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CONTROLLING CARBON EMISSIONS FROM U.S. POWER PLANTS: HOW A TRADABLE PERFORMANCE STANDARD COMPARES TO A CARBON TAX

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1. INTRODUCTION AND POLICY SCENARIOS

Different pollution control policies, even if they achieve the same emissions goal, could have importantly different effects on the composition of the energy sector and economic outcomes. In this paper, we use the G-Cubed[1] model of the global economy to compare two basic policy approaches for controlling carbon emissions from power plants:

1) A tradable performance standard
2) A carbon tax

We choose these two approaches because they resemble two key options facing policymakers: continue implementing a performance standard approach under the Clean Air Act or adopt an excise tax on the carbon content of fossil fuels instead. Our goal is to highlight the important high-level differences in these basic approaches, abstracting from the details of specific policy proposals. We explore a wide variety of the illustrative policies' economic outcomes including: changes in capital stocks and electricity production across eight types of generators, changes in end-user electricity prices, changes in gross domestic product (GDP), overall welfare impacts on the household sector and, finally, one outcome represented in the G-Cubed model and few others: short to medium-run changes in aggregate employment.

Tradable performance standard

As EPA (2003) and Burtraw et al. (2012) explain, under a tradable performance standard (TPS) program, the regulating authority determines a performance standard (e.g., a maximum amount of emissions allowed per unit of output) for a sector it is regulating. This is also called a rate-based standard or intensity standard. Sources with emission rates below the performance standard earn credits they can sell; sources with emission rates above the standard must acquire those credits to cover their excess emissions. The resulting market for TPS credits thus subsidizes production from lower-emitting sources while it discourages production from higher-emitting sources. The United States' Environmental Protection Agency (EPA) has used rate-based trading programs to phase out lead in gasoline and control mobile source emissions.

Here, we analyze a highly stylized version of a tradable performance standard for carbon emissions from electric power plants that approximates the overall national stringency of EPA's draft Clean Power Plan (CPP) regulation.[2] In that rule, EPA gives each state a target rate of carbon emissions from existing power plants based on a set of calculations that take into account the state's current and potential emissions profile. EPA formulates the state-specific

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[1] See McKibbin and Wilcoxen (2013). The version in this paper is 124e.

[2] *Federal Register*, Vol. 79, No. 117, June 18, 2014, p. 34895, Table 8. http://www.gpo.gov/fdsys/pkg/FR-2014-06-18/pdf/2014-13726.pdf. The targets we use are those under EPA's "Option 1."

goals in pounds of CO_2 per megawatt hour (MWh) generated in the state (with some adjustments, and where $MWh_{efficiency}$ is a credit for demand reductions relative to baseline due to energy efficiency):

$$rate\ goal = \frac{pounds\ of\ CO_2}{MWh_{fossil} + MWh_{nonfossil} + MWh_{efficiency}}$$

States must achieve their target rates by 2030. Several important details apply, such as a requirement to meet less-stringent interim goals and the option for states to convert their rate-based goals into mass-based goals. The rule also allows groups of states to comply jointly, for example through emissions trading programs like the Regional Greenhouse Gas Initiative in nine northeast and Mid-Atlantic states.[3]

Our policy scenario is similar (with important caveats) to an implementation of the proposed CPP in which all states comply jointly through participating in a national tradable performance standard system. According to EPA modeling, the proposed CPP would reduce CO_2 emissions in the US electricity sector from a base-case projected level in 2030 of 2,256 million metric tons to 1,701 million metric tons, a decline of 555 million metric tons or about 25 percent.[4] This is about 30 percent below 2005 emissions.[5]

The projected percent reduction in emissions rate attributable to the rule is somewhat smaller than the decline in emissions levels because EPA projects the rule to dampen electricity generation. EPA's projection in 2030 for overall electricity generation is 4,557 terawatt hours (TWh) in the base case and 4,051 under the rule. [6] This implies a national emissions rate decline from about 1091 lbs of CO_2 per MWh to 926 lbs of CO_2 per MWh, or a decline of about 15 percent. As of 2012, U.S. CO_2 emissions from electricity generation totaled 2022 million metric tons,[7] while U.S. power generation was 4047 TWh.[8] The emissions rate was thus 1101 pounds of CO_2 per MWh generated, so this target represents a reduction of about 16 percent relative to the 2012 rate.

We examine a TPS policy that achieves the same 15 percentage point reduction in the 2030 emissions rate from our baseline that EPA projects from its base case. This approach helps

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[3] Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont

[4] EPA(2014), Table ES-2. Summary of Climate and Air Pollutant Emission Reductions Option 1, State Compliance Approach.

[5] Op cit. p. 3-19, Table 3-5. Option 1, state implementation.

[6] Op cit, p. 3-27, Table 3-17. Option 1, state implementation.

[7] EPA (2014a), p. 34843.

[8] EIA (2015), p. 105.

control for differences between the G-Cubed model's baseline and EPA's.[9] Our TPS policy includes an annual compliance requirement such that the overall emissions intensity of the U.S. electricity sector declines linearly from current emissions rates to the target rate. After 2030, we assume the emissions-rate reduction target levels off at the 2030 value. That is, we assume that emissions rates are constrained to remain 15 percentage points below their baseline levels indefinitely.

Consistent with a typical TPS, we assume that in each year operators of power plants with emission rates below that year's target rate can sell credits to operators of units with emissions higher than the target rate. They earn one pound of credit for each MWh they produce under the target rate multiplied by how far under the rate their production falls. For example, if the target rate is 1,000 pounds of CO_2 per MWh generated in a given year, and a renewable electricity generator produces 5,000 MWh in that year, then that producer earns five million pounds (about 2268 metric tons) of credits.

We assume credits are not bankable, so the number of credits bought and sold each year must balance. In each year, we solve for an equilibrium TPS credit price that clears that year's market. As Burtraw et al. (2012) note, banking increases the efficiency of a TPS system by allowing sources to shift their abatement efforts to lower-cost time periods, and it allows utilities to handle unexpectedly large electricity demands, for example from an abnormally hot summer. In contrast to the policy we examine here, EPA's proposed rule is actually an amalgam of bankable and annual approaches; it offers states flexibility to meet a cumulative emissions rate target in the interim compliance period through 2029, but it requires states not to exceed their specified target rates during calendar 2030.

In addition to the points mentioned above, our policy scenario differs from implementation of the CPP in several other ways. First, it sets a single rate-based standard for the nation as a whole, so it does not reflect the inter-state transfers that would arise from EPA's disparate state targets. Also, we assume that all new and existing generation goes into the MWh total in the denominator of the emissions rate target. The CPP's focus in on existing power plants, and as of this writing EPA has not yet finalized the way in which certain new generation capacity would be counted in the rate formula.[10]

Finally, in our TPS scenario, we do not include a measure of energy efficiency or demand reduction in the denominator of the rate calculation. This means that compliance must come solely through the composition of generation across technologies and not through reductions in the total amount of generation. In principle, however, the way we have represented the rule's environmental performance (matching the projected percentage decline in the unadjusted

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[9] G-Cubed's baseline in this study projects significantly greater generation growth and emissions rate reduction than EPA's base case.

[10] Such as new natural-gas-fired combined cycle units, for which separate rules have been proposed.

national emissions rate) incorporates the overall effect of existing state-level energy efficiency programs and other demand-side management efforts.

TPS vs. clean energy and renewable electricity standards

A clean energy standard (CES) is a policy that sets numerical goals for the share of electricity generated with fuel sources deemed "clean." In most proposed implementations, electric utilities would receive tradable credits for electricity they generate in qualifying ways.[11] These are similar to the tradable credits in a TPS except that a CES does not distinguish between the different carbon intensities of generation sources that are not classified as clean. For example, suppose two operators of coal-fired power plants produce identical amounts of electricity, but one is more efficient than the other and so burns less fuel (technically, it has a lower heat rate) and thus emits less CO_2 for the electricity it produces. In a CES, those two operators would face the same compliance obligation and have to buy the same number of CES credits. In a TPS, the less-emissions-efficient operator would have to acquire more credits. Thus, a TPS is more economically efficient than a CES, all else equal, because it creates incentives on the margin to improve heat rates as well as all the other incentives a CES produces.

A CES is in turn more efficient at reducing carbon emissions than a renewable electricity standard (RES) or renewable portfolio standard (RPS) because in a CES, the crediting for clean generation is tied directly or indirectly to carbon dioxide emissions per unit of electricity generated. In contrast, an RES sets a minimum market share for renewables (in some cases carving out established hydroelectric facilities) and makes no distinction between the carbon content of different fossil fuels. Also, most RPS programs do not allow for credit from nuclear power. It is important to note that under any of these policies—a TPS, CES, or RPS—if overall electricity production increases proportionately faster than emissions fall, total emissions can rise even when regulated sources are in full compliance.

The TPS, CES, and RPS approaches offer no direct incentives for reductions in demand, such as through energy efficiency investments. In fact, the subsidies to cleaner production may shift out the overall supply of electricity such that the retail price drops. Thus without special adjustments (such as EPA includes in its draft CPP), an important channel of abatement incentives is foregone.

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[11] An example of a CES proposal appears in the *Clean Energy Standard Act of 2012* (S. 2146) offered in the 212th Congress by Senators Jeff Bingaman and Lisa Murkowski. That bill would have set a CES beginning at 24 percent in 2015 and increased the requirement by three percentage points per year through 2035. http://www.energy.senate.gov/public/index.cfm/featured-items?ID=1cac9909-e86f-4486-89d5-a13a763ad6ee.

Carbon tax

A carbon tax is likely to be even more efficient than a TPS. Not only does it create an incentive for utilities to switch fuels in exact proportion to the carbon content of each fuel, it also creates retail price signals that encourage end users to reduce demand. On the other hand, a TPS or CES may not raise retail electricity prices as much as a carbon tax, and therefore may be more attractive on political, distributional, and competitiveness grounds.[12] Thus, there may be tradeoffs between the efficiency of the policies and their politically salient outcomes. We return to this in our discussion of the modeling results.

In this paper, we analyze a carbon tax that delivers electric-sector environmental performance equivalent to the TPS policy. We define a tax policy scenario that establishes a simple excise tax on the carbon content of fossil fuels used in the U.S. electricity sector, with the revenue rebated to households as a lump sum.[13] In each year, we solve for the carbon tax rate that achieves the same electric-sector emissions levels that the TPS policy produces. This means our carbon tax scenario produces both the same annual and cumulative emissions outcomes of the TPS, but not necessarily the same emissions per MWh generated.

Finally, it is important to note that the carbon tax trajectory that matches the TPS emissions outcomes will not be cost-minimizing because it will not optimize the intertemporal allocation of capital. Rather, it will match the no-credit-banking limitation in the TPS scenario.

Discussion and literature

A number of modeling studies of TPS, CES, RPS, and carbon tax policies appear in the literature. The studies demonstrate that a CES approach can indeed reduce carbon emissions from the electricity sector and increase the share of renewables in the generation mix. For example, Paul et al. (2011) outline important CES design considerations and model different approaches using the Haiku electricity market model. The authors find that a CES with an initial target of 12.3 percent clean electricity and ramping up to a target of 57 percent in 2035 would result in a 30 percent reduction in cumulative electricity-related CO_2 emissions from 2013 to 2035. Annual electricity-related CO_2 emissions fall by almost 60 percent over the same period.

The likely effect of an RPS or CES on electricity prices is less clear. Fischer (2010) notes that an RPS acts as both a subsidy to renewable generators and a tax on non-renewable generators in the form of the credits that one group sells and the other buys. As mentioned earlier, this system can lower or raise overall electricity prices, despite driving deployment of relatively-

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[12] Rivers and Jaccard (2010) discuss advantages and disadvantages of intensity-based policies in the Canadian context.

[13] In McKibbin, Morris, Wilcoxen and Cai (2015) we show that the assumption about revenue use can have important implications for the carbon tax policy.

high-cost renewable capacity, depending on whether the subsidy or tax effect dominates.[14] Fischer's analysis suggests that overall electricity price reductions relative to baseline are likely only under modest RPS standards. Palmer et al. (2011) also note that the effect of an RPS on electricity prices depends on the nature of the electricity markets in particular areas. In areas with competitive electricity prices, an RPS that shifts electricity supply out with new renewables can lower prices. On the other hand, an RPS in areas using cost-of-service regulation can raise prices, particularly if renewable generators are not exporting credits to other markets.

Coffman et al. (2012) used the HELM model, which provides a partial equilibrium projection of Hawaii's electricity usage to 2030, to determine the cost-effectiveness of a CO_2 emissions-weighted CES. According to their study, policies which provide clean energy credits for electricity technology based on lifecycle GHG emissions can decrease costs up to 90% relative to a standard RPS because they provide incentives for fuel switching and improved efficiency for fossil-fired units.

An additional literature compares CES policies to policies that directly price carbon, such as a cap-and-trade program or carbon tax, and other policies that subsidize renewables, such as production tax credits. In general, the literature finds that carbon pricing is more cost effective than a CES, but a CES is more efficient than subsidies. Using the Haiku model, Palmer et al. (2011) evaluate the climate benefits and cost-effectiveness of a cap-and-trade program, an RPS, and renewable electricity production tax credits. They find that the cap-and-trade program reduces more CO_2 emissions than the RPS or the tax credits, even for similar levels of renewable electricity production, because it does not lower the price of electricity, and because it allows for the lowest cost abatement actions.

Fischer and Newell (2008) analyze the cost-effectiveness of six major greenhouse gas emissions reduction policies for the electricity sector: a CO_2 emissions price, a tax on fossil-fuel energy, a tradable emissions performance standard, a portfolio standard, a production subsidy for renewable energy, and subsidies for R & D. They evaluate the policies on the following criteria: emissions reduction, renewable energy production, R&D, and economic surplus. They also evaluate how knowledge spillovers and innovation through learning from R &D impact the desirability of each policy. They find the policies, in order of desirability, are as follows: emissions price, emissions performance standard, fossil power tax, renewables share requirement, renewables subsidy, and R&D subsidy.

[14] A standard that displaces natural gas with renewables can drive down natural gas prices and lower overall generation costs.

Sensitivity analysis: elasticity of substitution across electricity technologies

Finally, in addition to comparing the TPS and carbon tax policies, we also explore the sensitivity of our results to one of the model's key parameters: the elasticity of substitution between electricity from different generation technologies. Although electricity itself is perfectly substitutable, our substitution elasticity accounts for important differences between the technologies in: (1) ramp costs and times (varying the output of coal and nuclear plants is costly and slow relative to natural gas); (2) intermittency (solar and wind), and (3) geographic distribution in the presence of grid congestion (prime sites for solar and wind are remote from load areas).

2. MODELING APPROACH

In this section we present a brief overview of the G-Cubed model and its features that are most relevant for our analysis. An extended technical discussion of G-Cubed appears in McKibbin and Wilcoxen (2013) and a more detailed description of the theory behind the model can be found in McKibbin and Wilcoxen (1999).[15] We use a version of the model that includes the nine geographical regions listed in Table 1. The United States, Japan, Australia, and China are each represented by a separately-modeled region while the rest of the world is aggregated into five composite regions: Western Europe, the rest of the OECD (not including Mexico and Korea); Eastern Europe and the former Soviet Union; OPEC oil exporting economies; and all other developing countries.

Table 1: Regions in the G-Cubed Model

Number	Description
1	United States
2	Japan
3	Australia
4	Western Europe
5	Rest of the OECD, i.e. Canada and New Zealand
6	China
7	Eastern Europe and the former Soviet Union
8	Other Developing Countries
9	Oil Exporting Countries and the Middle East

[15] The type of CGE model represented by G-Cubed, with macroeconomic dynamics and various nominal rigidities, is closely related to the dynamic stochastic general equilibrium models that appear in the macroeconomic and central banking literatures.

Relative to earlier versions of G-Cubed discussed in the references above, the model used here has an extended treatment of electricity production. It disaggregates electricity into eight generation technologies and a delivery sector. The industrial and energy sectors are listed together in Table 2, including a column of codes that will be used in graphs of results. Technical details regarding the extended treatment of electricity can be found in McKibbin, Morris and Wilcoxen (2014).

Table 2: Industry Sectors in the G-Cubed Model

Number	Description	Code
1	Electricity delivery	ElecU
2	Gas utilities	GasU
3	Petroleum refining	Ref
4	Coal mining	CoalEx
5	Crude oil extraction	CrOil
6	Natural gas extraction	GasEx
7	Other mining	Mine
8	Agriculture and forestry	Ag
9	Durable goods	Dur
10	Nondurables	NonD
11	Transportation	Trans
12	Services	Serv
13	Coal generation	Coal
14	Natural gas generation	Gas
15	Petroleum generation	Oil
16	Nuclear generation	Nuclear
17	Wind generation	Wind
18	Solar generation	Solar
19	Hydroelectric generation	Hydro
20	Other generation	Other

The Baseline Scenario

We begin by constructing a baseline scenario that projects future emissions and economic activity under business as usual—that is, in the absence of either a TPS or an electric sector carbon tax. The baseline is generated following the approach outlined in McKibbin, Pearce and Stegman (2009). It begins in 2013 and is calibrated, approximately, to the Department of Energy's Updated *Annual Energy Outlook* Reference Case Service Report from May 2015. It sets G-Cubed's projected productivity growth rates so that the model's baseline results approximate the report's forecasts for oil prices and real gross domestic product (GDP) as well as matching other characteristics of the 2013 starting point.

Along with the baseline for the U.S., we construct a baseline scenario for the rest of the world that reflects our best estimate of the likely evolution of each region's economy without new climate policy measures. To generate this scenario, we begin by calibrating the model to reproduce, approximately, the relationship between economic growth and emissions growth in the U.S. and other regions over the past decade. In the baseline, neither the U.S. nor other countries adopt an economy-wide price on carbon through 2050.

Policy Scenarios

Table 3 summarizes the two policy scenarios we analyze. Both begin in 2013, the first year after the model's 2012 benchmark and the starting point for simulations.[16] We assume the policies are adopted only in the U.S. and cause no changes from baseline in the carbon policies in other countries. We stress that this is not a study of a particular regulation or piece of legislation, or a prediction of how the international climate regime will evolve. Rather, this study is meant to examine the potential economic and environmental outcomes of policies whose ambition is broadly consistent with current proposals and to compare the high level differences in two basic approaches.

Table 3: Summary of Policies

Policy	Emissions goal
TPS	• Achieve 15 % reduction in lbs CO_2 per megawatt hour generated in 2030 relative to baseline and maintain the 15% reduction indefinitely thereafter. • Impose linear decline in emissions rates from current emissions rate to target rate in 2030. • Solve for TPS credit price each year.
Carbon Tax	• Achieve the same electric sector emissions level in each year as achieved by the TPS.

To analyze the role of the elasticity of substitution across generation technologies, we rerun the policy scenarios with higher and lower elasticity parameters. The standard version of the model sets the elasticity to one. The other values include a larger elasticity, 2 ("high elast"), and a smaller elasticity, 0.5 ("low elast"). These runs allow us to test how sensitive our results are

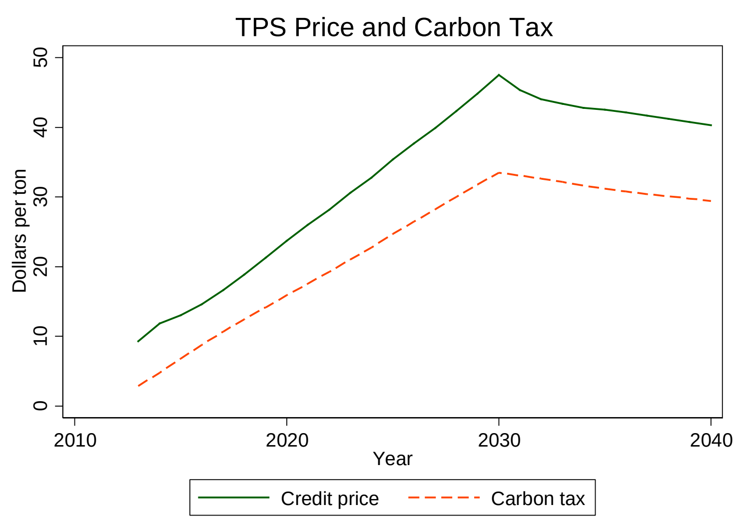
[16] We begin the policies in 2013 rather than 2015 or 2016 because G-Cubed includes foresight and launching the polices at a later date would, in effect, allow them to be anticipated in 2013. This means that the transition in the electric sector will be spread out over an additional two years relative to the proposed version of the CPP.

to assumptions about how easily the electricity sector can shift from dirtier sources to cleaner sources.

3. RESULTS

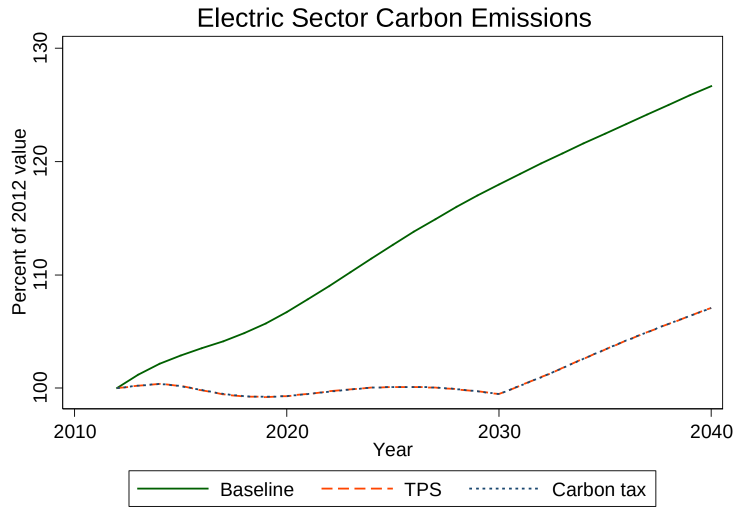
Figure 1 shows the price path for TPS credits and comparable carbon tax path needed to achieve the 2030 target. The TPS price begins around $9 per metric ton of CO_2 in 2013 and rises each year until 2030, when it reaches $47. The carbon tax starts at about $3 per ton of CO_2 in 2013 and rises at a rate similar to the credit price until it reaches about $33 in 2030.

Figure 1



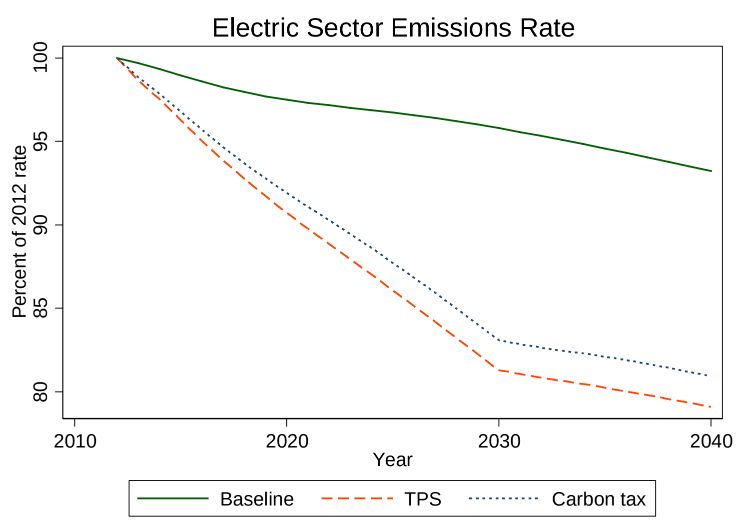
The effects of the policies on electric-sector emissions relative to 2012 are shown in Figure 2. The TPS almost exactly offsets baseline emissions growth and essentially holds emissions constant through 2030. By construction, the carbon tax produces the same outcome.

Figure 2



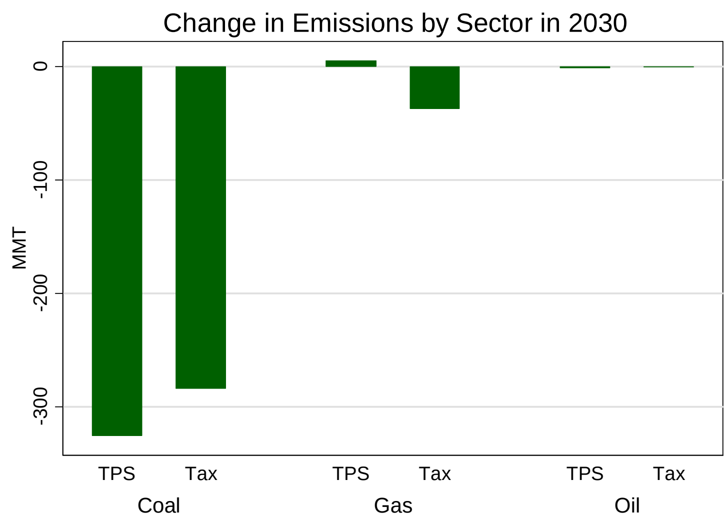
The emissions rates under the baseline and each policy (measured relative to 2012's rate) appear in Figure 3. Both policies are effective in reducing the carbon intensity of electricity generation. The carbon tax produces a slightly smaller long-term reduction in the emissions rate because total electricity generation falls more under the tax (that is, the denominator is smaller) while emissions are identical by construction. The rate continues to fall after 2030 due to the trend reduction in carbon intensity in the baseline.

Figure 3



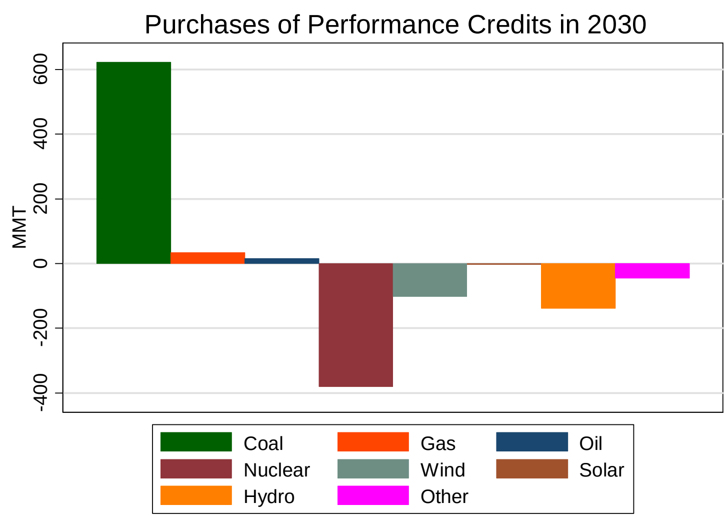
The effects of the policies on CO_2 emissions from the electric sector in 2030 are shown in Figure 4 in millions of metric tons (MMT). Emissions from coal under each policy are at the left followed by emissions from gas and then oil. Emissions from coal fall substantially under both policies. Emissions from gas rise very slightly under the TPS but fall under the carbon tax. Emissions from oil are small and change little in absolute terms under either policy.

Figure 4



Substantial credit trading occurs under the TPS, as shown in Figure 5. By 2030, coal-fired generators are buying more than 600 MMT of credits annually at a total value of over $28 billion. Most of the credits are sold by the largest non-fossil sectors: nuclear, hydroelectric generation and wind.

Figure 5



The two policies have sharply different effects on the producer prices of electricity from different generating sectors. Producer prices in 2030 under the TPS change as shown in Figure 6, where each bar indicates the percentage change in the relevant price from its baseline value. Prices for nuclear and hydroelectricity rise substantially because capital adjustment costs are high in those sectors and it is difficult to expand output.[17] Under the carbon tax, in contrast, producer prices for the fossil-fuel sectors rise but there is little change in the prices for other sectors, as shown in Figure 7.

Figure 6

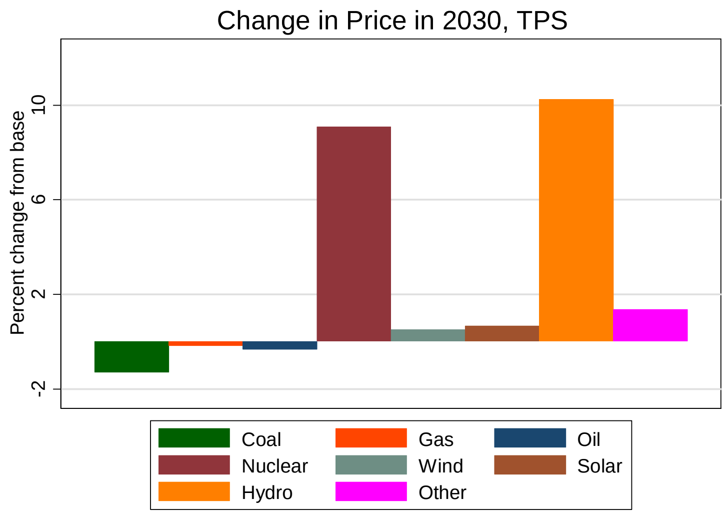
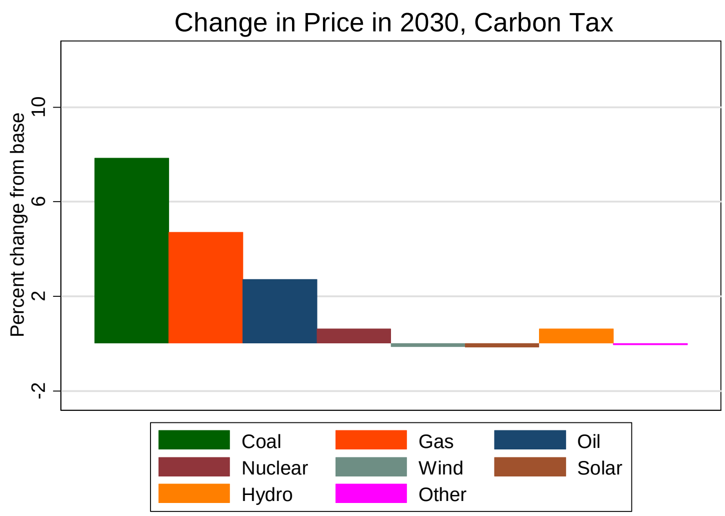


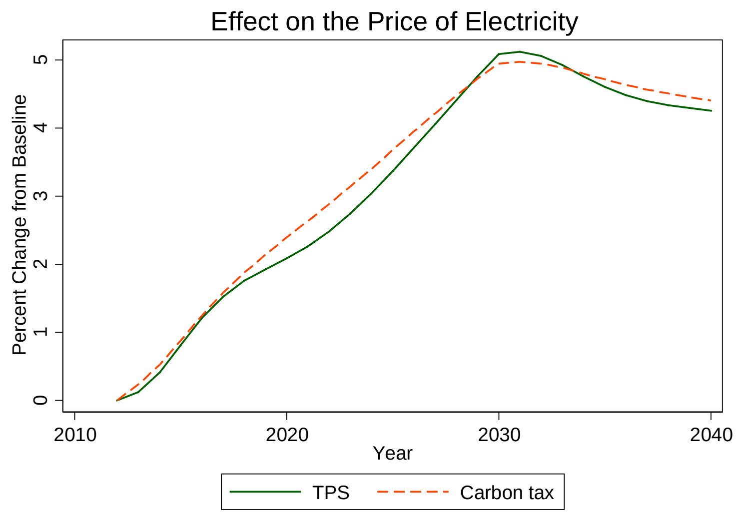
Figure 7



[17] See McKibbin, Morris and Wilcoxen (2014).

Although the policies produce sharply different price effects across generating sectors, their effects on the overall price of electricity, as shown in Figure 8, are very similar. By 2030 the price is about 5 percent above its baseline in real terms. As noted above, it rises under the TPS because the policy drives up the producer prices of the non-fossil sectors more than it lowers the prices of the fossil sectors. Under the tax, the electricity price rises simply because the tax increases fossil fuel costs for generators.

Figure 8



Policies that target emission reductions in the electricity sector can produce emissions changes outside the electricity sector. *Economy-wide* emissions in the United States appear in Figure 9, along with separate curves for emissions from the electric sector and the rest of the economy. We find that both policies reduce economy-wide emissions by more than the reduction in the electric sector alone, largely because overall economic activity falls slightly (discussed in more detail below).

Figure 9

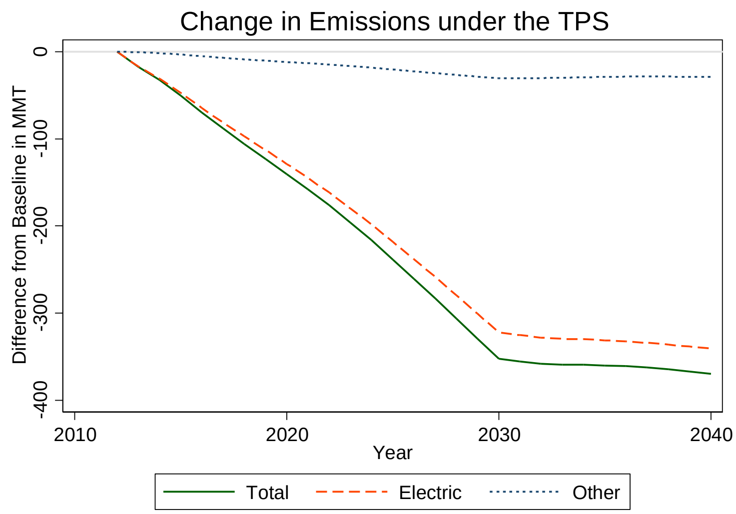
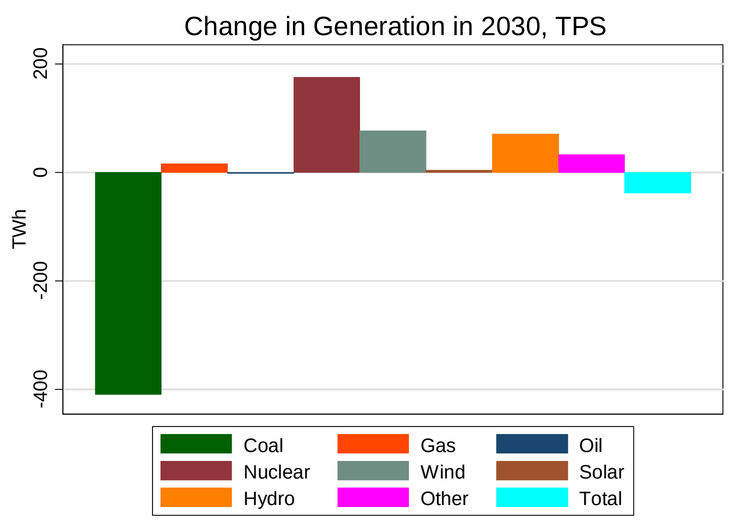


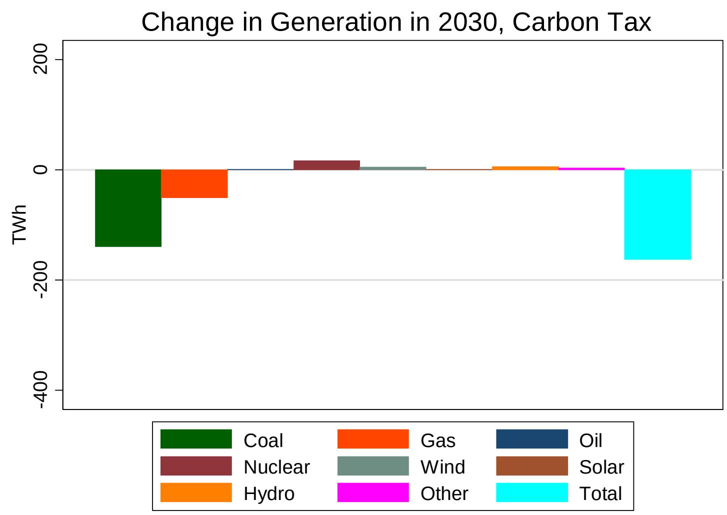
Figure 10 shows the changes induced by the TPS in 2030 electricity generation relative to baseline. Generation from coal falls by more than 400 TWh, and the output of the below-target-rate electricity sectors expands significantly. As shown by the bar at the far right of the graph, the rise in non-fossil output (plus a small rise in natural gas generation) is not quite enough to offset the drop in coal-fired generation and overall electricity output falls slightly. In effect, the power sector achieves its TPS target largely by shifting generation to the non-fossil sectors rather than merely reducing fossil-fired output.

Figure 10



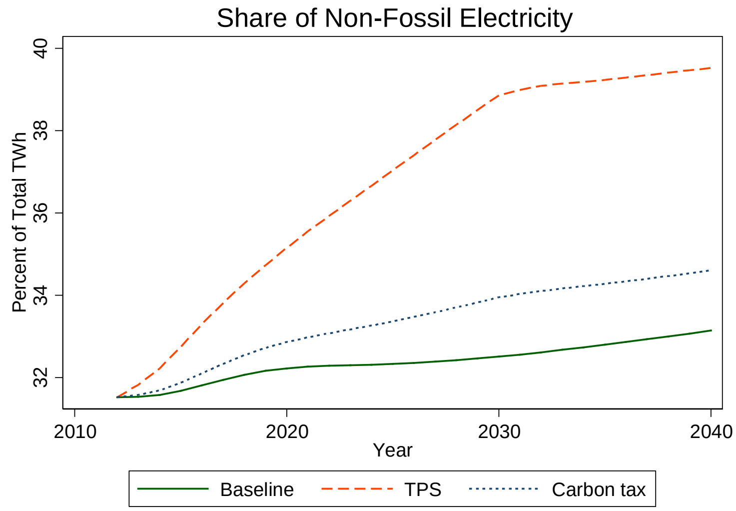
Under the carbon tax, in contrast, the emissions target is achieved almost entirely by reductions in fossil generation, as shown in Figure 11. As indicated by the bar as the far right, overall generation falls by more than 100 TWh, which is essentially the sum of the reductions in the coal and gas-fired sectors; there is little compensating increase in non-fossil generation.

Figure 11



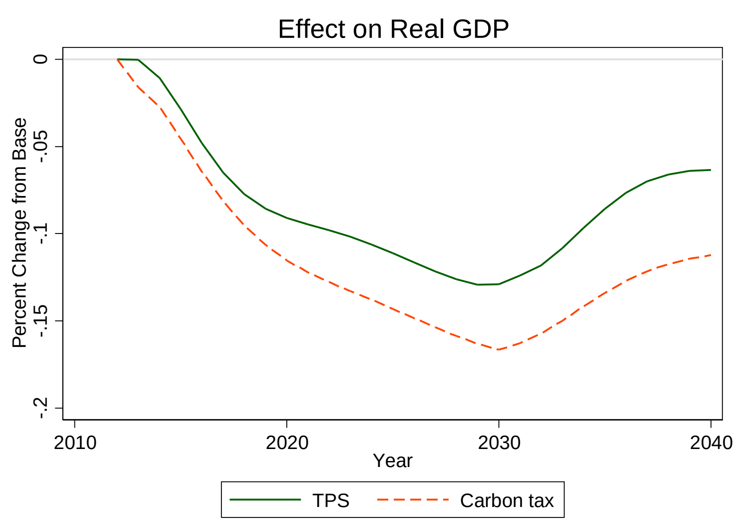
As a result of the change in the generating mix, the share of non-fossil electricity rises under both policies. Under the TPS, the change is significant: as shown in Figure 12 it is about 7 percentage points higher than baseline by 2030. The increase is smaller under the carbon tax: about 2 percentage points by 2030.

Figure 12



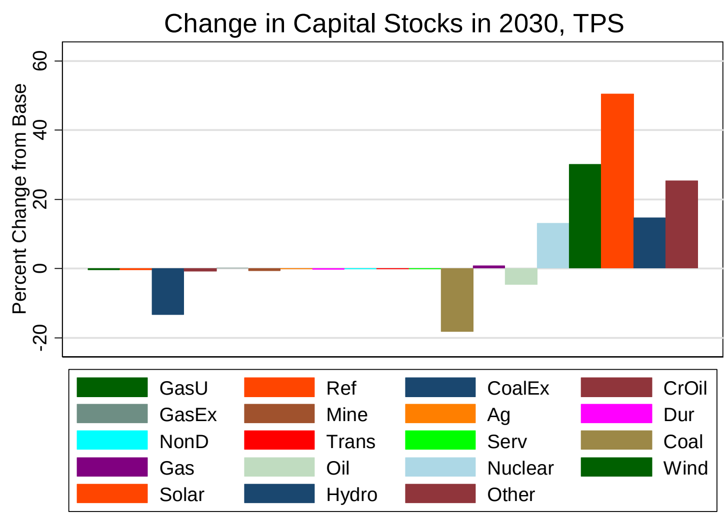
The effects of the policies on GDP are shown in Figure 13. Both policies cause a decrease in real GDP relative to baseline by 2030 of less than 0.2 percent. The drop is up to 0.05 percent larger under the carbon tax. In part, that occurs because the reductions in the coal and gas generating sectors are not counterbalanced by expansions in the non-fossil sectors.

Figure 13



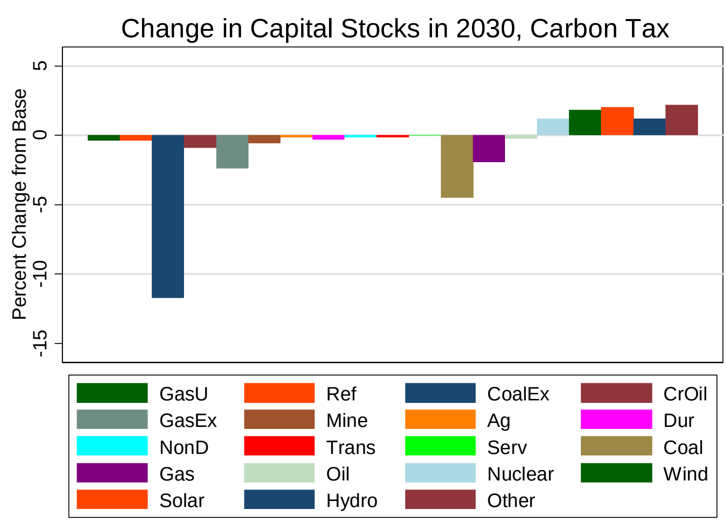
The shift in generation stimulated by the TPS causes capital stocks in the energy sectors to change over time. As shown in Figure 14, capital stocks in coal mining and coal-fired generation decrease by 10 to 20 percent by 2030. However, capital stocks increase in all of the non-fossil generating sectors: by about 50 percent in solar (which is initially small), 30 percent in wind, about 10 percent in nuclear and hydroelectricity (which have large costs of adjustment), and 25 percent in other generation.

Figure 14



In contrast, changes in capital stocks under the carbon tax are generally smaller in magnitude and concentrated in the fossil sectors, as shown in Figure 15.

Figure 15

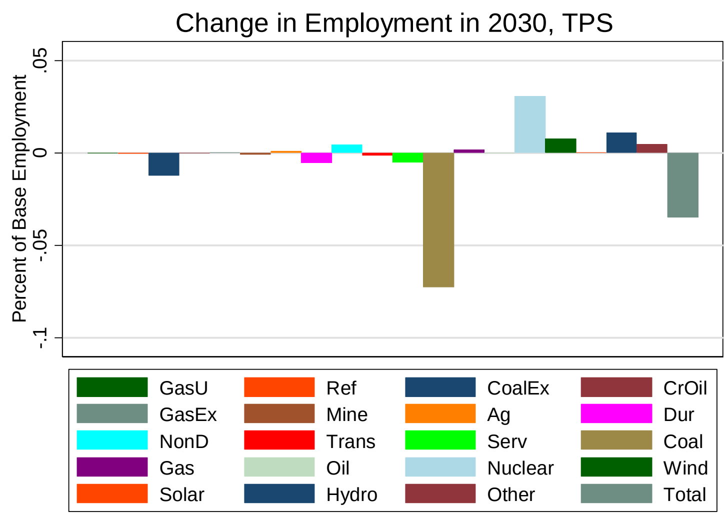


The policies also change employment across the economy slightly. Figure 16 shows the 2030 change in each sector's employment as a percent of national employment in the baseline.[18] The largest reduction is in the coal-fired generating sector, with a somewhat smaller reduction in

[18] That is, 0.1 indicates one-tenth of one percent of the economy-wide labor force, not 0.1 percent of the sector's labor force.

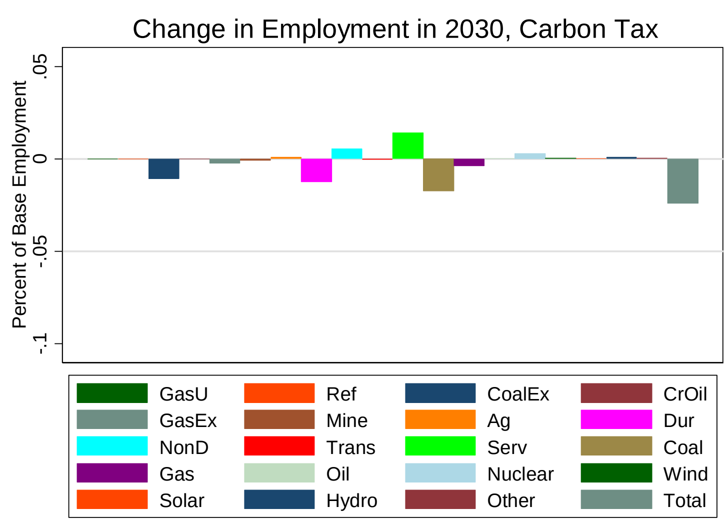
coal mining. Employment rises in most of the non-fossil generating sectors, as well as in non-durables. Overall employment falls very slightly: less than five one-hundredths of one percent, as shown by the bar at the far right.

Figure 16



In contrast, as shown in Figure 17 (plotted using the same scale as Figure 16) the carbon tax causes a smaller employment change in the coal-fired generating sector but also causes a small reduction in the durable goods sector (because it reduces overall investment slightly) and causes increases in employment in nondurables and service sectors. The overall change in employment, again shown by the bar at the far right, is smaller than under the TPS.

Figure 17



Finally, the overall effects of the policies on households can be summarized by the equivalent variation of each policy expressed as a percent of baseline wealth, as shown in Table 4. The TPS has a very small overall welfare cost: about one one-hundredth of one percent of wealth. The carbon tax, in contrast, causes a slight gain relative to baseline: about 3 one-hundredths of one percent of wealth. The increase is due to the lump-sum rebates received by the households as a result of the tax. A carbon tax is thus slightly more efficient than the TPS.

Table 4: Equivalent Variation as a Percent of Baseline Wealth

Policy	Percent
TPS	-0.01
Carbon Tax	0.03

Overall, both policies would reduce electric-sector emissions significantly with very modest effects on the economy as a whole. For an equivalent effect on electric sector emissions, a TPS produces a significantly larger shift to non-fossil generation due to the large credit payments induces between the fossil and non-fossil generating sectors. However, a carbon tax, which shifts some revenue to households through the tax system, produces a slightly better equivalent variation. Neither policy has much effect on overall employment.

Sensitivity to Elasticity of Substitution between Generation Sources

In this section, we examine the sensitivity of the model to a key parameter: the elasticity of substitution in the electricity distribution sector (sector 1) between electricity from different generation sectors (sectors 13-20). In the version of the model used for the results above, the elasticity is set to unity. To explore the importance of this assumption, we also applied the TPS price and equivalent carbon tax under two alternative models: one with a larger elasticity, 2 ("high elast"), and one with a smaller elasticity, 0.5 ("low elast"). For both sensitivity cases we followed the same set of steps used for our main analysis: we calculated the baseline emissions-rate trajectory, applied the TPS reduction, and then calculated the carbon tax that produced equivalent electric-sector reductions.

Table 5 shows results for all three models for key variables in 2030, as well as for each policy's equivalent variations. As the elasticity of substitution rises from left to right across the table, the price of credits falls substantially: from $82 per ton to $28. The carbon tax falls as well: from $40 per ton to $28. Both results reflect the fact that as sources of generation become better substitutes, smaller incentives are needed at the margin to drive generation away from fossil fuels. Interestingly, the TPS and carbon tax results converge as the elasticity increases—both at 2030 as shown in the table, and at other dates as well. Because the marginal incentives converge, other values in the table do as well: the impact on electricity prices falls to 4%, the impact on real GDP declines in magnitude to -0.1%, and the total impact on employment falls in magnitude to about -0.02%. The welfare impact of the TPS policy is nearly zero and essentially unaffected by the elasticity. The effect of the carbon tax is small but positive, and the magnitude declines slightly as the elasticity increases and more of the sector's adjustment is shifted toward the present.

Table 5: Sensitivity of Results to Distribution Elasticity

Variable		Units	Policy	Elasticity Low $\sigma = 0.5$	Elasticity Standard $\sigma = 1$	Elasticity High $\sigma = 2$
Values at 2030						
	Credit price	$ per ton	TPS	$82	$47	$28
	Carbon tax	$ per ton	Tax	$40	$33	$28
	Electricity price	% of base	TPS	7%	5%	4%
			Tax	6%	5%	4%
	Real GDP	% of base	TPS	-0.2%	-0.1%	-0.1%
			Tax	-0.2%	-0.2%	-0.1%
	Employment	% of base	TPS	-0.05%	-0.03%	-0.03%
			Tax	-0.03%	-0.02%	-0.02%
Intertemporal welfare						
	Equiv. Variation	% of wealth	TPS	-0.01%	-0.01%	-0.01%
			Tax	0.03%	0.03%	0.02%

Overall, these results suggest that our core finding—that both policies have very modest effects on the economy outside the electric sector—is robust: the impacts on GDP, employment and welfare are very small and largely invariant to changes in the elasticity. Within the sector, however, the elasticity plays an important role: if it is low, the price of tradable credits could be substantially higher than our main results suggest. The emissions-equivalent carbon tax would rise as well, although considerably less in percentage terms.

4. CONCLUSION

In sum, we find that a national TPS of the ambition reflected in EPA's draft CPP could achieve a significant reduction in future economy-wide emissions relative to business as usual, and would stabilize emissions from electricity generation through 2030 with only a very small reduction in GDP. A carbon tax on fuel purchased by the electric sector would have a similarly small effect on GDP but would be slightly more efficient.

While both policies would have similar and relatively modest effects on the economy as a whole, they have markedly different effects on the electricity generation sector. For an equivalent effect on electric sector emissions, a TPS produces a significantly larger shift to non-fossil generation as a result of the large credit payments it induces between the fossil and non-fossil generating sectors. However, a carbon tax, which shifts some revenue to households through the tax system, produces a slightly better economy-wide outcome as measured by equivalent variation. Both policies cause a variety of reallocations of investment and employment between the clean energy sectors and the rest of the economy.

Finally, it is important to note that many of our key results are robust to wide variations in the assumed elasticity of substitution between different generation technologies. Effects on electricity prices, overall GDP, employment and welfare are modest and change little in response to changes in the elasticity. However, some results are more sensitive: as it becomes easier to substitute between energy generation technologies (particularly between fossil and non-fossil technologies), the price of a TPS credit falls, as does the size of the carbon tax, and the many of the outcomes under the two policies tend to converge. On the other hand, as it becomes more difficult to substitute generation technologies, the differences between the TPS and the carbon tax become larger, as does the efficiency advantage of the carbon tax.

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