supercritical pulverized coal plants and carbon capture and storage retrofits at existing facilities are not available in the model.

Price formation is determined by cost-of-service regulation or by competition in different regions, corresponding to current regulatory practice. Electricity markets are assumed to maintain their current regulatory status throughout the modeling horizon; that is, regions that have already moved to competitive pricing continue that practice, and those that have not made

[9] Natural gas price forecasts are updated because, unlike other fuel prices, these projections and the associated underlying natural gas supply assumptions have changed substantially between the Annual Energy Outlook (AEO) for 2011 and AEO 2013. Given the implications of those price changes for the way electricity is produced in the Baseline, an up-to-date version of the electricity sector responses to carbon taxes is enabled through this natural gas price update.

[10] Investment (in both generation capacity and pollution controls) and retirement are determined according to cost minimization. This fails to account for the potential Averch–Johnson effect (Averch and Johnson 1962) in cost-of-service regions, which tends to lead to overinvestment in capital relative to fuel and increased costs.

that move remain regulated.[11] The retail price of electricity does not vary by time of day in any region, though all customers in competitive regions face prices that vary from season to season. The reserve price component of retail prices reflects the scarcity value of capacity and is set just high enough to retain just enough capacity to cover the required reserve margin in each time block.[12] We do not model separate markets for spinning reserves and capacity reserves. Instead, the fraction of reserve services provided by steam generators is constrained to be no greater than 50 percent of the total reserve requirement in each time block.

Scenarios

A baseline (BL) scenario and four scenarios of a carbon tax on an SCC trajectory comprise the core scenarios analyzed here. The BL is described below, followed by a brief description of the SCC scenarios. Each SCC scenario differs from the BL and from the other SCC scenarios only by the level of carbon tax imposed (zero for BL). Two other sensitivity scenarios, based on a cap-and-trade policy, are used to generate a carbon price trajectory unlike the SCC paths; these are also discussed below. The scenario specifications are summarized in Table 2 and are described in more detail in the subsequent paragraphs.

Table 2. Scenario Definitions

Scenario name	Scenario description
Baseline	No greenhouse gas policy. Included are policies under Title IV of the Clean Air Act, the Clean Air Interstate Rule, and the Mercury and Air Toxics Standards, which are maintained in all scenarios.
Low	**Carbon tax** set at the **5 percent, mean** SCC estimates for each year on all CO_2-emitting electricity generators beginning in 2015.
Medium	**Carbon tax** set at the **3 percent, mean** SCC estimates for each year on all CO_2-emitting electricity generators beginning in 2015.

[11] Electricity market regulatory restructuring currently has little momentum in any part of the country. Some of the regions that have already implemented competitive markets are considering reregulating, and those that never instituted these markets are no longer considering doing so.

[12] Required reserve margins vary across regions and range from a low of 8 percent of peak load in Illinois and parts of New York State to a high of over 18 percent in the Missouri and Kansas region.

High	**Carbon tax** set at the **2.5 percent, mean** SCC estimates for each year on all CO_2-emitting electricity generators beginning in 2015.
Tail	**Carbon tax** set at the **3 percent, 95th percentile** SCC estimates for each year on all CO_2-emitting electricity generators beginning in 2015.
Cap-and-Trade: Medium	**Cap-and-trade** regulation with banking and borrowing of emissions allowances and initial distribution of allowances through a government auction, achieving the same amount of cumulative emissions reductions between 2015 and 2035 as the **Medium** scenario.
Cap-and-Trade: High	**Cap-and-trade** regulation with banking and borrowing of emissions allowances and initial distribution of allowances through a government auction, achieving the same amount of cumulative emissions reductions between 2015 and 2035 as the **High** scenario.

Baseline

In the BL scenario, projections for electricity demand and fuel prices, with the exception of natural gas prices, come from AEO 2011. Natural gas supply is represented by supply curves that are calibrated to the more recent AEO 2013 forecasts, which have lower gas price projections than those of previous AEOs.

This scenario includes regulations under Title IV of the Clean Air Act, the Clean Air Interstate Rule (CAIR), and the US Environmental Protection Agency's recently finalized Mercury and Air Toxics Standards, also known as MATS. Title IV governs nationwide SO_2 emissions, setting the national-level constraint of 8.95 million emissions allowances annually. CAIR alters this constraint for plants in the eastern United States, which comprise the largest share of national SO_2 emissions. It changes the value of an emissions allowance for plants in that region of vintage 2010 or later, requiring two allowances per ton in 2010 and increasing over time. Facilities outside of the CAIR region continue to operate under the Title IV constraint. CAIR also imposes annual and summertime emissions caps on nitrogen oxides in a similar, but not identical, group of states. MATS restricts emissions of heavy metals and acid gases from new and existing coal- and oil-fired power plants. It sets plant-specific emissions standards for mercury, regulates the emissions of filterable particulate matter as a surrogate for nonmercury heavy metals, and limits the emissions of hydrogen chloride as a surrogate for acid gases. MATS is expected to lead the cap on SO_2 emissions under CAIR to go slack, driving the Title IV allowance prices to zero (Burtraw et al. 2013).

The BL includes state-level mercury regulations where they apply, the Regional Greenhouse Gas Initiative, all state-level renewable portfolio standards and renewable production tax credits, and federal renewable production and investment tax credits.

SCC: High, Medium, Low, Tail

The policy scenarios represent four different carbon tax trajectories based on the most recent US government SCC estimates, as represented in Table 1. In each scenario, the relevant carbon tax levels are imposed on all CO_2-emitting electricity generators beginning in 2015, and all other regulations remain unchanged from the BL. The High case corresponds to an SCC trajectory based on a 2.5 percent discount rate, the Medium case has an underlying discount rate of 3 percent, and the Low case has an underlying discount rate of 5 percent. These three price paths are based on mean estimates from the three integrated assessment models used to generate the SCC values. The Tail case, however, is based on a 3 percent discount rate but relies on the 95th percentile estimates from the underlying models.

Sensitivity: Cap and Trade with Banking

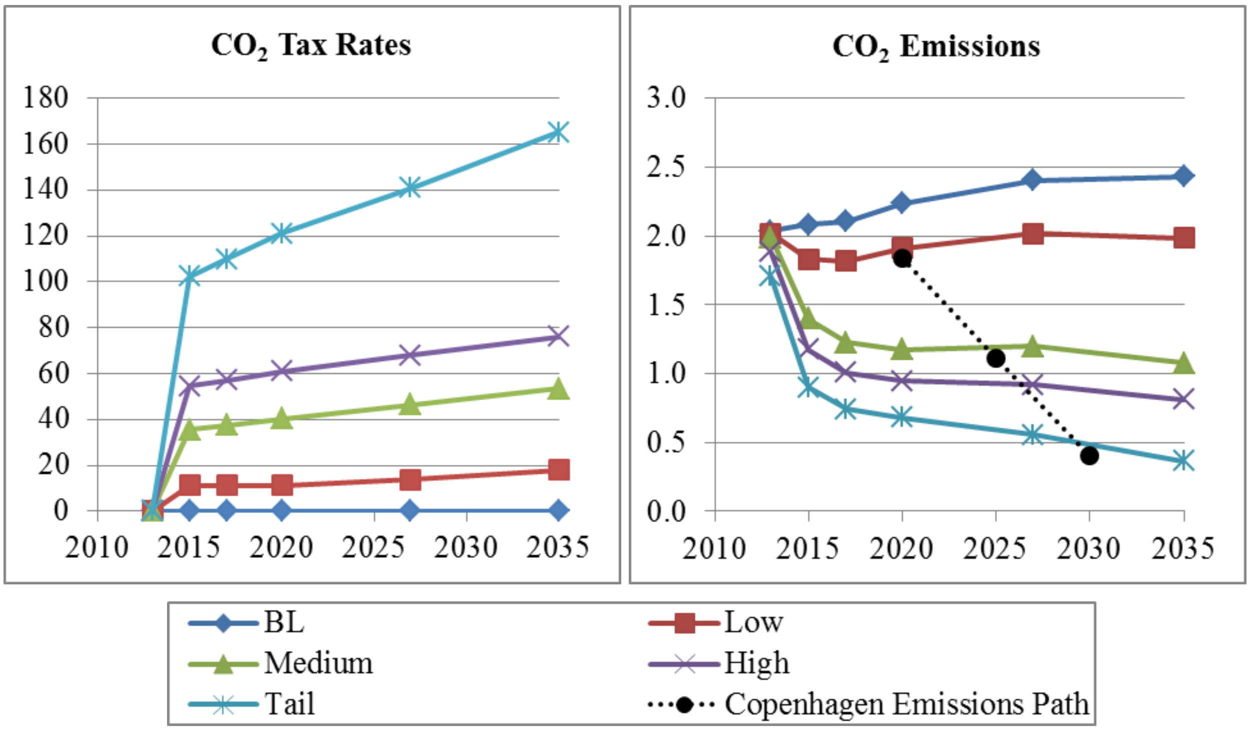
As noted above, the SCC tax rates increase over time at a relatively slow rate of change, between 0 and 4 percent per year depending on the scenario. In contrast, if CO_2 emissions were regulated under a cap-and-trade policy with banking of emissions allowances, then the price of CO_2 would be expected to rise at a constant discount rate, assumed to be 5 percent in Haiku. To compare the effects of these two price paths, we include two scenarios that represent cap-and-trade regulation with banking and borrowing of emissions allowances. The first achieves the same amount of cumulative emissions reductions between 2015 and 2035 as the Medium SCC case; the second matches the cumulative emissions reductions of the High SCC case. In both cases, emissions allowances under the cap are assumed to be auctioned by the government, so this form of regulation also generates government revenue.

Results

In this section, the CO_2 emissions outcomes associated with the different scenarios are presented first, followed by a discussion of sources of emissions reductions, emissions tax revenues, and electricity price results. This section concludes with a discussion of the differences between the SCC scenarios and analogous cap-and-trade scenarios with banking. Some results mentioned in the text are not presented in the figures in this section; those results are reported in the tables in the appendix.

The effect of a carbon tax on electricity production and emissions depends on the level of the tax and how it changes over time. The carbon tax trajectories of the four SCC scenarios are shown in the left-hand panel of Figure 1.

Figure 1. CO_2 Tax Rates ($/Short Ton) and Emissions (B Short Tons)



Emissions

In all of the scenarios, relatively large emissions reductions occur in the initial year of the carbon tax, followed by more modest growth in reductions thereafter. In the right-hand panel of Figure 1, cumulative emissions reductions through 2035 are 7.8 billion short tons for the Low case, or 15 percent of cumulative BL emissions. In the Medium, High, and Tail cases, cumulative emissions reductions are, respectively, 46, 56, and 71 percent of cumulative BL emissions.

At the 2009 international climate meetings in Copenhagen, President Obama pledged to reduce greenhouse gas emissions in the United States to 17 percent below 2005 levels by 2020. This pledge was part of a plan to cut emissions by 83 percent by 2050 (The White House 2009) that included interim targets at 2025 and 2030. The target pathway is nearly linear and the Copenhagen targets apply to the full economy. If the country is to achieve these reductions, the electricity sector will play a large role. The ultimate amount of emissions reductions from electricity will depend on what happens in other sectors. Moreover, the fraction of reductions coming from the electricity sector under a carbon tax scenario depends on the timing and the level of the carbon tax. Prior modeling analysis of climate policies has held that the electricity sector will do more than its proportional share under an economy-wide price on carbon. The carbon tax side cases in the AEO 2013—which include tax rates of $10, $15, and $25 per metric ton of CO_2 starting in 2014 and growing at 5 percent per year—suggest that the share of total reductions from economy-wide Reference case CO_2 emissions levels coming from the electricity sector would be in the neighborhood of 90 percent under all three tax levels. Presumably, for higher economy-wide tax rates, the share of emissions reductions from electricity would be smaller as the inexpensive abatement opportunities in that sector are exhausted and reductions from other sectors become more economical.

The black dotted line on the right-hand panel of Figure 1 shows projected emissions for the electricity sector if the United States is to achieve 90 percent of the emissions reductions necessary to hit the Copenhagen emissions targets from within the power sector. The projection for total reductions required to hit the targets is based on economy-wide CO_2 emissions in the AEO 2013 Reference case (EIA 2013). The figure shows that the Copenhagen targets are not timed like any of the SCC-based tax emissions trajectories. The SCC scenarios all achieve relatively large initial reductions in the first year of the tax followed by slower growth in reductions, whereas the Copenhagen targets begin with modest reductions and ramp up over time. The Copenhagen targets are not legally binding, and they are economy-wide, not specific to the electricity sector. This graph of electricity sector outcomes with SCC-based taxes suggests that policies intended to meet the Copenhagen targets should engender relatively large initial reductions within the electricity sector—larger than the linear trajectory in the targets for the whole economy—if they are to correspond with any of the SCCs.

Sources of Emissions Reductions

The emissions reductions identified under each scenario discussed in the previous section are attributable to different combinations of sources depending on the level of the tax. Emissions reductions under the Low carbon tax scenario would be achieved through reductions in coal-fired electricity generation and end-use electricity consumption along with an increase in natural gas–fired generation. At higher tax levels, expanded use of lower carbon intensity electricity generation resources—renewables (mostly wind) and nuclear—would help offset reduced coal generation.[13] For a high enough carbon tax, increased natural gas generation will cease to help offset reduced coal generation and will instead be displaced, like coal, by cleaner generation sources. Figure 2 shows the relative contributions to emissions reductions of shifting sources of supply and contracting demand.[14] The figure shows that, as the carbon tax rises across the SCC scenarios, an additional margin for emissions reductions is operative at each step. At the Low SCC tax rate, the natural gas and demand reduction margins are in effect. For the Medium SCC case, expansion in nuclear generation becomes a source of emissions reductions, and in the High SCC case, increased generation from renewables, which consist primarily of wind, starts to play a role. The Tail case brings about a reduction in natural gas generation by 2035.

The top-left panel of Figure 2 shows that emissions reductions under the Low SCC scenario are attributable to electricity demand reductions and growth in natural gas–fired generation, in roughly even shares throughout the modeling horizon. The Medium SCC scenario, in the top-right panel, shows more demand reductions and fuel switching to natural gas, as well as some growth in nuclear generation beginning in 2020. The bottom-left panel shows the High SCC scenario, with greater demand reductions and increases in nuclear generation, less growth in natural gas than under the Medium SCC scenario, and some incremental investments in renewables that occurs right away. The Tail scenario is shown in the bottom-right panel. More growth in demand reductions and renewables and nuclear generation is offset by a further decline in natural gas growth. Indeed, by 2035 under the Tail scenario, natural gas–fired generation actually declines relative to BL.

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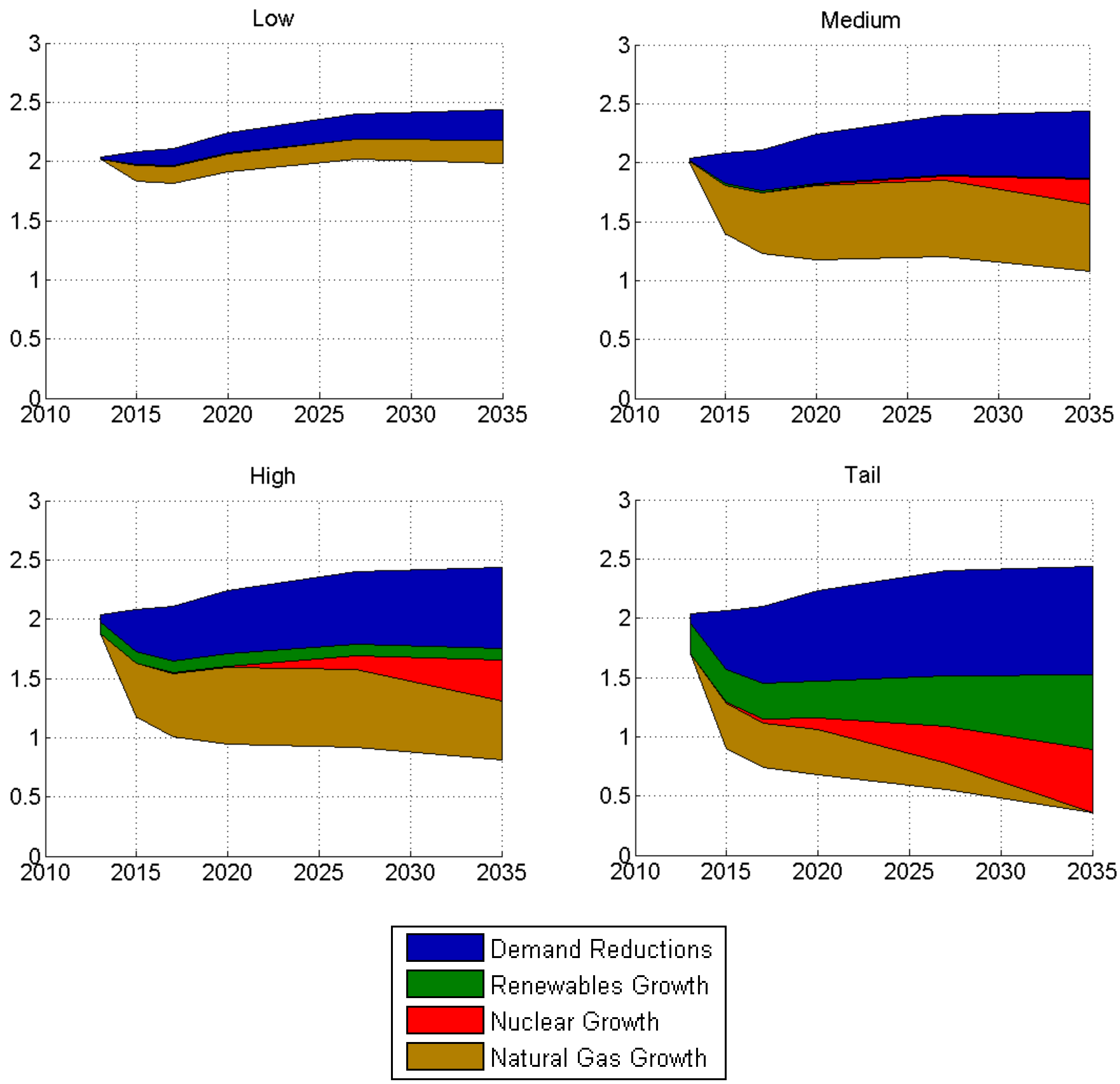
[13] The Haiku model does not include solar photovoltaic technology, and the introduction of carbon taxes has virtually no effect on generation by concentrating solar generation, hydro power generation, or generation with biomass.

[14] The attribution of emissions reductions to different sources in each simulation year depends on the change (relative to Baseline) in the emissions rate for each category of generators, including those that reduce their emissions and those that do not. Which category a particular type of generator falls into can vary over time and by policy scenario. For each generator type (nuclear, renewables, sometimes natural gas) that increases generation, the share of emissions reductions attributable to that increase is equal to the increase multiplied by the difference between the change in emissions rates at emitting generators that reduce generation (typically coal and, at high tax rates, natural gas) and the change in emissions rates from the type of generator that increases emissions (for renewables and nuclear this is zero by definition). The share of emissions reductions attributable to lower demand is the product of the change in demand times the average marginal change in the emissions rate across all types of generators that reduced emissions.

Figure 2. CO_2 Emissions Reductions Profile (B Short Tons)

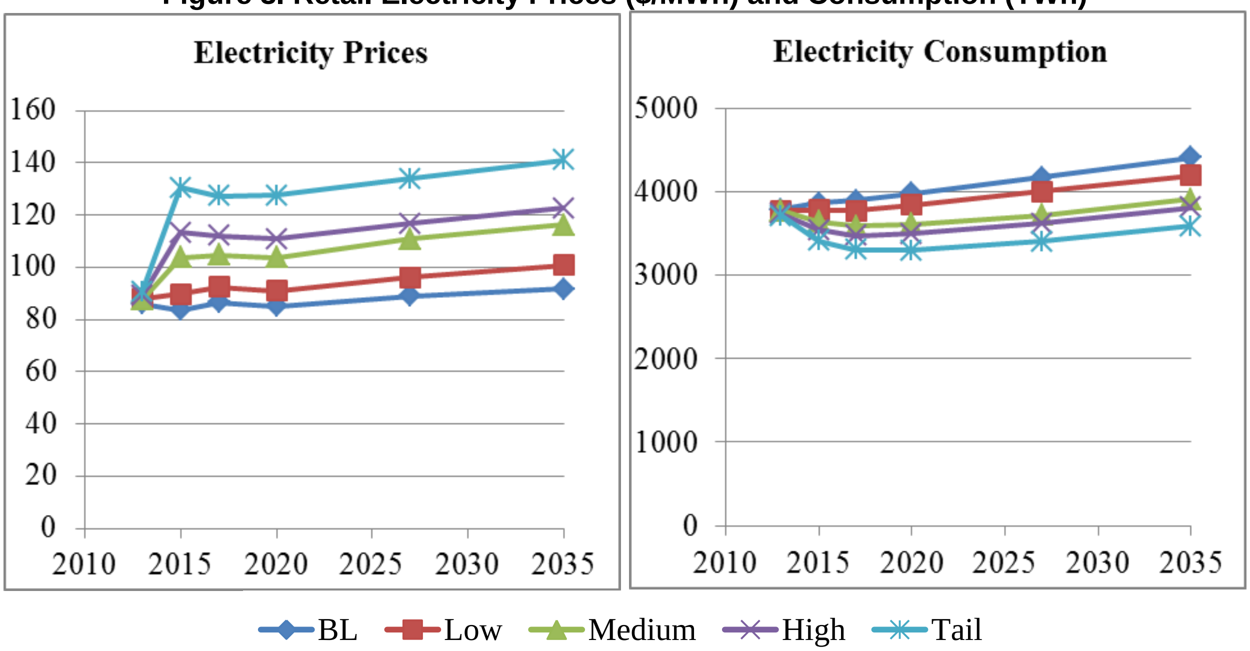


Electricity Prices and Consumption

Carbon taxes could have significant effects on the price of electricity and, in turn, on electricity consumption, causing prices to rise and consumption to fall.[15] The retail price effects are shown in the left-hand panel of Figure 3, with consumption outcomes shown in the right-hand panel. The national average price effect under the Low case is modest, only $6 per MWh by 2020, or a 7 percent increase from BL. The Medium case results in a national average price increase from BL of 22 percent in 2020. The Tail case affects consumers the most, by about $42 per MWh in 2020, or a 50 percent increase from BL. The effects of the carbon tax on retail prices change little after the initial adjustment period when the taxes begin.

The electricity consumption impacts of the carbon taxes are the mirror image of the price effects, but with consumption effects compounding slightly over time. The Low case reduces consumption by 3 percent in 2020, growing to 5 percent by 2035. The greatest reductions occur in the Tail scenario, with a nearly 20 percent reduction by 2035.

Figure 3. Retail Electricity Prices ($/MWh) and Consumption (TWh)



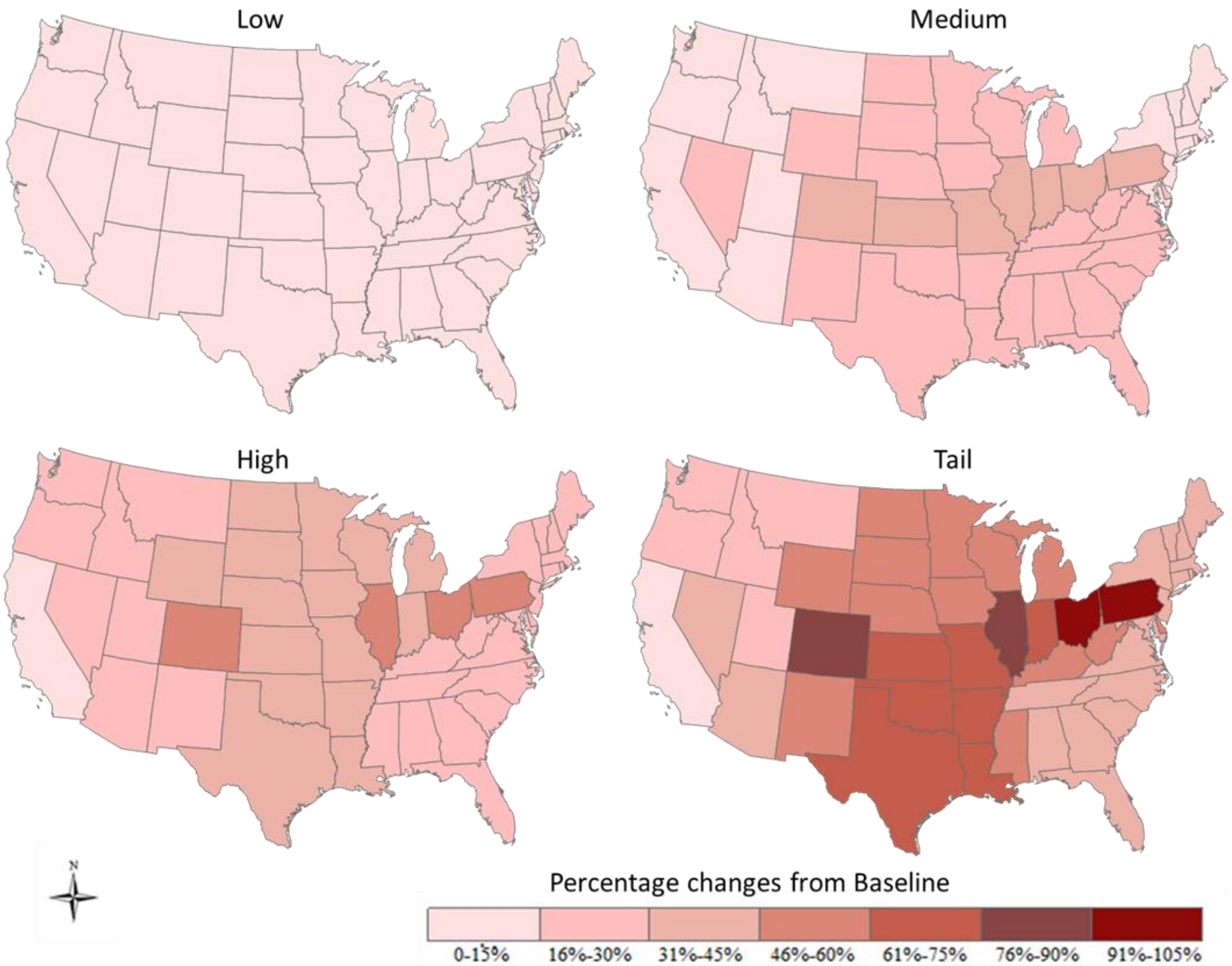
Note: TWh = terawatt-hour.

[15] If carbon tax revenues are allocated in ways that distort electricity markets, such as by subsidizing electricity production to mitigate the effect of the tax on consumers, then the price and consumption effects of the tax will vary from those shown here. The allocation of allowance revenue under a cap-and-trade policy is analogous and is analyzed by Paul et al. (2010).

The national average retail electricity prices shown in the left-hand panel of Figure 3 mask substantial regional heterogeneity in the price effects of the taxes. The state-specific electricity price effects of a carbon tax depend on factors that vary across the country, including the mix of installed capacity, the availability of resources (like wind or sunlight) for capacity expansion, electricity market regulation (competition or cost of service), weather, and consumer responsiveness to changes in price. Because the grid links local markets within each interconnection, the local price effects of a carbon tax depend not only on local conditions, but also on conditions in other parts of the interconnection. Figure 4 provides a state-level look at retail electricity price effects in 2020 of the SCC-based carbon taxes.[16] The colors in the figure indicate the percentage increase in state average electricity price relative to BL; darker colors indicate larger increases. For the Low SCC carbon tax, none of the regions sees a retail price increase of greater than 15 percent. Under the Medium Tax, the third color intensity (31 percent to 45 percent) is reached across several of the plains and midwestern states, with only a few western states and the Northeast remaining in the lightest color. The High scenario further ratchets up prices, especially in some coal-intensive states, including Pennsylvania and Ohio, with only California remaining in the lightest color. The Tail scenario raises prices further in most of the nation, with the central and coal-intensive parts of the country bearing the greatest burden. Table A3, in the appendix, provides the state-level data behind the maps displayed in Figure 4.

[16] Haiku operates for electricity supply on a 22-region configuration of the contiguous United States. These state-level prices are derived by extrapolating prices from the 22 region levels to the state level using historical data on electricity prices and consumption.

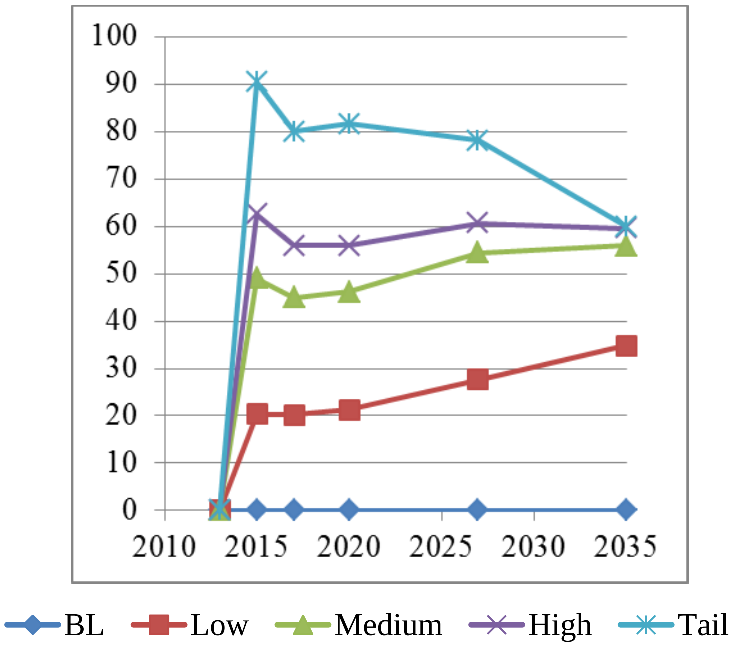
Figure 4. State-Level Retail Electricity Price Impacts in 2020



Tax Revenues

The revenues collected by the government under a carbon tax could make a contribution to addressing the nation's current deficit. The effectiveness of a carbon tax in raising revenue depends on how responsive emissions are to a carbon tax; higher taxes induce fewer emissions, eating up the tax base. Figure 5 shows carbon tax revenues from the electricity sector. The Low case generates in the neighborhood of $20 billion annually through the first half decade, climbing to almost $35 billion per year by 2035. The tax level for the Medium case is more than twice as high as the Low level rate, yet due to declining emissions (the tax base), tax revenues will rise less than proportionally, reaching nearly $56 billion by 2035. In 2035, the tax roughly triples from the Low to Medium cases, but revenues rise by less than 50 percent. The pattern of declining tax base persists across the other two more expensive scenarios. Emissions decline so much under the Tail case that even though the price of carbon emissions is roughly doubled in 2035 between the High and the Tail scenarios, annual tax revenues are virtually unchanged because emissions are halved.

Figure 5. Electricity Sector Carbon Tax Revenues (B$)



An economy-wide carbon tax would generate disproportionately more tax revenue than a tax imposed only on the power sector. Because the carbon price elasticity of emissions is greater in the power sector than in the other major emitting sectors (at least for relatively low carbon prices), electricity is the least efficacious sector in which to tax carbon if the objective is to raise revenue. An economy-wide carbon tax in 2020 could raise 3.6 times more revenue than an electricity sector tax even though it would cover only about 2.6 times as many emissions at the current emissions share between the electricity sector and other sectors.[17]

[17] This statistic comes from the $25 Carbon Tax side case and the Reference case from AEO 2013 (Energy Information Administration 2013).

Social Welfare

The economic welfare costs, environmental benefits,[18] and total welfare consequences of the policies are shown in Table 3, all as changes from the BL scenario. Economic surplus is the sum of three components: consumer surplus, producer surplus, and government surplus. Avoided CO_2 damages are equal to the product of reduced CO_2 emissions and their value per ton. The SCC is the estimate of the value of a marginal reduction in CO_2 emissions, and that estimate changes across the four SCC scenarios. The dramatic increase in avoided CO_2 damages and total welfare moving from left to right across the table reveals not only higher CO_2 emissions reductions, but also the impact of placing greater value on reductions. One cannot conclude from these results that the Tail scenario is superior, only that for each estimate of the SCC, taxing carbon emissions at the SCC will enhance total welfare. The greater the value assigned to the SCC, the greater the welfare enhancement.

Table 3. Discounted[a] Change in Cumulative Welfare, 2013–2035 (B$)

	Low	Medium	High	Tail
Economic Surplus	-31	-259	-450	-895
+Avoided CO2 Damages	47	478	865	2,196
=Total Welfare	15	219	415	1,301

[a] Costs and benefits are discounted at 5 percent per year.

In a perfectly competitive, first-best setting, taxing an environmental externality at marginal damages maximizes social welfare. The SCC is the measure of marginal damages, but US power markets are not perfectly competitive; thus, electricity prices never equal marginal costs. The divergence between price and marginal cost comes from cost-of-service regulation (average, not marginal cost pricing) and the lack of real-time pricing (marginal cost varies in real time, but price does not). Despite these divergences from the competitive model, a carbon tax set at the SCC may be close to the optimum. Table 4 shows the social welfare consequences of each SCC-based carbon tax scenario for each SCC valuation. If the first-best model holds, then the diagonal from upper-left to lower-right right maximizes each row. The values in bold italics represent the best carbon tax among these four for each SCC valuation, and it is not consistently on the diagonal. Cost-of-service pricing and the lack of real-time pricing explain the divergence

[18] Note that this estimate excludes benefits from reductions in other pollutants, such as emissions of sulfur dioxide or nitrogen oxides, which would be in addition to the benefit estimates reported here.

from the diagonal; this suggests that, for higher valuations of the SCC, lower carbon taxes may be preferable.[19]

Table 4. Cumulative Discounted Change in Social Welfare, 2013–2035 (B$)

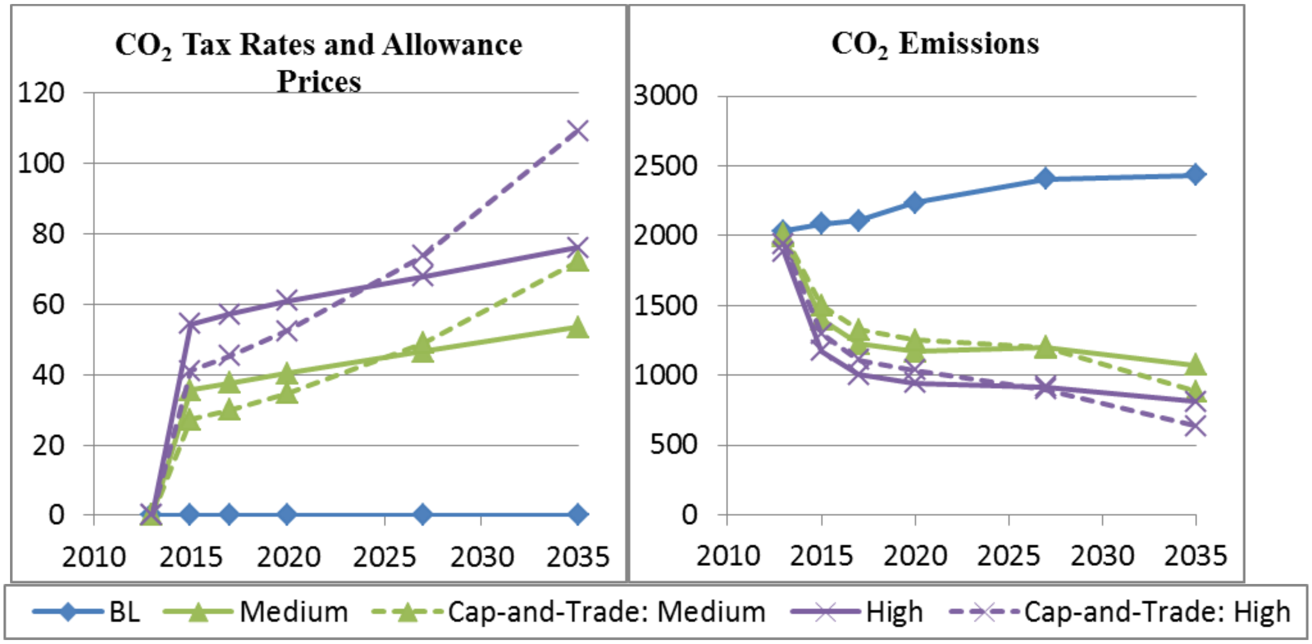
		CO_2 Tax			
		Low	Med	High	Tail
Valuation of CO_2 Emissions (SCC)	Low	***15***	-114	-273	-674
	Med	123	***219***	136	-166
	High	196	***446***	415	181
	Tail	434	1,180	***1,314***	1,301

Sensitivity: Cap-and-Trade

The cap-and-trade sensitivity cases, based on the total cumulative emissions reductions in the Medium and High Tax scenarios, result in a substantially different trajectory of CO_2 emissions and costs than the associated tax scenarios, as shown in Figure 6. The emissions tax rates for the SCC scenarios are on approximately linear paths, notably different from the cap-and-trade allowance prices that fall on a convex curve and rise at a constant discount rate of 5 percent per year, the discount rate used to evaluate investment and retirement decisions in the model. The cap-and-trade scenarios have lower marginal emissions abatement costs (tax or allowance price) than the corresponding SCC scenarios in the early years of the simulation horizon and higher costs in the later years. Emissions follow a path corresponding to the relationships between the tax rates and allowance prices, with more emissions reductions occurring later in the horizon under cap and trade, but fewer reductions occurring in the earlier part of the horizon.

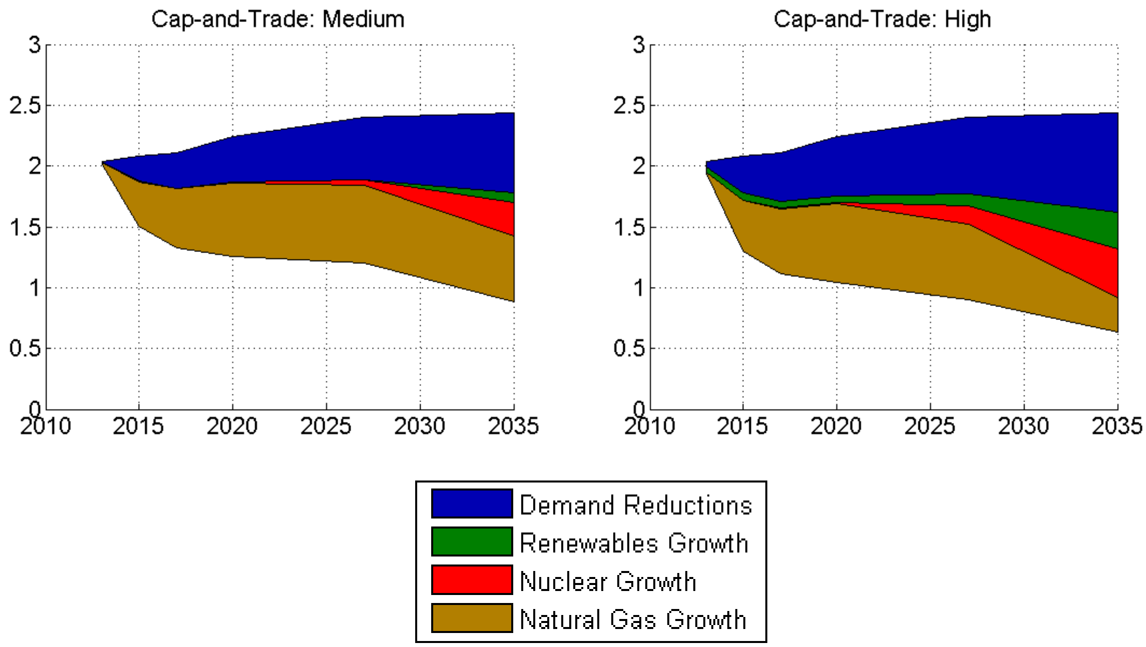
[19] Further analysis of the factors that drive this result remains an objective of future research.

Figure 6. CO_2 Tax Rates and Allowance Prices ($/Short Ton) and Emissions (B Short Tons)



A consequence of the higher emissions cost trajectory in later years under a cap-and-trade scenario is a stronger incentive to invest in nonemitting technologies such as renewables during that period. Figure 7 shows that a small portion of the emissions reductions under the Medium Cap-and-Trade scenario in the later years comes from increased investment in renewables, which do not play a role under the Medium Tax scenario. A similar result is apparent for the High Cap-and-Trade scenario, in which the emissions reductions attributable to switching to renewables are greater than under the analogous tax case (see Figure 2 for the tax cases).

Figure 7. CO_2 Emissions Reductions Profile (B Short Tons)



By assumption in the cap-and-trade scenarios modeled here, the government auctions emissions allowances and thereby generates revenue, as in the carbon tax scenarios. Under the Medium Tax scenario, the present discounted value of tax revenues through 2035 is $517 billion, whereas the present discounted value of allowance revenues under the analogous cap-and-trade scenario is $442 billion. The High Tax scenario also generates more revenue ($607 billion) than the analogous cap-and-trade scenario ($524 billion). The fact that tax rates are higher than allowance prices in the earlier years and lower in the later years contributes to the higher cumulative revenues under the SCC-based tax scenarios because distant revenues are discounted more than near-term revenue.[20]

[20] The welfare consequences of the cap-and-trade policies are not discussed here because they depend on the pace at which allowances are created by the government and the timing chosen by state public utility commissions to account for the value of banked allowances. For a scenario like those modeled here with a positive allowance bank throughout the modeling horizon, the government can pace the creation of allowances in an infinite number of ways—it needs only to create them fast enough for a positive allowance bank to persist and for the allowance price to rise at a constant discount rate. The alternatives for allowance creation that retain constant banking can have different welfare consequences depending on the choices made by the public utility commissions. For these reasons, welfare outcomes for the cap-and-trade scenarios are not reported here.

Conclusions

Concerns about the federal budget deficit, tax reform, and climate change all could be addressed by taxing carbon emissions, which would generate government revenue and reduce the greenhouse gas emissions that contribute to climate change. The electricity sector, a major source of CO_2 emissions in the United States, can achieve emissions reductions at lower cost than other sectors. A carbon tax would affect both the size of electricity markets and the resources used to produce power. Conventional economic wisdom suggests that the socially efficient approach to regulating carbon externalities would be to adopt a tax equal to the social damages associated with an additional ton of CO_2 emissions—the SCC. The federal government has recently published a range of estimates of the SCC that can be used to set a carbon tax. This study analyzes the revenue implications of imposing a range of SCC-based taxes on the electricity sector as well as the impacts on emissions, electricity prices, electricity demand, the technologies and fuels used to produce electricity, and social welfare. These results are also compared to the effects of a cap-and-trade policy with banking that is designed to yield the same total emissions reductions over a 20-year horizon as two of the SCC-based carbon tax paths.

The differences in CO_2 emissions trajectories across the four SCC tax scenarios are substantial, but all of these scenarios produce large initial reductions, followed by more slowly growing reductions. This is in contrast to the reductions path laid out in the Copenhagen Accord, which is less ambitious in the early years, but ramps up quickly over time. We confirm that the level of the carbon tax affects tax revenues, and that revenues are concave in the tax rate because higher taxes reduce the tax base. Depending on the tax level, annual tax revenues in 2020 range from $20 billion to over $80 billion. For the lower tax rate scenarios, revenues grow over time, but for the Tail SCC tax case, revenues decline steadily over time as the tax rate grows and the tax base shrinks.

Electricity prices rise as a result of a carbon tax, with national average prices increasing between 7 and 50 percent in 2020. Price increases are especially large in the middle of the country and in those states that rely heavily on coal generation. States along the coasts are the least affected by a carbon tax, although under the High and Tail SCC scenarios, electricity prices in 2020 rise by at least 16 percent in every state except California.

The changes in electricity demand and technology mix induced by the carbon tax also vary across the different SCC tax scenarios. For the Low SCC scenario, the carbon reductions come primarily from an even mix of reductions in electricity demand and fuel switching from coal to natural gas. In the Medium SCC case, demand reductions and coal–gas fuel switching grow, and nuclear expansion makes a contribution. The High SCC case induces some increased generation from renewables on top of more contributions from demand reductions and nuclear, but a smaller contribution from increased natural gas. Under the Tail scenario, natural gas generation actually declines, with even greater shares of reductions coming from reduced demand and increased generation from nuclear and renewables.

The welfare consequences of an SCC-based carbon tax are similar to what economic theory would predict for a perfectly competitive market in which the optimal tax rate on carbon emissions is set at the value of marginal damages of carbon emissions (i.e., the SCC). We find that taxing emissions based on SCC is welfare enhancing, no matter the value of the SCC. However, it is not necessarily welfare maximizing because the US electricity market is not perfectly competitive. Especially at larger valuations of the SCC, the optimal tax rate may be below the SCC.

Cap-and-trade policies with banking and borrowing produce steeper CO_2 price paths than analogous SCC-based carbon tax scenarios, resulting in expected carbon allowance prices that are lower in the near term and higher in the long term under cap and trade. A consequence of this is that a cap-and-trade scenario results in greater reliance on renewables and a lower carbon intensity configuration of the generation fleet in the long run. Given the uncertainty about the future evolution of estimates of the SCC and the fact that society is risk averse, moving more quickly toward a lower carbon generation fleet could be socially desirable.

Recent federal government efforts to estimate the SCC have produced a range of numbers that are currently being used by federal regulatory agencies to value the climate-related benefits of a host of government regulations. SCC estimates could also form the basis for a carbon tax and would provide a tax level that is commensurate with marginal damages of increased emissions. The large uncertainties represented by the range of SCC estimates complicate the identification of the right tax level. As our results show, the level of the tax matters for its efficacy in reducing emissions, its revenue-raising potential, and the extent to which it accelerates the transition toward a cleaner generation fleet. A solution to this multiobjective problem remains a subject for future research.

Appendix

Table A1. Electricity Sector Outcomes in the Baseline and Policy Scenarios (2020)

	BL	Low	Medium	High	Tail	Cap-and-Trade: Medium	Cap-and-Trade: High
Electricity Price ($/MWh)	85	91	104	111	128	102	109
Consumption (TWh)	3,985	3,848	3,617	3,501	3,300	3,658	3,552
Generation (TWh)							
Coal							
Boilers	1,607	1,247	309	67	3	400	160
IGCC	4	4	4	4	6	4	4
Natural Gas							
Existing CC	705	751	568	489	350	586	550
New CC	411	582	1,465	1,552	1,297	1,428	1,541
Other	42	36	30	59	32	16	16
Nuclear	847	847	854	857	937	853	856
Wind	175	180	188	278	505	172	229
Hydro	255	255	255	255	260	255	255
Other	101	100	85	75	33	87	78
Total	4,149	4,003	3,757	3,635	3,422	3,801	3,688
Nameplate Capacity (GW)							
Coal							
Boilers	311	267	113	57	19	127	85
IGCC	1	1	1	1	1	1	1
Natural Gas							
Existing CC	198	197	195	194	191	194	194
New CC	61	86	212	224	192	207	224
Other	191	184	175	190	177	175	175
Nuclear	111	111	111	112	122	111	112
Wind	61	63	66	97	187	61	81
Hydro	96	96	96	96	96	96	96
Other	60	55	47	45	36	49	48
Total	1,088	1,060	1,016	1,015	1,020	1,021	1,014
CO_2 Tax Rate ($/Ton)	-	11	40	61	121	35	52
Annual CO_2 Emissions (B Tons)	2.2	1.9	1.2	0.9	0.7	1.3	1.0
Cumulative CO_2 Emissions (B Tons)	17	15	11	10	8	12	10
Environmental Surplus (B$)	-	13	28	34	48	30	37
Cumulative NPV Environmental Surplus (B$)	-	83	189	236	337	203	260
Economic Surplus (B$)	41	39	23	7	(27)	(1)	(21)
Cumulative NPV Economic Surplus (B$)	210	198	146	71	(86)	356	325
Tax Revenue (B$)	-	15	32	39	57	30	37
Cumulative NPV Tax Revenue (B$)	0	98	222	277	399	193	245

Notes: Cumulative values cover 2013–2020. CC=combined cycle, GW=gigawatt, IGCC=integrated-gasification combined cycle, NPV=net present value, TWh=terawatt-hour, Ton=short ton, $ are 2009.

Table A2. Electricity Sector Outcomes in the Baseline and Policy Scenarios (2035)

	BL	Low	Medium	High	Tail	Cap-and-Trade: Medium	Cap-and-Trade: High
Electricity Price ($/MWh)	92	101	116	123	141	122	131
Consumption (TWh)	4,419	4,204	3,914	3,816	3,593	3,837	3,719
Generation (TWh)							
Coal							
Boilers	1,835	1,354	270	39	0	97	7
IGCC	4	4	5	34	154	22	91
Natural Gas							
Existing CC	334	354	263	257	132	259	209
New CC	823	1,076	1,736	1,613	749	1,688	1,336
Other	14	12	7	18	5	6	5
Nuclear	874	874	1,078	1,209	1,381	1,134	1,239
Wind	307	286	309	404	945	388	602
Hydro	255	255	255	255	256	255	256
Other	101	101	85	75	48	76	56
Total	4,547	4,316	4,007	3,904	3,668	3,926	3,801
Nameplate Capacity (GW)							
Coal							
Boilers	311	265	109	50	8	90	48
IGCC	1	1	1	5	21	3	12
Natural Gas							
Existing CC	197	196	191	191	181	189	182
New CC	141	166	260	259	200	261	250
Other	202	184	169	177	149	157	141
Nuclear	111	111	136	153	175	144	157
Wind	108	100	113	146	352	141	221
Hydro	96	96	96	96	96	96	96
Other	60	56	46	42	32	42	41
Total	1,226	1,174	1,120	1,118	1,215	1,121	1,148
CO_2 Tax Rate ($/Ton)	-	18	54	76	165	72	109
Annual CO_2 Emissions (B Tons)	2.4	2.0	1.1	0.8	0.4	0.9	0.6
Cumulative CO_2 Emissions (B Tons)	53	45	29	23	15	29	23
Environmental Surplus (B$)	-	10	16	17	17	13	14
Cumulative NPV Environmental Surplus (B$)	-	253	517	607	793	523	618
Economic Surplus (B$)	59	54	12	(7)	(71)	(33)	(58)
Cumulative NPV Economic Surplus (B$)	558	526	299	108	(337)	295	121
Tax Revenue (B$)	-	11	18	19	19	20	22
Cumulative NPV Tax Revenue (B$)	0	294	600	702	943	583	690

Notes: Cumulative values cover 2013–2035. CC=combined cycle, GW=gigawatt, IGCC=integrated-gasification combined cycle, NPV=net present value, TWh=terawatt-hour, Ton=short ton, $ are 2009.

Table A3. Average Electricity Prices in 2020 ($/MWh)

	BL	Low	Medium	High	Tail
AL	90	97	107	113	128
AZ	87	93	100	103	115
AR	72	78	92	99	117
CA	128	130	137	141	147
CO	78	84	103	120	143
CT	153	157	170	179	203
DC	103	104	117	126	148
DE	95	96	110	119	139
FL	104	111	123	131	151
GA	91	98	108	114	130
ID	53	56	61	62	67
IL	77	84	102	113	137
IN	68	76	90	95	113
IA	70	78	91	99	109
KS	78	90	103	111	131
KY	61	66	73	77	89
LA	67	73	86	93	109
ME	108	112	121	128	146
MD	105	105	119	127	148
MA	124	128	140	148	169
MI	86	95	111	117	137
MN	78	86	100	108	119
MS	86	93	104	111	127
MO	60	70	81	87	103
MT	63	67	72	75	80
NE	69	76	89	96	106
NV	93	99	107	110	122
NH	124	128	139	147	167
NJ	117	118	133	143	166
NM	76	81	92	97	111
NY	131	135	150	159	178
NC	81	87	95	99	108
ND	64	70	81	88	97
OH	69	73	93	107	132
OK	72	76	90	100	117
OR	61	64	69	71	76
PA	73	79	101	116	143
RI	118	121	131	139	158
SC	81	87	95	100	109
SD	71	77	90	99	110
TN	81	88	96	101	116
TX	70	74	88	95	116
UT	55	58	63	65	69
VT	106	109	119	125	143
VA	85	91	99	104	114
WA	54	57	61	63	68
WV	61	67	73	78	90
WI	86	95	111	118	137
WY	53	57	65	71	79

References

Averch, H., and Johnson, L. L. 1962. Behavior of the Firm under Regulatory Constraint. *American Economic Review* 52: 1052–1069.

Baumol, W. J., and Oates, W. E. 1988. *The Theory of Environmental Policy,* Second edition. Cambridge, UK: Cambridge University Press.

Bovenberg, L. A., and Goulder, L. H. 1997. Costs of Environmentally Motivated Taxes in the Presence of Other Taxes: General Equilibrium Analyses. *National Tax Journal* 50: 59–88.

Bovenberg, L. A., and Goulder, L. H. 2002. Environmental Taxation and Regulation, in *Handbook of Public Economics,* A. J. Auerbach and M. Feldstein (eds.). Amsterdam: Elsevier.

Burtraw, D., Palmer, K., Paul, A., Beasley, B., and Woerman, M. 2013. Reliability in the US Electricity Industry under New Environmental Regulations. *Energy Policy* 62: 1078–1091.

Burtaw, D., and Woerman, M. 2013. *Technology Flexibility and Stringency for Greenhouse Gas Regulations.*Washington, DC: Resources for the Future.

Carbone, J., Morgenstern, D., Williams, R., and Burtraw, D. 2013. *Deficit Reduction and Carbon Taxes: Budgetary, Economic, Distributional, and Economic Impacts*. Report to the Smith Richardson Foundation. Washington, DC: Resources for the Future.

Cronshaw, M. B., and Kruse, J. B. 1996. Regulated Firms in Pollution Permit Markets with Banking. *Journal of Regulatory Economics* 9: 179–189.

EIA (Energy Information Administration). 2011a. *Annual Energy Outlook 2011*. Washington, DC: EIA.

EIA. 2011b. *Assumptions to the Annual Energy Outlook 2011*. Washington, DC: EIA.

EIA. 2013. *Annual Energy Outlook 2013*. Washington, DC: EIA.

Goulder, L. 1995. Environmental Taxation and the “Double Dividend”: A Reader’s Guide. *International Tax and Public Finance* 2: 157–183.

Goulder, L. (ed.). 2002. *Environmental Policy Making in Economies with Prior Tax Distortions*. Northampton, MA: Edward Elgar.

Greenstone, M., Kopits, E., and Wolverton, A. 2013. Developing a Social Cost of Carbon for US Regulatory Analysis: A Methodology and Interpretation. *Review of Environmental Economics and Policy* 7: 23–46.

Hotelling, H. 1931. The Economics of Exhaustible Resources. *The Journal of Political Economy* 39: 137–175.

IWG (Interagency Working Group on Social Cost of Carbon, US Government). 2010. *Technical Supporting Document: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866*. Washington, DC.

IWG. 2013. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866*. Washington, DC.

Johnson, L.T., and Hope, C. 2012. The Social Cost of Carbon in US Regulatory Impact Analysis: An Introduction and Critique. *Journal of Environmental Studies and Sciences*. 2(3): 205–221.

Office of Management and Budget. 2003. *Circular A-4*. Washington, DC: Office of Management and Budget.

Parry, I. W. H., and Oates, W. E. 2000. Policy Analysis in the Presence of Distorting Taxes. *Journal of Policy Analysis and Management* 19: 603–614.

Paul, A., Burtraw, D., and Palmer, K. 2009. *Haiku Documentation: RFF's Electricity Market Model Version 2.0.* Washington, DC: Resources for the Future.

Paul, A., Burtraw, D., and Palmer, K. 2010. Compensation for Electricity Consumer under a US CO_2 Emissions Cap, in *Reforming Rules and Regulations*, V. Ghosal (ed). Cambridge, MA: MIT Press.

Pindyck, R.S. 2013. Climate Change Policy: What Do the Models Tell Us? *Journal of Economic Literature.* 51(3): 860–872.

Rubin, Jonathan. 1996. A Model of Intertemporal Emission Trading, Banking and Borrowing, *Journal of Environmental Economics and Management* 31: 269–286.

Stern, N. 2006. The Stern Review on the Economic Effects of Climate Change. *Population Development Review* 35: 793–798.

US Environmental Protection Agency. 2013. *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2011*. Washington, DC: US Environmental Protection Agency.

White House, The, Office of the Press Secretary. 2009. President To Attend Copenhagen Climate Talks. Press release, November 25.