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A MODEL-BASED ANALYSIS OF POWER SECTOR ONLY APPROACHES

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EXECUTIVE SUMMARY

In June 2010, as the prospects in the U.S. Senate for an economy-wide cap-and-trade bill dimmed, some proponents of climate policy began to push for an approach more limited in scope. One proposed way to limit the scope of the bill was to apply the cap-and-trade program only to the carbon dioxide (CO_2) emissions from electricity generation. This paper uses an intertemporal computable general equilibrium (CGE) model of the world economy called G-Cubed to compare a power-sector-only climate policy with economy-wide measures that either place the same price on carbon or achieve the same cumulative emissions reduction as the program limited to the power sector.

We first model a power-sector-only scenario (the Core Scenario) that broadly represents the emissions reduction ambition of a proposal offered by Senator Bingaman in July 2010. We calculate a linearly declining series of emissions caps for U.S. electricity generation from 2012 to 2030 that fall to 17 percent below 2005 levels in 2020 and 42 percent below 2005 levels in 2030. We calculate the CO_2 price path that rises at the real interest rate that achieves cumulative emissions equal to the sum of the caps. The price rises at the real interest rate to 2030 and is constant thereafter. We assume that all tax revenues are distributed lump sum back to U.S. households. We then model a second scenario (the Same Price Scenario) in which the carbon price from the first scenario is applied to all fossil CO_2 emissions in the US economy, not just CO_2 from the power sector. Comparing this with the Core Scenario shows the incremental emissions reductions and other effects of expanding the policy from the power sector to the entire economy. The third scenario (the Same Emissions Scenario) calculates the increasing CO_2 price path that if applied to all fossil energy CO_2 achieves the same cumulative reductions as the Core Scenario through 2030. Comparing it with the Core Scenario shows the consequences, for both carbon prices and other effects, of using a narrow rather than a broad-based policy. To isolate the effects of U.S. policy, we assume the U.S. alone adopts these climate policies, with no comparable efforts abroad.

As might be expected, the Core Scenario results in a carbon price in the power sector that is almost twice the economy-wide price that achieves the same cumulative emissions. In particular, the power-sector-only approach requires a price on CO_2 that begins at \$23 in 2012 and rises to \$46 in 2030, whereas the economy-wide price begins at \$13 in 2012 and rises to \$25 in 2030. We find that a price on carbon only in the power-sector does not produce offsetting increases in emissions in other sectors. Rather, we find that carbon emissions outside the power sector fall slightly relative to baseline. This is because of the economic linkages between sectors and the consequences of higher electricity prices on overall economic activity. Global emissions leakage is negligible as the price of oil in other currencies changes little.

All three policies have modest (less than one percent) negative effects on employment in the first decade and little effect thereafter. The policies that price carbon in oil, the Same Price and Same Emissions scenarios, produce much more revenue than the Core scenario.

We find that GDP grows in all of the scenarios at a rate slightly below the reference average in the first decade, but then remains close to reference thereafter. The most environmentally effective policy, the Same Price scenario, also produces the largest short run negative effect on GDP growth and long run negative effect on investment and consumption levels.

We find that all three policy scenarios reduce investment in the capital-intensive energy sector, which lowers imports of durable goods and strengthens the U.S. terms of trade. Thus we find trade consequences of climate policy even in the power-sector-only scenario, which one might think would have relatively low effects on terms of trade given that the U.S. electricity sector uses mostly non-traded fuels. All of the policy scenarios produce an overall decrease in consumption and investment in the U.S. relative to baseline. For consumption, the positive effect from relatively lower price of imported goods is offset by the declines due to higher embodied energy prices.

1. INTRODUCTION

In June 2010, as the prospects in the U.S. Senate for an economy-wide cap-and-trade bill dimmed, some proponents of climate policy began to push for a more limited-scope approach. One proposed way to limit the scope of the bill was to apply the cap-and-trade program only to the carbon dioxide (CO_2) emissions from electricity generation. For example, Senator Bingaman proposed to cut electric utilities' CO_2 emissions by 17 percent by 2020 from 2005 levels and 42 percent by 2030. Starting in 2012, his proposal would have covered utilities that emit more than 25,000 metric tons of carbon dioxide-equivalent per year starting in 2012. Large manufacturers could opt in to the program. Although the Senate did not take up the measure, the proposal established a new line of climate policy discussion.

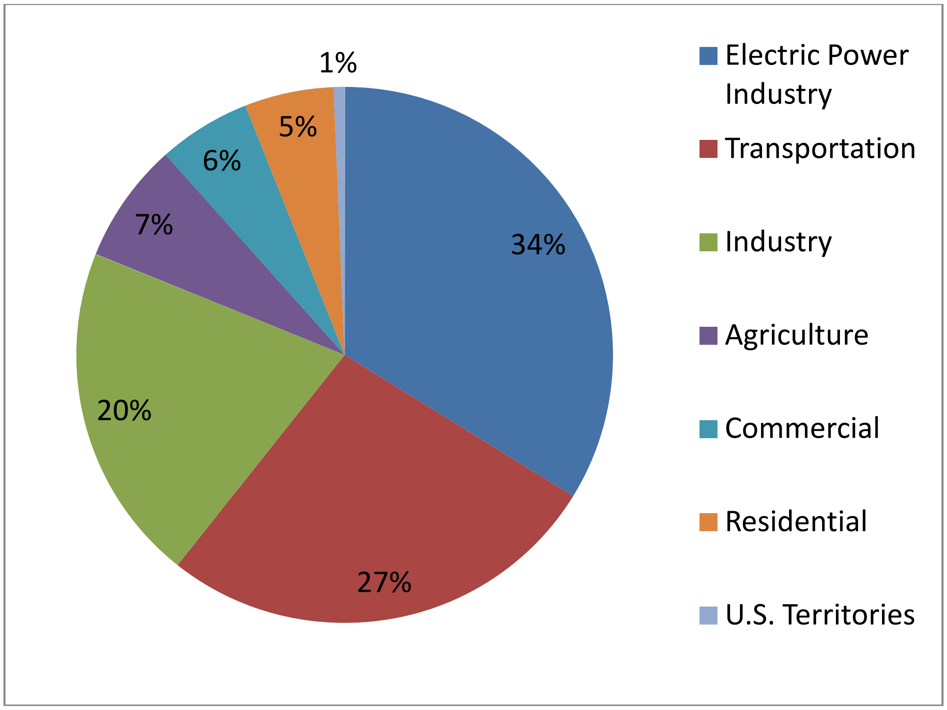
A power-sector only approach offers several advantages that some believe might make it easier to pass than an economy-wide cap-and-trade system.[1] It would be simpler and regulate fewer entities. It would apply to a sector that doesn't oppose the bill (at least under certain conditions) and that already has cap-and-trade experience from the Acid Rain program. It could also potentially provide the bulk of emissions reductions that an economy-wide program would have produced in its early years, owing to the relatively lower cost of abating emissions from electricity generation than from other sources. Along with controlling carbon, a bill focused on the power sector could also rationalize regulation of conventional pollutants from the same sources such as particulate matter, mercury, and coal ash.

However, a power sector only approach would differ importantly from an economy-wide approach. First, it would cover far fewer emissions. Figure 1 below shows that in 2009, the power sector contributed only about 33 percent of total U.S. greenhouse gas emissions.[2] Most

[1] Kyle Danish, "Is a Power Sector Cap a Workable Plan B?" National Journal online edition, June 22, 2010, downloaded August 17, 2010, from *http://energy.nationaljournal.com/2010/06/what-fits-the-bill.php*.
[2] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010*, April 2012. http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-ES.pdf

importantly a power-sector only approach would exclude nearly all U.S. petroleum consumption and coal and gas in industrial and residential uses.

Figure 1: U.S. Greenhouse Gas Emissions by Economic Sector, 2010 (by tons of CO_2 Equivalent)



This limited coverage is intrinsically less economically efficient than an economy-wide approach because it would fail to equalize the marginal abatement costs across sectors and greenhouse gases. That said, the GDP and welfare effects of climate policy depend on more than abatement costs, including adjustment costs and effects on prices of traded goods. This study examines just such general equilibrium outcomes.

Emissions constraints in the power sector, like any non-comprehensive approach, could affect emissions and output in other sectors in complex ways. Higher electricity prices could reduce output in electricity-intensive sectors in particular. More generally, higher electricity prices pass through to all goods and services, and those higher real price levels can lower aggregate output and thus emissions in non-electricity sectors. On the other hand, in theory emissions constraints in the electricity sector could induce substitution into other energy sources within the U.S. economy and thereby raise emissions outside the power sector. We find here that a price on carbon in the power-sector only does not produce offsetting increases in emissions in other sectors. Rather, emissions outside the power sector fall slightly relative to baseline.

For a given price on carbon, we expect the overall economic footprint of an economy-wide approach to be much larger than a power-sector only approach. In particular, an economy-wide tax on greenhouse gases will produce much greater revenue than a power-sector only tax of the same price per ton. Not only would the economy-wide measure cover far more emissions, especially from petroleum-based transportation fuels, but those additional sources are less elastic in demand than fuels used in electricity. We find just such a result in this study.

Also, because the revenue from an economy-wide price signal would be larger, the transfers associated with the program and the resulting distributional effects would also be larger. An extensive literature explores the economic importance of the allocation of the tax revenue or allowance value of a climate policy,[3] including the distributional effects of the transfers and the interactions of the allocation policy with the tax system. In this study we assume that carbon tax revenues are transferred lump sum back to households. We find that policy scenarios with larger transfers increase consumption by liquidity-constrained households most.

This paper uses an intertemporal computable general equilibrium (CGE) model of the world economy called G-Cubed to compare a power-sector only climate policy with economy-wide measures that place the same price on carbon or achieve the same cumulative emissions reduction. This is the first CGE modeling study to model and compare two different sectoral scopes of carbon pricing in the United States. A number of studies have investigated the effects of a carbon tax and/or cap-and-trade system exclusively within the electricity generation sector, and many studies have modeled economy-wide price signals on greenhouse gases.

For example, Chen and Tseng (2011) and others have compared the likely results of a carbon tax and cap-and-trade system confined to the electric power sector. They find that the fluctuating and uncertain price signals of a cap-and-trade system can induce emissions reductions, generator profits, and investments in generation technology that are different than those prompted by an equivalent carbon tax.

We assume all policies are adopted only in the U.S. and that other countries pursue policies consistent with baseline projections. Thus this paper also contributes to the literature on the effect of unilateral climate policy on terms of trade, capital accumulation, and welfare. Other scholars have noted the potential for climate policy to affect terms of trade. For example, Boehringer et al. (2010) model and compare scenarios in which the US and the EU individually and jointly cut CO_2 emissions by 20 percent relative to 2004 levels by employing one of five different policy approaches. Using a static CGE model, they find that the changes in terms of trade “imply secondary effects that can significantly alter the effects of the primary domestic policy.” Paltsev et al. (2010) and Paltsev et al. (2009) examine a wide variety of greenhouse gas abatement policies in the United States. They consider policies that exempt important sectors, but unlike this study, the policy scenarios scale the emissions objective accordingly.

Bednar-Freidl et al. (2010) review the literature on the effects of unilateral climate policy on terms of trade, capital accumulation, and welfare in the world economy. They note that numerous scholars find that import demand declines in countries that unilaterally reduce emissions and that the burden of unilateral policy is shifted—at least partly—from domestic consumers to consumers abroad. They present a two-good, two-country overlapping generations model and investigate unilateral emissions reductions by one country. They

[3] See Morris (2009) for an overview.

conclude that the emissions-reducing country experiences a strengthening of its terms of trade. We return to this issue in our modeling results below.

Whatever its potential advantages and disadvantages, a power-sector only approach would delay the inevitable. To achieve deep cuts, Congress will have to expand climate policy beyond the power sector to address the other 67 percent of U.S. carbon emissions and include other greenhouse gases.

2. MODELING APPROACH

A brief technical discussion of G-Cubed appears in McKibbin et al. (2009) and a more detailed description of the theory behind the model can be found in McKibbin and Wilcoxen (1999). [4] We use a version of the model that includes the nine geographical regions listed in Table 1 below and the 12 industrial sectors listed in Table 2. The United States, Japan, Australia, and China are each represented by a separately modeled region. The model aggregates the rest of the world 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 (Country Aggregation E)

Region Code	Region Description
USA	United States
Japan	Japan
Australia	Australia
Europe	Western Europe
ROECD	Rest of the OECD, i.e. Canada and New Zealand
China	China
EEFSU	Eastern Europe and the former Soviet Union
LDC	Other Developing Countries
OPEC	Oil Exporting Developing Countries

[4] 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.

Table 2: Industry Sectors in the G-Cubed Model

Sector Number	Sector
1	Electric Utilities
2	Gas Utilities
3	Petroleum Refining
4	Coal Mining
5	Crude Oil & Gas
6	Mining
7	Agriculture
8	Forestry & Wood
9	Durables
10	Non-Durables
11	Transportation
12	Services

The Baseline Scenario

A model's assumptions (or in the case of G-Cubed, its endogenous projections) about future emissions and economic activity in the absence of climate policy is called the baseline scenario. A detailed discussion of the baseline in G-Cubed appears in McKibbin, Pearce and Stegman (2009). The baseline in this study is calibrated to the Department of Energy's Updated *Annual Energy Outlook* Reference Case Service Report from April 2009.[5] 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 other key factors.

Along with the baseline for the U.S., we construct a baseline scenario for the entire world that reflects our best estimate of the likely evolution of each region's economy without concerted 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.

The Policy Scenarios

We use the G-Cubed model to compare a cap-and-trade or carbon tax program that covers only those CO_2 emissions that come from fossil fuels used for electricity production to a program that would cover CO_2 emissions from all fossil fuels. We examine three policy scenarios.

[5] The report appears at the DOE's Energy Information Administration website: http://www.eia.doe.gov/oiaf/servicerpt/stimulus/index.html.

The first, which we call our Core Scenario, broadly represents the emissions reduction ambition of the proposal offered by Senator Bingaman in July 2010 to cut electric utilities' CO_2 emissions by 17 percent by 2020 from 2005 levels and 42 percent by 2030. We assume the program imposes a price signal on CO_2 from the electricity sector beginning in 2012. For simplicity we model it as a carbon tax that achieves the cumulative performance of the emissions targets but doesn't necessarily hit the caps year by year. To determine the limit on cumulative emissions, we calculate a series of emissions caps for the power sector for each year from 2012 to 2030. The caps decline linearly from baseline in 2011 to 17 percent below 2005 levels target in year 2020. With a slightly different slope, emissions caps fall from the 2020 target to 42 percent below 2005 levels in 2030. We then sum all the allowed emissions from 2012 to 2030 to compute the total allowed cumulative emissions for electric utilities for the period 2012 to 2030.

Using G-Cubed, we determine a trajectory of prices per ton of CO_2 applied only in the power sector that ensures that the cumulative (2012 to 2030) emissions from the power sector hit the cumulative cap. The price signal on emissions from the power sector begins in 2012 and rises each year by four percent over inflation until 2030. Four percent represents an estimate of the risk-free rate of return that drives the optimal intertemporal choice of incurring abatement costs.[6] A higher discount rate would result in lower estimated initial prices on emissions but faster growth. From 2030 on, the real price per ton of CO_2 emissions in the power sector is held constant at the 2030 level. Emissions outside the power sector are not constrained.

The Core Scenario is consistent with a cap-and-trade program that allows full banking and borrowing of emissions allowances, with no offsets or allowance trading outside the capped sector. It is also consistent with a CO_2 tax on power sector emissions with the specified trajectory of tax rates.

The second policy scenario we model examines what happens if the price on carbon that emerges in the Core Scenario would have instead applied to all fossil CO_2, not just CO_2 from the power sector (the "Same Price" scenario for short). This diagnostic scenario represents a policy with a more stringent cumulative emissions abatement objective but one that still has an intertemporally optimized price path or an economy-wide carbon tax. The result reveals how much more abatement would result from a policy that imposes the same marginal cost of abatement economy-wide as the sector-specific measure does in the Core Scenario.

The third scenario examines what happens if we seek to achieve the same cumulative emissions as the Core Scenario with an economy-wide price signal instead of a power-sector-only price signal (the "Same Emissions" scenario for short). We expect overall costs to be lower despite the equivalent environmental benefit, because the abatement can come from whichever sector provides it at least cost, not just the power sector.

In the third scenario the cumulative economy-wide cap for 2012 to 2030 is the sum of U.S. emissions in the Core Scenario from 2012 to 2030. Thus we determine a trajectory of prices

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[6] McKibbin et al (2009), p. 6, explains the connection between a price signal that rises at the real rate of interest and cost minimization.

per ton of CO_2 that when applied economy-wide ensures that the cumulative (2012 to 2030) emissions economy-wide are the same in both scenarios. Again, we assume the price path begins in 2012 and increases at a real rate of interest of 4 percent each year until 2030, after which the price is held constant.

One important feature of the third scenario is that the scenario achieves the same cumulative *economy-wide* emissions performance relative to baseline as the Core Scenario, not the emissions reductions it achieved solely in the power sector. This distinction is important. Our scenario accounts for any change in emissions the power-sector-only policy induces in other sectors and thus carefully equates the overall environmental performance of the two policies. Alternatively, we could have specified a scenario that would achieve the reductions from baseline the Core Scenario achieves solely within the power sector.

In all of the policy scenarios, we compute the government revenue from the tax on CO_2 and rebate all the revenue lump sum to households. Although we call this price signal a tax, the results broadly apply to an analogous cap-and-trade scenario that auctions allowances and uses the revenue for the same lump sum transfers we posit here.[7] In all the policy simulations, we hold the real value of government spending on goods, services, and labor at baseline levels.[8] Assumptions about how government spending changes (or not) as a result of a carbon tax have important implications for consumption-based measures of household welfare. That's because a carbon tax can lower wages. If government labor quantity demanded is exogenous (as is typically assumed) and wages fall, then the carbon tax induces lower government spending on labor and lower total government consumption. Thus lower wages in the policy simulation effectively shrink the burden of the government and expand consumption by households. This particular beneficial outcome for household welfare doesn't arise directly from the carbon tax but rather by its indirect effects on the overall size of government. To isolate the effect of the carbon tax on welfare independent of changes in the overall burden of supporting government, we hold government spending in these simulations to its baseline by imposing an endogenous lump sum tax that is just the right size to finance baseline government spending.

We have specified policy scenarios in which the carbon price increases at the real interest rate, a trajectory known as a "Hotelling path" after the work of Harold Hotelling. Hotelling (1931) showed that the price of an exhaustible resource grows at the real interest rate when owners maximize the value of their resource over the extraction period. A Hotelling path has the property that it minimizes the present value of the abatement cost of achieving a specified reduction in cumulative emissions. In each year, polluters will reduce emissions whenever the

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[7] As noted above, outcomes of tax and cap-and-trade systems are not necessarily equivalent in practice, for example because the carbon price risks associated with a cap-and-trade system could prompt different investments in pollution abating technology. See Chen and Tseng (2011) and Green (2008) for illustrative investigations of this point.

[8] This paper's results differ substantially from an earlier draft (dated April 20, 2012) for three reasons. The earlier version held government spending on goods and services, but exclusive of labor, constant in in real terms. However, the policy lowers the real wage slightly, so that approach allowed total government expenditure to fall in real terms, which boosted household consumption. The revised assumption used here is that real government expenditure *inclusive* of labor costs is constant relative to baseline. This draft also value-weights the components of GDP, consistent with national accounting methods, whereas the previous draft reported model-based quantity indices. Finally, the new results use an updated trade elasticity for durable goods.

marginal cost of doing so is less than the carbon price. If the carbon price rises at the real interest rate, then present value cost of the last unit abated in each future period will be equal, which is precisely the condition required for minimizing the present value cost of a fixed quantity of abatement.

We stress that one should not interpret this study as an analysis of a particular bill. Rather, we have chosen scenarios that are broadly consistent with the environmental goals under debate to explore policy design options with an eye towards assessing the tradeoffs associated with limiting the scope of climate policy to the power sector, other things equal.[9]

Unless otherwise indicated, all of the assumptions in the Core Scenario (such as the policies of other countries and the tax revenue rebate to households) apply in the second and third scenarios as well. The greenhouse gas emissions included in G-Cubed comprise only CO_2 from energy-related fossil fuel consumption including combustion of coal, natural gas, and oil. This represents a large majority of total U.S. greenhouse gas emissions and the vast majority of emissions growth since 2000. For example, according to the U.S. Environmental Protection Agency, fossil fuel combustion comprised 94 percent of all U.S. CO_2 emissions in 2008, and over 80 percent of gross U.S. greenhouse gas emissions on a CO_2-equivalent basis.[10]

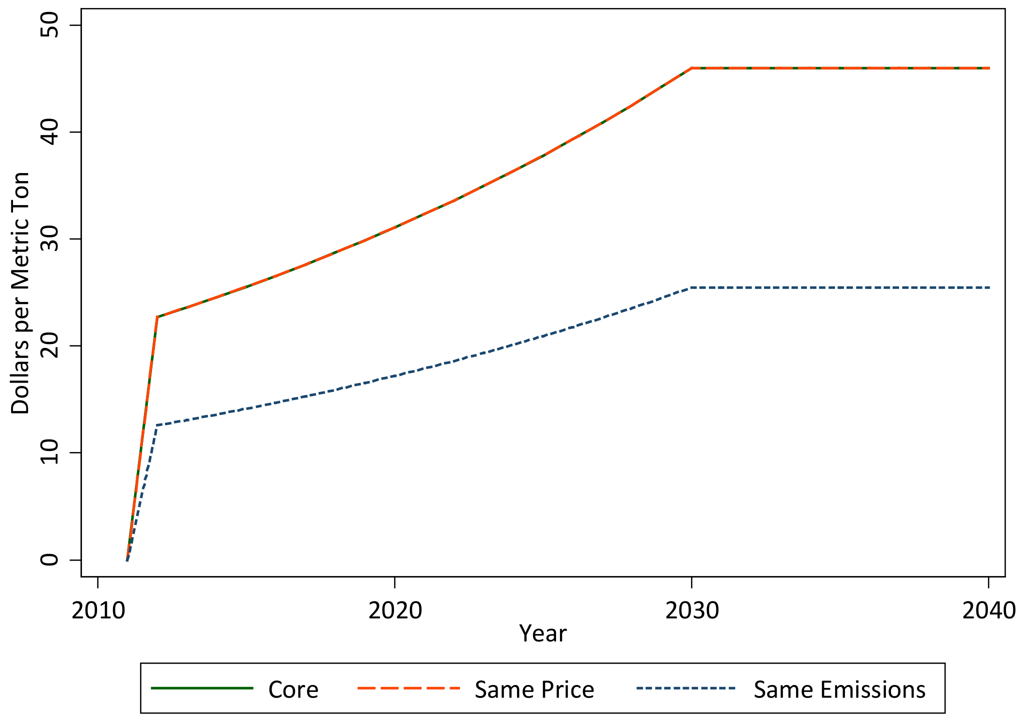
3. RESULTS

Figure 2 shows the price per ton of CO_2 emissions under each of the three scenarios. Under the Core scenario, the model determines the price path such that the electric sector achieves the same cumulative reductions by 2030 as a piecewise linear set of emissions targets hitting 17% below 2005 emissions in 2020 and 42% below in 2030. The result is a path that begins at $23 in 2012 and rises along a Hotelling path to $46 in 2030, after which it is held constant. By design, the price trajectory under the "Same Price" scenario is identical to the Core scenario with the difference that the price applies economy-wide rather than to only fossil fuels used by electric utilities. Under the "Same Emissions" scenario, the CO_2 price applies economy-wide to achieve the same cumulative emissions as the Core scenario. The resulting price trajectory is substantially lower than for the other two scenarios: it begins at $13 in 2012 and rises to $25 in 2030.

[9] Most actual policy proposals include important provisions (such as limiting allowance borrowing, allowing offsets, and controlling non-CO_2 gases) that could result in significantly different costs and environmental performance than the policy scenarios we model here.

[10] U.S. Environmental Protection Agency (2010), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008*, p. ES-4, Table ES-2. Accessed on July 8, 2010: http://epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_ExecutiveSummary.pdf.

Figure 2: CO_2 Prices in the Three Scenarios



The effect of each scenario on electricity prices is shown in Figure 3 below. The Core simulation raises the price immediately by about 10 percent and by almost 40 percent in the long run relative to baseline. The price change under the Same Price scenario is nearly identical apart from some small deviations due to general equilibrium effects. Consistent with the CO_2 price results in Figure 2, the Same Emissions scenario has a much smaller rise in electricity prices: about 5 percent in the short run and a little less than 20 percent in the long run.

Figure 4 shows how the policies impact prices of energy goods in 2030. In the Core simulation, the tax is applied only to coal going into electricity so it doesn't appear in the overall coal industry price. That is, the coal price in the graph is the pre-tax price. It falls slightly due to the drop in coal demand. In the other scenarios, the tax is applied on *all* coal, so it appears in the substantially higher price.

Figure 3: Effect of the Policies on Electricity Prices

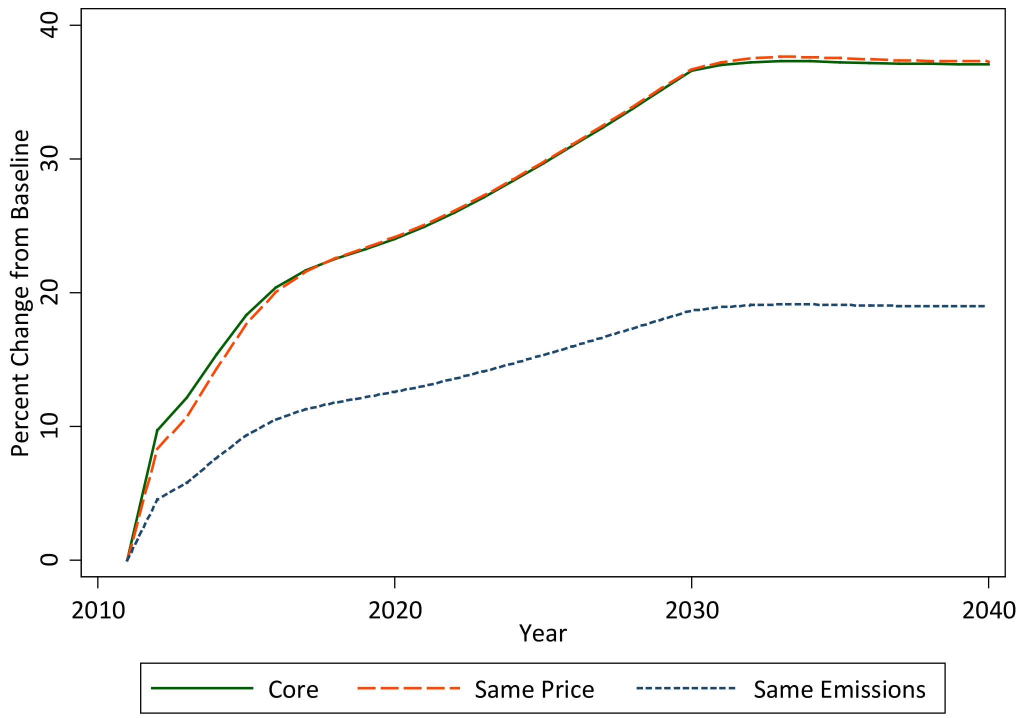


Figure 4: Effect of the Policies on Energy Good Prices in 2030

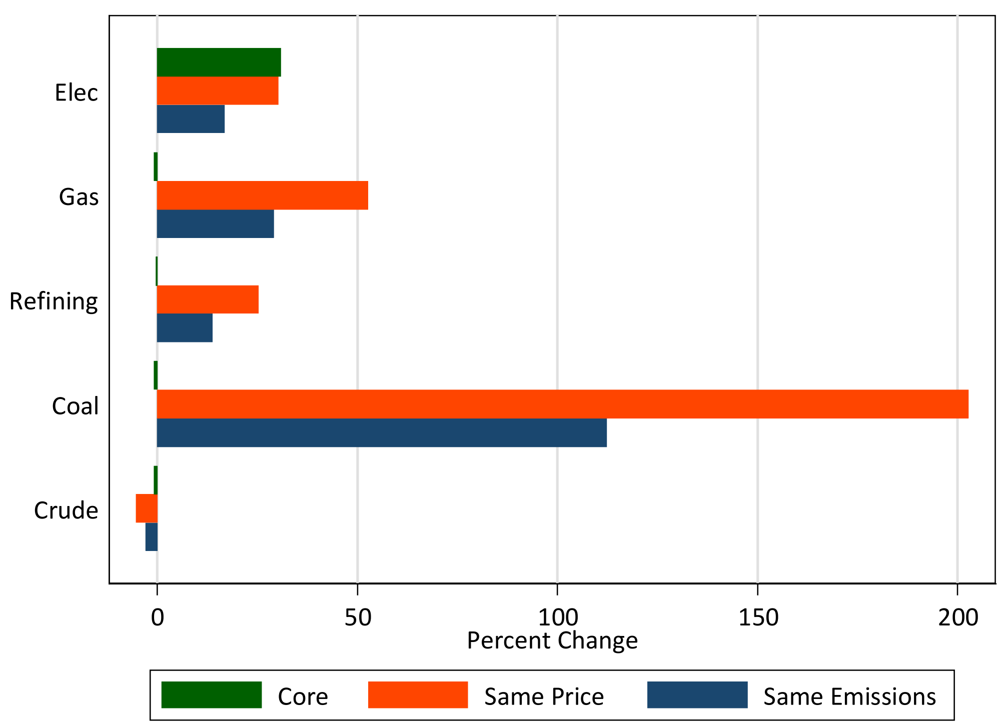


Figure 5 shows the effects of the three scenarios on carbon dioxide emissions from the electric sector. The model's reference case is a solid green line, and the target emissions trajectory is a piecewise-linear gray line. The Core scenario sharply reduces emissions when it is imposed in 2012. Emissions fall slightly below the target trajectory and decline more gradually through 2030. After 2030, when the carbon price stabilizes, emissions begin to rise as the economy continues to grow. Under the Same Price scenario, electric sector emissions fall a bit further than in the Core scenario because the effects due to the CO_2 price in the power sector are augmented by an economy-wide decline in electricity demand that derives from the CO_2 price outside the power sector. In contrast, electric sector emissions in the Same Emissions scenario decline far less than in the other scenarios because some of the abatement occurs outside the power sector.

Figure 5: Effects of the Policies on Electric Sector CO_2 Emissions

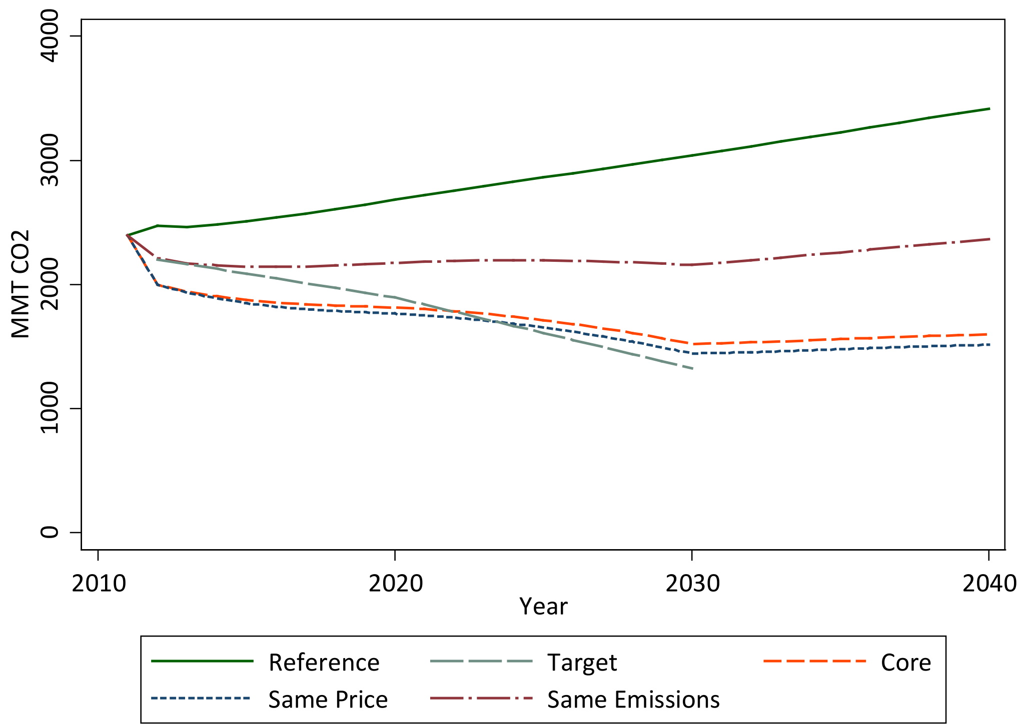


Figure 6 and Table 3 show the effects of the scenarios on total U.S. carbon dioxide emissions. All three scenarios reduce emissions substantially relative to the reference case. The Core scenario reduces cumulative emissions through 2030 by 19 billion metric tons and through 2040 by 37 billion metric tons (17 percent of reference case emissions over that period. By design, the reductions under the Same Emissions scenario match those from the Core simulation. The Same Price scenario results in substantially larger reductions since the price applies to the entire economy rather than just electric utilities: cumulating to 66 billion metric tons by 2040, or 30 percent of reference emissions. Thus, these modeling results suggest that expanding the scope of the policy from power sector only to economy-wide can result in either nearly doubling the emissions reduction relative to baseline (if the CO_2 price in the power sector is applied equally elsewhere) or creating about half the increase in electricity prices (if the environmental performance of the policy is held constant).

Figure 6: Effects of the Policies on U.S. Fossil CO_2 Emissions from Energy

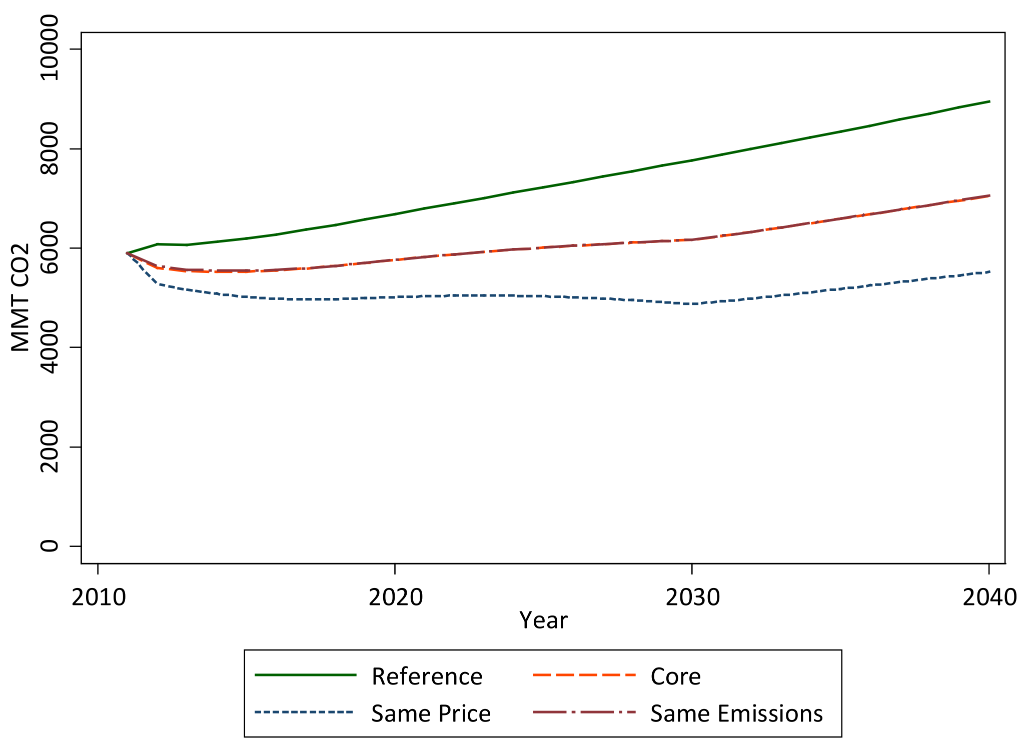
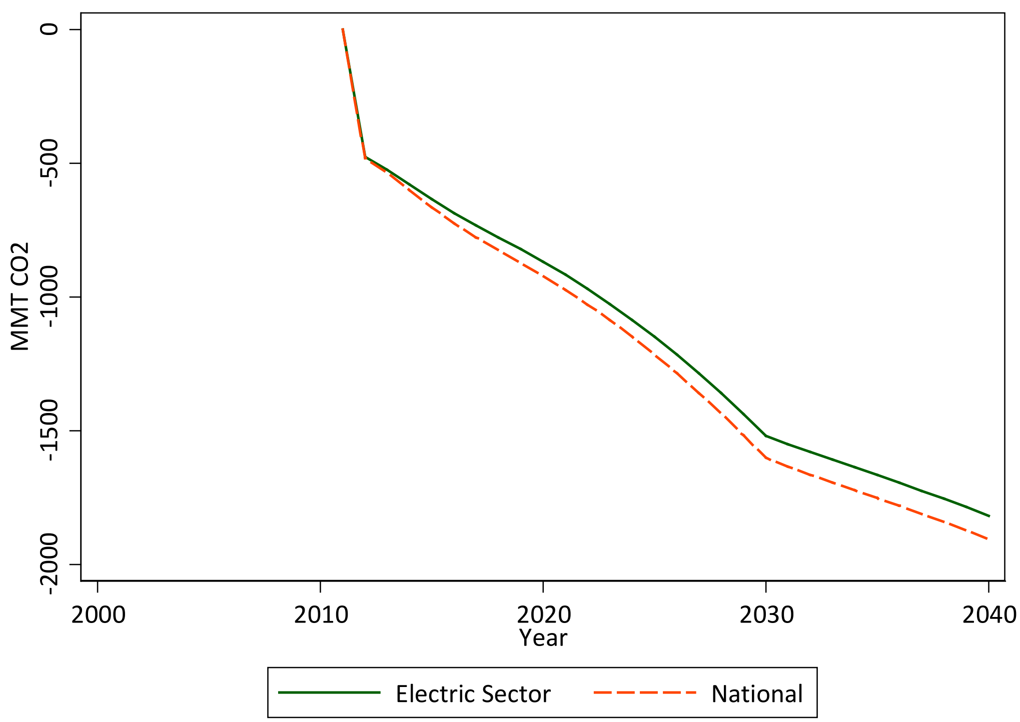


Table 3: Effect of Policies on U.S. Annual and Cumulative Emissions (Billions of metric tons of CO_2 and percentage declines from reference)

	Reductions Relative to the Reference Case				
	2020	2030	2040	Cumulative 2010 to 2030	Cumulative 2010 to 2040
Core	0.9 (14%)	1.6 (21%)	1.9 (21%)	19 (14%)	37 (17%)
Same Price	1.7 (25%)	2.9 (37%)	3.4 (38%)	34 (25%)	66 (30%)
Same Emissions	0.9 (14%)	1.6 (21%)	1.9 (21%)	19 (14%)	37 (17%)

One might wonder whether a power-sector-only approach would induce greater emissions outside the power sector as other fuel users take advantage of the slightly lower fuel prices shown in Figure 4. Figure 7 shows the emissions reductions in the Core Scenario within the electricity sector (the green line) and nationally. We find that emissions leakage outside the electricity sector is actually negative, meaning that any tendency to increase emissions as a result of lower fuel prices is dominated by the broader decline in economic activity.

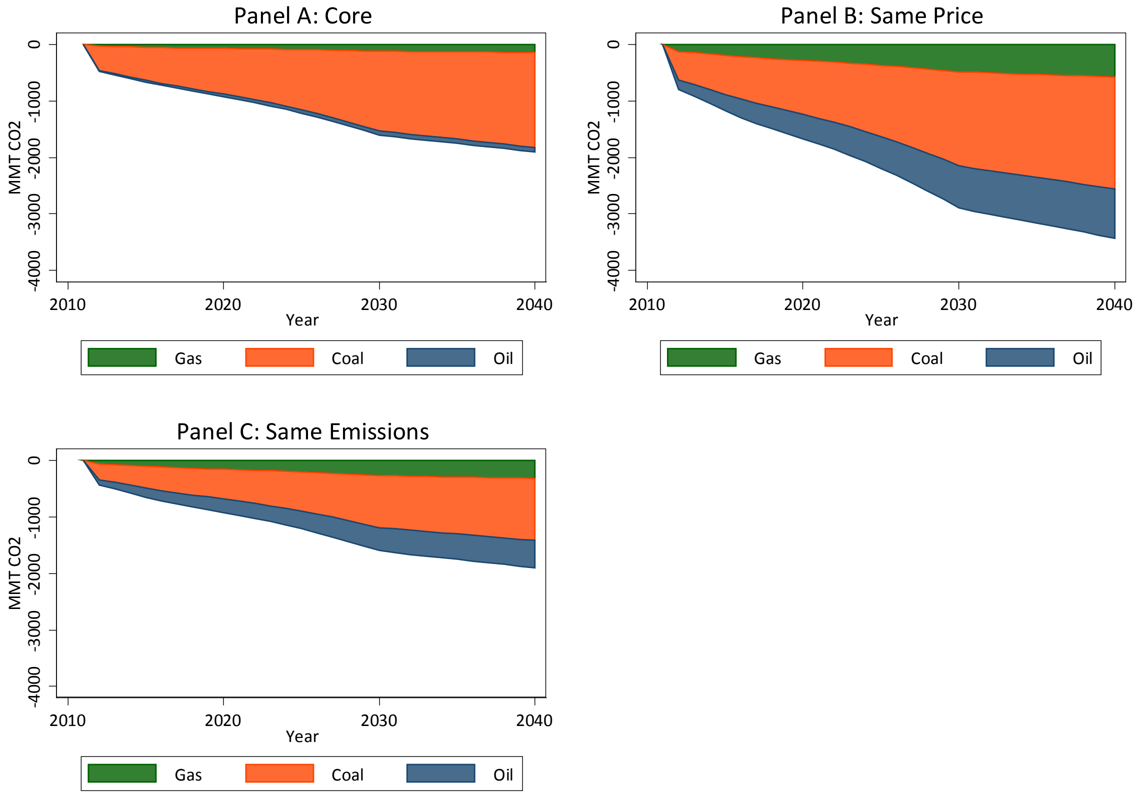
Figure 7: Emissions Reduction in Electricity Sector and U.S. Economy-Wide Core Scenario



The reductions in U.S. emissions can be decomposed into changes associated with each fossil fuel as Figure 8 shows. All fuels decline relative to baseline in all scenarios. Under the Core scenario, about 90 percent of the reduction comes from lower consumption of coal. In contrast under both of the economy-wide scenarios, coal consumption accounts for a significantly lower share of the total decline—about 60 percent rather than 90 percent—while oil and gas together account for about 40 percent. Although as expected the response of fuel consumption to a CO_2 price is less elastic for oil than it is for other fuels, our results show more elasticity for oil than some other studies.[11] The G-Cubed model employs price elasticities estimated from historical relationships between prices and consumption for each fuel type in the U.S. between 1947 and 1987.

[11] For example, EPA(2010) p. 27.

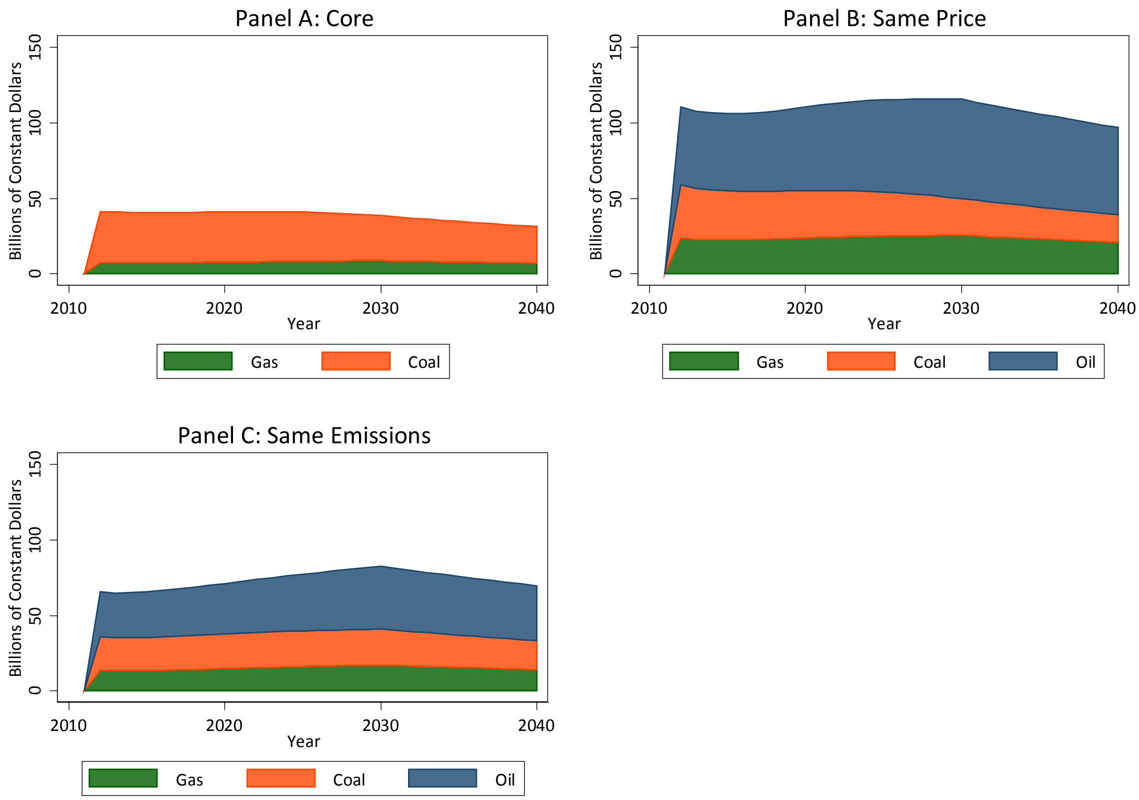
Figure 8: Decomposition of Emissions Reductions by Fuel



The gross revenue effects of the policies appear in Figure 9 below; the net revenue is zero as the revenue returns to households through lump sum rebates. Each panel shows the revenue from charges associated with each of the fossil fuels under one of the three policies. Panel A shows that revenue under the Core scenario comes mostly from coal. The total annual revenue starts at slightly below $50 billion and erodes gradually over time. Although the CO_2 price rises steadily (see Figure 2), the base to which it applies shrinks at about the same rate. The Same Price scenario, shown in panel B, generates far more revenue, nearly three times the Core simulation. About half the revenue comes from charges on oil.

As shown in Figure 8, the demand for oil is relatively inelastic and the amount consumed falls more slowly than the carbon price rises. As a result, revenue associated with oil rises over time in both absolute terms and as a percentage of total revenue. Revenue from natural gas is considerably higher than under the Core scenario because the economy-wide program includes natural gas used outside the power sector as well as inside it. Tax revenue from coal is lower in the Same Price scenario because consumption of coal is lower (Figure 9). Finally, the Same Emissions scenario (Panel C) also generates more revenue than the Core scenario, and the sources of revenue are similar to the Same Price scenario.

Figure 9: Revenue From Carbon Pricing



Exploring the results in more detail, Figure 10 shows the effects of the Core scenario on output of the industries in Table 2 through 2040. Each panel shows percentage changes in annual output relative to the reference case for three sectors. The energy sectors appear in panels A and B, which share a common vertical scale ranging from -50 percent to zero. The policy's largest effect is on the coal sector (panel B) where output falls by about 50 percent by 2030 relative to baseline. The next largest effects are on electricity and natural gas (panel A), where output in 2030 falls by about 20 percent for electricity and 10 percent for natural gas. Output of the remaining sectors is shown on panels C and D; note that the vertical scale is narrower and ranges from -2 percent to 1 percent. Output for those sectors drops much less: generally by 1 to 2 percent in 2030. The output of services (panel D) increases slightly.

Figure 10: Effects of the Core Scenario on Industry Output

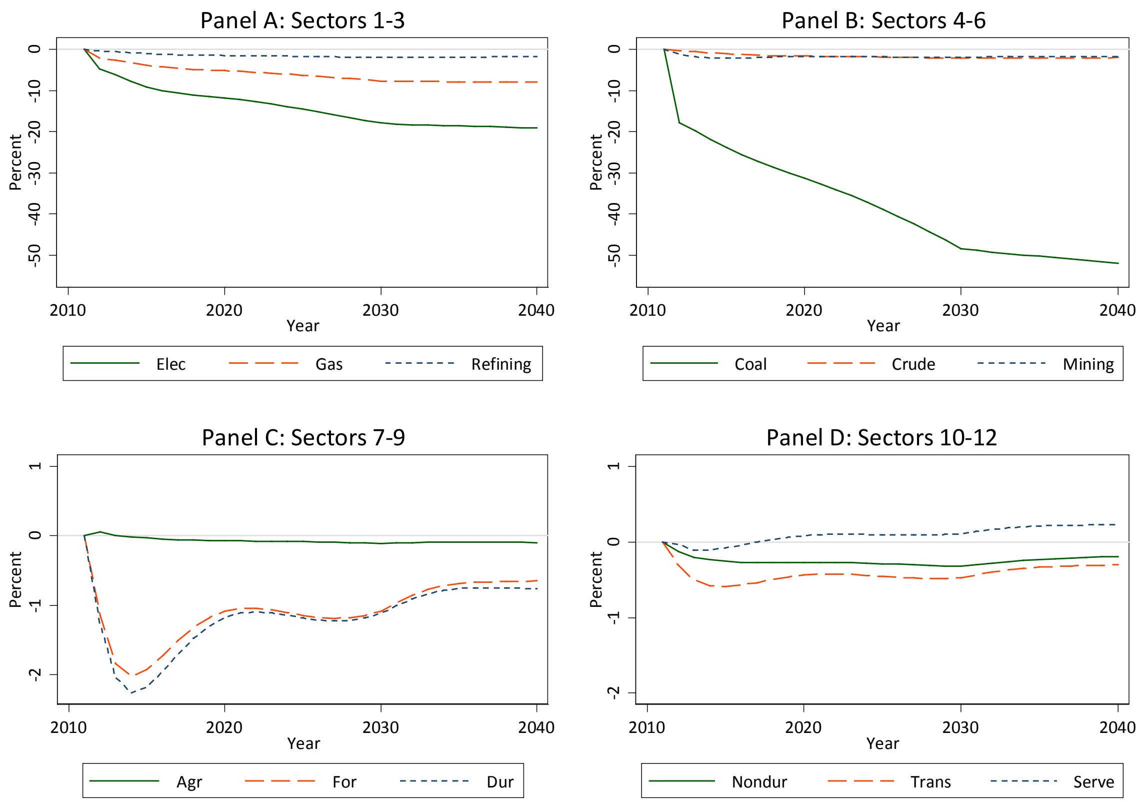
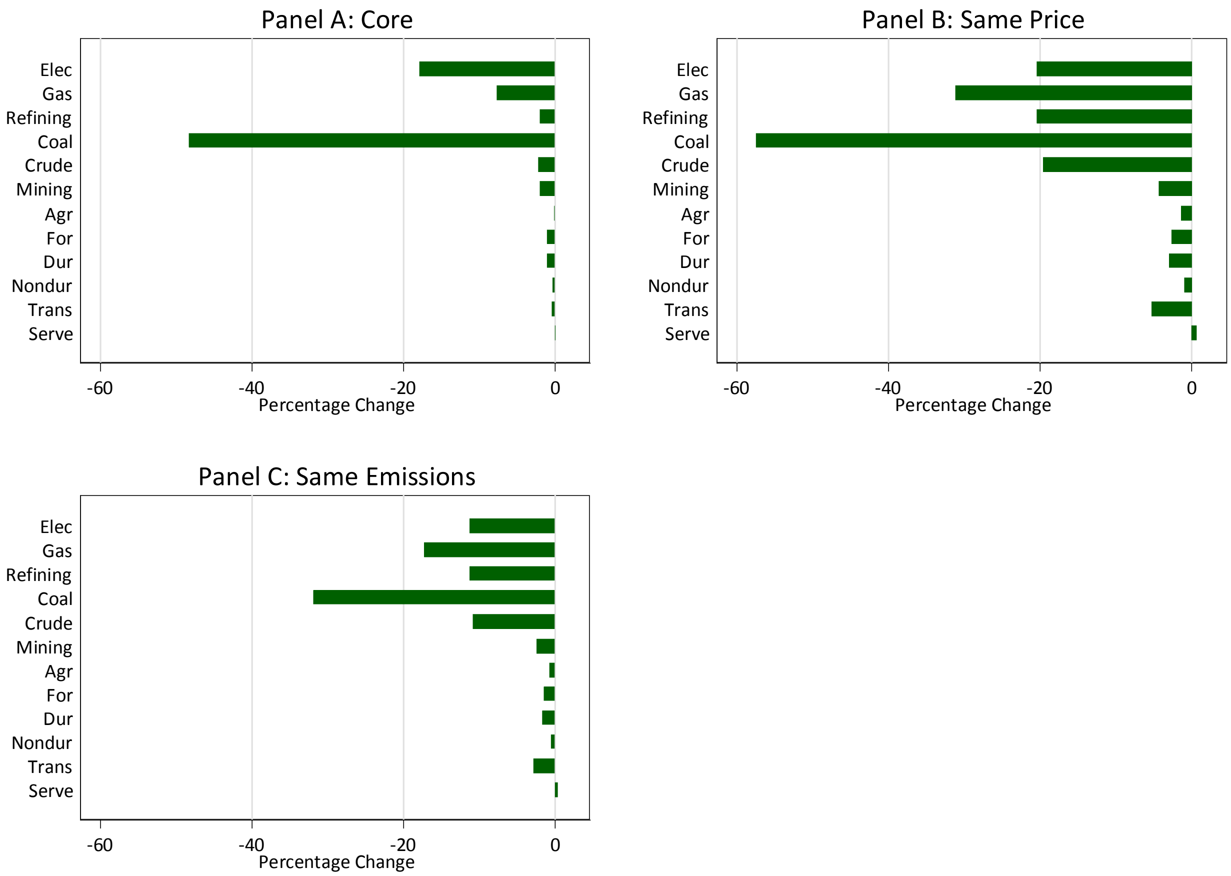


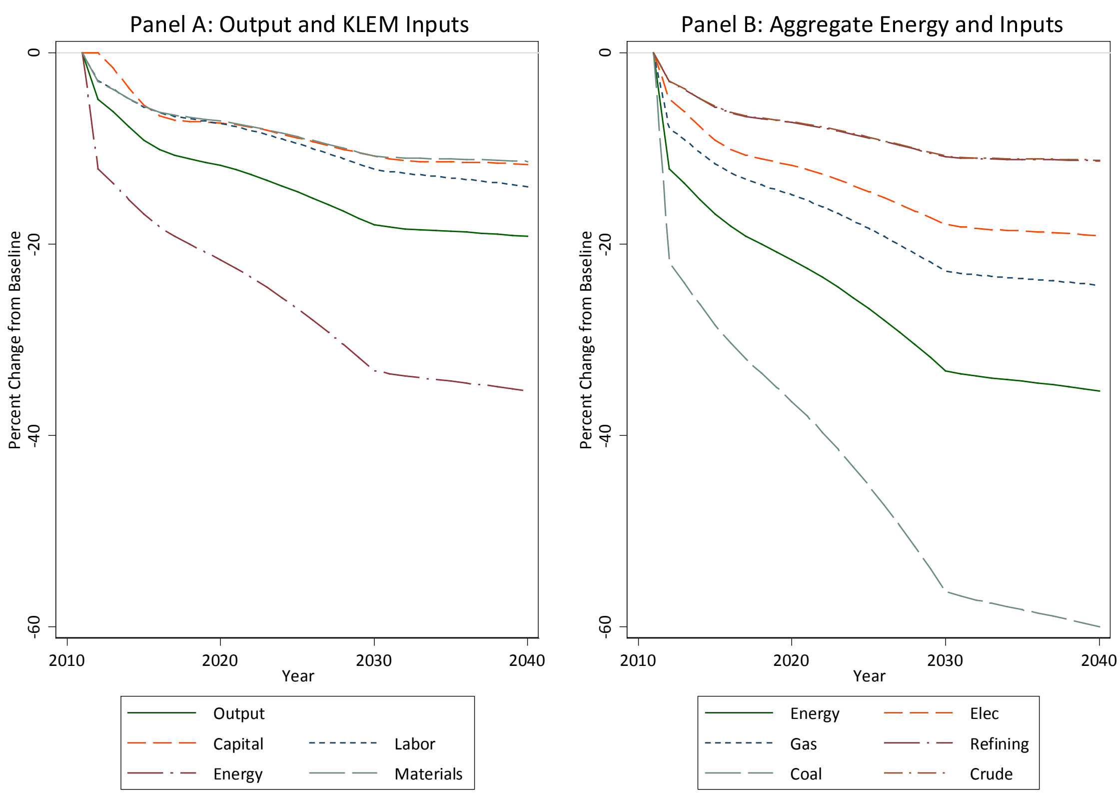
Figure 11 shows percentage changes in industry output in 2030 from the reference case under all three policy scenarios. Panel A shows the Core scenario and highlights the results mentioned above: the effects are concentrated in the coal, electricity and natural gas sectors. In contrast, the economy-wide policies in panels B and C show effects extending to petroleum-related sectors as well. Output declines significantly in the refined petroleum and crude oil sectors, as well as in the transportation sector.

Figure 11: Effects of the Core Scenario on Industry Output in 2030



Focusing on electric utilities, Panel A of Figure 12 shows that the Core scenario causes inputs to electric utilities to decline overall and for the mix to shift away from energy toward capital, labor and materials. In the long run, output drops by 18 percent but aggregate energy consumption drops far more: by 32 percent. Other inputs decline less than output in percentage terms: labor falls by 13 percent and capital and materials each fall by 11 percent. Overall, the carbon price causes both an overall reduction in the size of the industry and a strong shift in its input mix away from fossil fuels and into capital, labor and materials as generation shifts toward renewables and nuclear power.

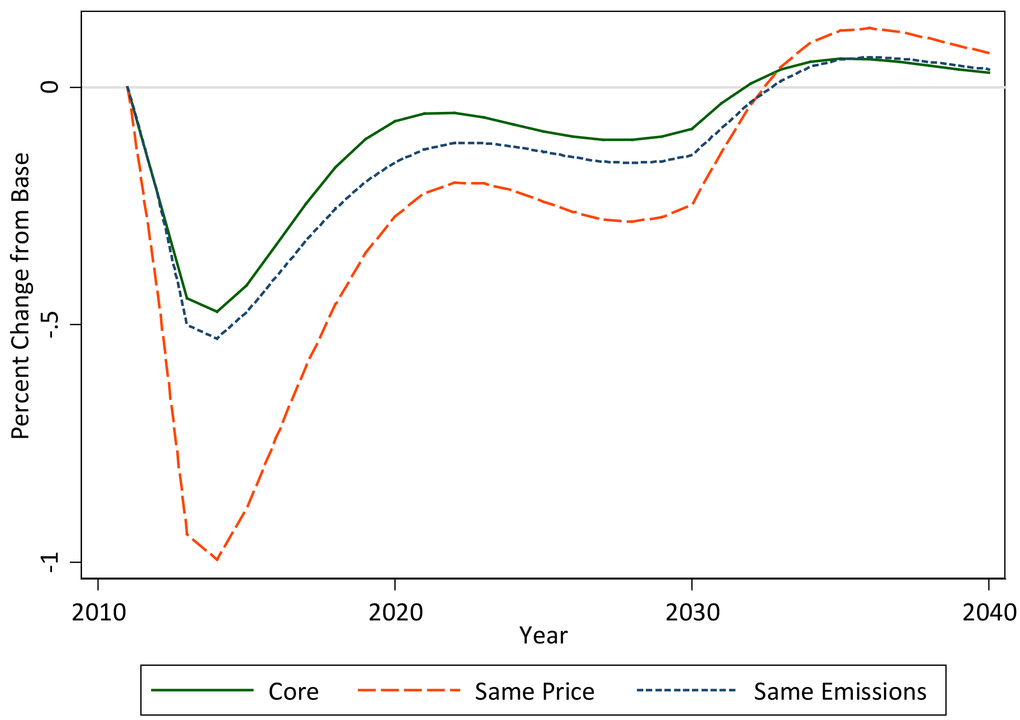
Figure 12: Effect of the Core Scenario on Output and Inputs to Electric Utilities



Panel B of Figure 12 shows the effect of the CO_2 price on the fossil fuel mix used by electric utilities. For reference, the aggregate energy input from Panel A is shown as a solid green line. Utilities shift strongly away from coal, which falls by nearly 60 percent in the long run (substantially more than the 38 percent decline in overall energy) and toward natural gas and other fuels, which fall by much less. Fuels other than coal and natural gas are small in the original fuel mix, so the overall effect of the policy is essentially a sharp shift in fossil generation away from coal and into gas.

A decline in labor costs occurs gradually as the nominal wage slowly adjusts downward in the wake of the policy shock. Figure 13 shows the change in aggregate employment under each scenario measured as a percentage change from the base case. Under the Core scenario, employment falls by about 0.5 percent at the onset of the policy. Over time, the reduction in employment drives wages down, increasing the demand for labor and returning employment to its reference level in the long run. The Same Emissions policy produces employment effects that are nearly identical to the Core scenario. The dip in employment due to the Same Price policy is larger in magnitude but exhibits the same basic pattern.

Figure 13: Effects of the Same Price Scenario on Employment



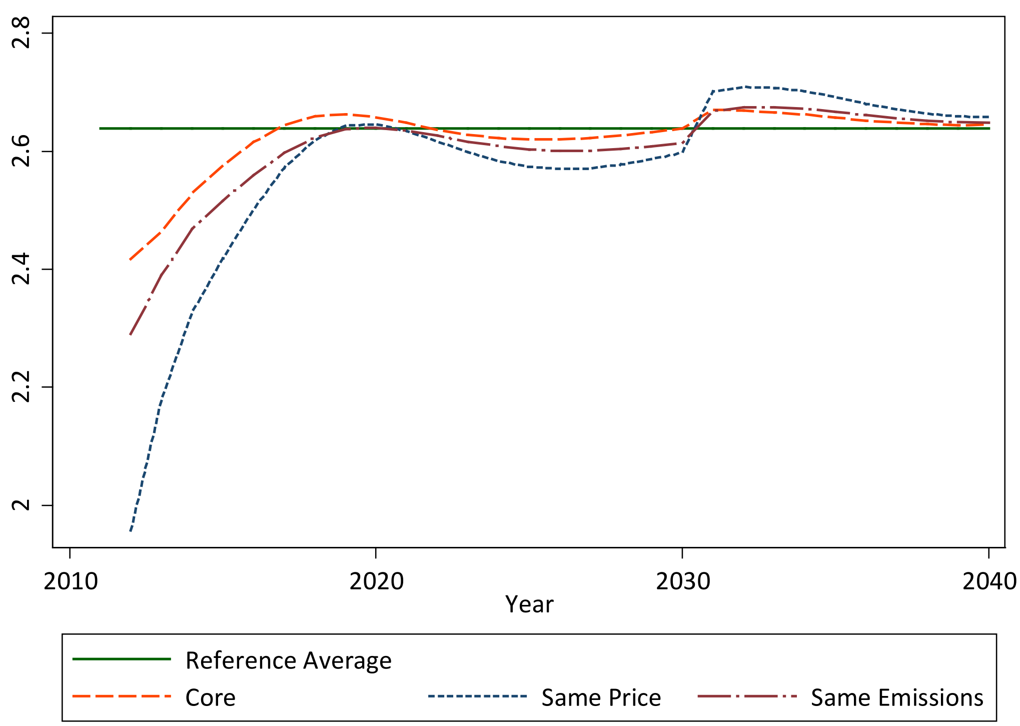
The following figures show the effects of the policies on the growth and composition of GDP and the terms of trade. All three policies strengthen U.S. terms of trade and lower the U.S. interest rate. There are several factors at work. The carbon price reduces the size of the U.S. economy in the long run, which helps drive up the U.S. dollar over the long run. U.S. trade partners demand American goods that are imperfect substitutes for products from other countries, and a lower supply of U.S. goods means a rise in their relative price. Because the relative size of the U.S. economy shrinks gradually as carbon prices rise, the expected real exchange rate appreciates over time rather than jumping to its new long run equilibrium level. At the same time, interest rate arbitrage equalizes the expected domestic-currency returns on holding U.S. versus foreign assets. This means that expectations for a higher dollar drive the U.S. real interest rate temporarily below the world interest rate.

Another channel through which the carbon price affects real interest rates operates through its impact on the marginal product of capital in the U.S. economy. The carbon price reduces the marginal product of capital in a particularly capital intensive sector. This leads to a fall in the real interest rate through arbitrage between the real return on bonds and the real return on capital.

Given the composition of U.S. imports and exports, the stronger dollar lowers the relative price of consumption goods and drives GDP toward consumption and away from investment, particularly in imported durable goods. An overall decrease in consumption arises in all of the policy scenarios because the relatively lower price of such goods is offset by the declines in consumption due to higher embodied energy prices.

At the aggregate level, all three policies cause a temporary decline in the rate of growth of Gross Domestic Product (GDP) at the time they are implemented, as shown in Figure 14. Although GDP growth rates are temporarily lower in the policy scenarios than in the baseline by less than a percent, none of the scenarios produce an absolute decline in GDP levels. From 2008 to 2040, the average annual rate of GDP growth in the baseline simulation is about 2.7 percent. Under the Core scenario, the growth rate drops somewhat in the first year of the policy, to about 2.5 percent, but it rebounds quickly and by 2015 is nearly back to the reference case average. The Same Emissions scenario is roughly similar but has a slightly larger initial drop in growth and doesn't return to the reference rate until about 2017. The Same Price scenario has a much larger initial drop but also returns to the reference rate around 2017. Under all three scenarios, growth is depressed slightly in the late 2020's prior to the stabilization of carbon prices in 2030 but is elevated slightly after that.

Figure 14: Effect of Policies on the Growth Rate of Real GDP



One might wonder why GDP growth is depressed slightly more in the Same Emissions scenario than in the Core scenario. After all, the economy-wide price signal that produces the same environmental benefits should be less costly than the power-sector specific approach, and we know from Figure 2 that the CO_2 price is significantly lower in the Same Emissions scenario. The GDP result derives from the broad application of the CO_2 price to sectors that that are less flexible in response to the price signal than coal reduction is in the electricity sector, along with the follow-on effects as those adjustment costs are passed along in other sectors. Thus we find that although a broader scope of coverage (to achieve the same emissions reductions) might incur lower direct abatement costs in partial equilibrium, the general equilibrium results can be quite different.

Figure 15 shows GDP changes from baseline and how those changes are composed across consumption, investment, government spending and net exports in each scenario. Government spending is unchanged by construction. Consumption quickly rises by about 0.25 to .5 percent of GDP but within a few years falls below baseline. Investment falls abruptly by 1 to 2 percent of baseline GDP and recovers only slightly in the long run. These patterns are strongest in the most environmentally stringent policy, the Same Price scenario.

Figure 15: Effect of Policies on the Composition of GDP

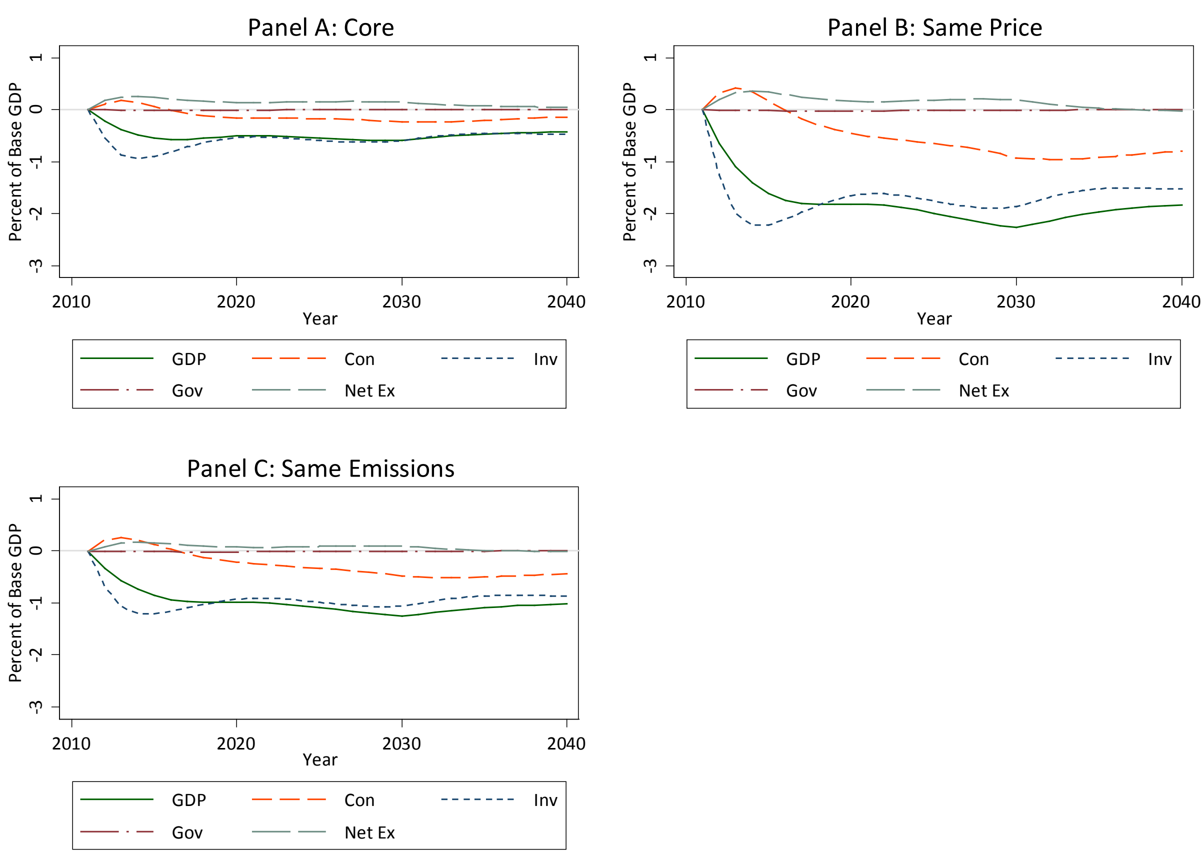
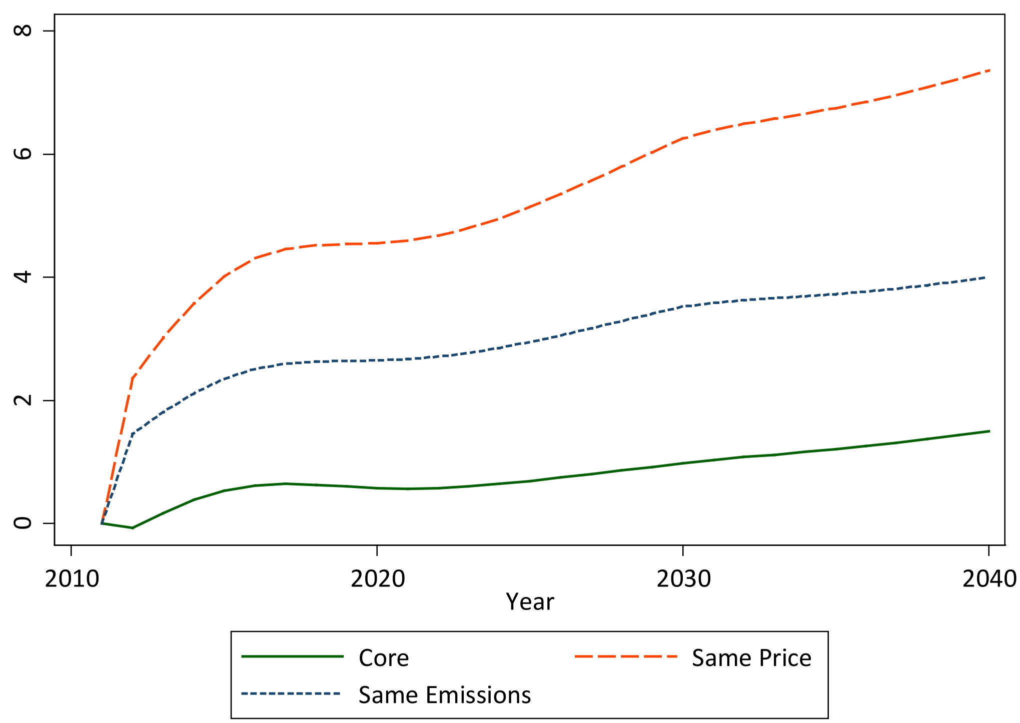


Figure 16 shows the trade-weighted real effective exchange rate for the United States. The positive and increasing percentage change in the graph indicates a strengthening of the U.S. dollar. Under the Core simulation, the exchange rate strengthens by about 1.5 percent in the long run. Under the economy-wide policies, however, the exchange rate strengthens substantially more than that immediately and then rises further in the long run.

In part, the difference between the scenarios is due to the different effects of the policies on U.S. oil consumption and oil imports. As shown indirectly in Figure 8, which charts emissions reductions by fuel, the Core simulation has very little effect on U.S. oil consumption. In contrast, both of the economy-wide policies have significant effects on oil consumption, with the largest effect occurring in the Same Price scenario. As consumption declines, imports of crude oil fall substantially, causing the U.S. trade balance to move toward surplus and the U.S. dollar to appreciate against other currencies. In addition, because the United States is a large consumer on the world oil market, the world price of oil falls, augmenting the strength of the U.S. dollar.

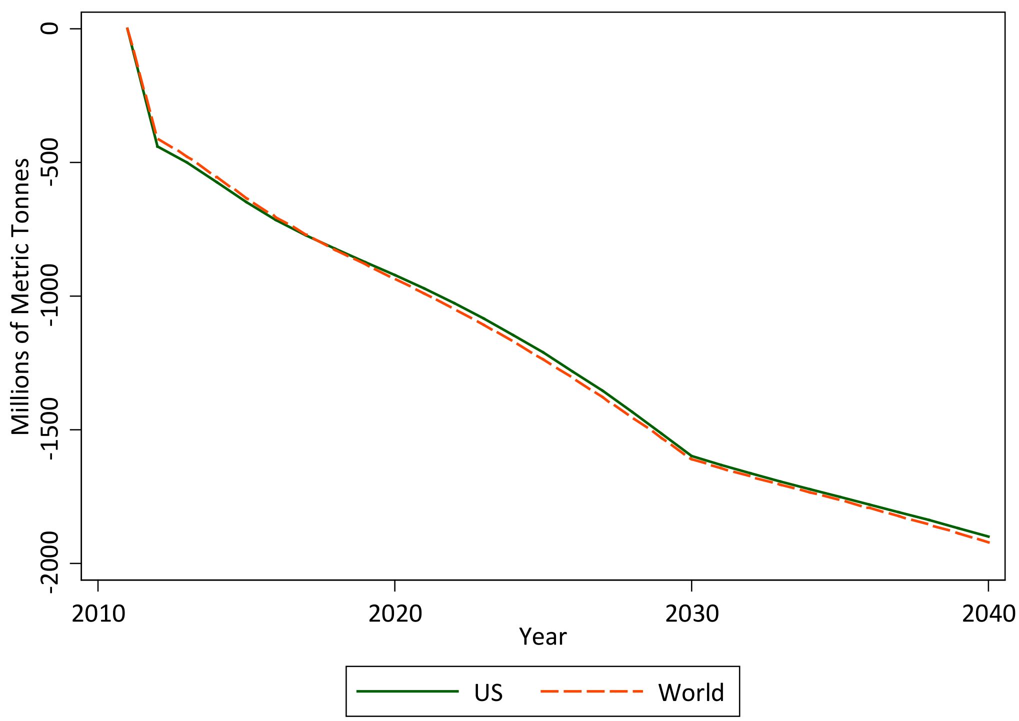
Figure 16: Effect of Policies on the U.S. Real Effective Exchange Rate



Other studies have shown that climate policy can strengthen the term of trade for large economies, but they have not found resulting positive effects on consumption that are as strong as the results here. Boeringer et al (2010) find that cutting US emissions lowers US consumption by about 0.1% and that a slight increase in U.S. terms of trade dampens the fall in consumption.

Finally, we report the results of the policies on global emissions. Just as one might be concerned that a policy confined to the electricity sector could induce greater emission outside that sector, one might be concerned that a policy confined to the U.S. could induce greater emissions abroad. Figure 17 shows emissions reductions relative to baseline (in millions of metric tons) in both the U.S. and the world for the Same Price scenario, the policy one would expect to result in the greatest leakage. We find no evidence of leakage. This is consistent with the results from Figure 4, which shows that the (pre-tax) price of oil changes little in U.S. dollars and Figure 16, which shows the strengthening of the dollar. Thus the price of oil in other currencies does not fall, and price-based leakage is negligible.

Figure 17: Effect of Same Price Scenario on U.S. and Global Emissions



4. CONCLUSION

Our results have several clear implications, summarized in Table 4. First, we find no evidence that confining a price on CO_2 to fossil fuels that go into the electric power sector will drive up CO_2 emissions outside that sector. Second, a power-sector only approach will require a substantially higher price signal on fossil carbon than an economy-wide price that achieves the same emissions reductions. In particular, we estimate that the power-sector-only approach begins at $23 per ton of CO_2 in 2012 and rises to $46 in 2030, whereas the economy-wide price begins at $13 in 2012 and rises to $25 in 2030. Third, expanding the scope of the policy from power-sector only to economy-wide can either increase cumulative emissions reduction relative to baseline by 12 percentage points (if the CO_2 price in the power sector is applied equally elsewhere) or roughly halve the increase in electricity prices (achieving the same environmental performance).

Table 4. Summary of Economic and Environmental Outcomes

	Carbon Price 2012 to 2030	Electricity Price Increase 2012 to 2030	Approx. Annual Revenue	Cumulative Reductions 2012 to 2040, Bmt and %	Approx Effect on Fuels
Core	\$23 to \$46	10% to 38%	\$40 b	37 (17%)	Nearly all coal, with some gas
Same Price	\$23 to \$46	10% to 38%	\$100 b	66 (30%)	½ oil, ¼ coal, ¼ gas
Same Emissions	\$13 to \$25	5% to 18%	\$65 b	37 (17%)	½ oil, ¼ coal, ¼ gas

The Core scenario achieves its emissions reductions almost exclusively from reductions in coal use. Achieving the same environmental outcome via the Same Emissions policy shifts much of the compliance burden onto oil and gas used outside the electricity sector. Because oil demand is inelastic, the Same Emissions scenario raises considerably more revenue than the Core policy. Because it reduces oil imports, the Same Emissions policy also produces a strengthening of the U.S. terms of trade. As would be expected, the effects of the Same Price scenario are qualitatively similar to those from the Same Emissions policy, except much larger in magnitude.

The preferred policy depends on one's objectives, as summarized in Table 5.

Table 5. Summary of Policies by Objective

Policy:	Goal:					
	Min GDP Loss	Min Electricity Price Increase	Min Job Loss	Max. Rev	Max Emissions Abatement	Spread effect more evenly across fuels/sectors
Core	X		X			
Same Price				X	X	X
Same Emissions		X				X

These results suggest that, contrary to what one might expect from considering only direct abatement costs, a carbon control policy that confines the carbon price to the electricity sector does not necessarily result in lower GDP or consumption than an environmentally equivalent policy that also prices carbon used outside the electricity sector and oil. It does, however, concentrate its effects in the price of electricity and places most of the burden of the abatement effort on coal. It also would raise substantially less revenue than a policy that includes oil, the demand for which is relatively less sensitive to price.

A few caveats are in order. Our results, such as some of the terms of trade effects, are likely to be specific to policies implemented by the U.S. because it is such a large economy. Our results could change if other countries adopt more stringent climate policies than are implied by our baseline. Action by other countries would push world oil prices down further, but at the same time it would raise the U.S. price of imported goods other than fuels.

REFERENCES

Bednar-Freidl, B., K. Farmer, and A. Rainer (2010) "Effects of the Unilateral Climate Policy on Terms of Trade, Capital Accumulation, and Welfare in a World Economy," *Environmental and Resource Economics*, Vol. 47, pp. 495-520.

Boehringer, C., Fischer, C., and Rosendahl, K. E. (2010) "The Global Effects of Subglobal Climate Policies," *The B.E. Journal of Economic Analysis & Policy*: Vol. 10: Iss. 2 (Symposium), Article 13.

Chen, Y. and C. Tseng (2011), "Inducing Clean Technology in the Electricity Sector: Tradable Permits or Carbon Tax Policies?" *Energy Journal*, v. 32, iss. 3, pp. 149-74

Environmental Protection Agency, "Supplemental EPA Analysis of the American Clean Energy and Security Act of 2009 H.R. 2454 in the 111th Congress," January 29, 2010. http://www.epa.gov/climatechange/economics/pdfs/HR2454_SupplementalAnalysis.pdf

Green, R. (2008). "Carbon Tax and Carbon Permits: The Impact on Generators' Risks." *The Energy Journal* 29(3): 67-90

McKibbin W., D. Pearce and A. Stegman (2009) "Climate Change Scenarios and Long Term Projections" *Climate Change*, 97(1-2), pp 23-47.

McKibbin, W., A. Morris, P. Wilcoxen, and Y. Cai (2009), "Consequences of Alternative U.S. Cap-and-Trade Policies: Controlling Both Emissions and Costs," The Brookings Institution, June.
http://www.brookings.edu/~/media/Files/rc/reports/2009/07_cap_and_trade/0727_cost_containment.pdf

McKibbin, W J. and P J. Wilcoxen (1999), "The Theoretical and Empirical Structure of the G-Cubed Model," *Economic Modelling,* 16(1999), pp. 123-148.

Morris, A., "Equity and Efficiency in Cap-and-Trade: Effectively Managing the Emissions Allowance Supply," The Brookings Institution, October 2009.
http://www.brookings.edu/~/media/Files/rc/papers/2009/10_cap_and_trade_emissions_allowance_morris/10_cap_and_trade_emissions_allowance_morris.pdf

Paltsev, Sergey, John M. Reilly, Henry D. Jacoby, Angelo Gurgel, Gilbert E. Metcalf, Andrei P. Sokolov, and Jennifer F. Holak. (2008) "Assessment of US GHG Cap-and-Trade Proposals." *Climate Policy* 8.4, pp. 395-420.

Paltsev, Sergey, John M. Reilly, Henry D. Jacoby, and Jennifer F. Morris, (2009) "The Cost of Climate Policy in the United States," *Energy Economics,* Volume 31, Issue 2, pp. S235-43

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