BROOKINGS

QUALITY. INDEPENDENCE. IMPACT.

Consequences of Alternative U.S. Cap-and-Trade Policies: Controlling Both Emissions and Costs

Warwick J. McKibbin
CAMA, Australian National University,
the Brookings Institution and
the Lowy Institute for International Policy

Adele Morris
The Brookings Institution

Peter J. Wilcoxen
Syracuse University and
the Brookings Institution

Yiyong Cai
CAMA, Australian National University

July 24, 2009

McKibbin acknowledges support from ARC Discovery Grant DP0988281. The views expressed in the paper are those of the authors and should not be interpreted as reflecting the views of any of the above collaborators or of the institutions with which the authors are affiliated, including the trustees, officers or other staff of the Australian National University, Syracuse University, the Lowy Institute or the Brookings Institution.

Consequences of Alternative U.S. Cap-and-Trade Policies: Controlling Both Emissions and Costs

Warwick J. McKibbin, Adele Morris, Peter J. Wilcoxen, and Yiyong Cai

Executive Summary

The U.S. Congress continues to debate a potential cap-and-trade program for the control of greenhouse gas emissions. The economic effects of such a bill remain in dispute, with some arguing that a cap-and-trade program would create jobs and improve economic growth and others arguing that the program would shift jobs overseas and hit households with large energy price increases. This report applies a state-of-the art global economic model to the question and offers insights to policymakers about how to design the program to achieve long-run environmental goals at minimum cost and with low risk to the economy.

The report analyzes a range of possible cap-and-trade policies for the U.S. The seven policy scenarios we analyze meet similar long run environmental objectives, but differ in their emissions trajectories and costs. The first policy we analyze hits the emissions targets proposed by the Obama administration. The second hits the targets in an early "discussion draft" version of the bill proposed by Representatives Waxman and Markey. We modeled both of these approaches as annual caps on U.S. emissions that decline linearly over the lifetime of the policy to reach in 2050 an emissions level that is 83 percent below 2005 levels.

We consider two additional policies that would achieve much the same long run environmental goals as the first two policies but which minimize the cost. Finally, we present three policies that augment the Obama administration's target proposal with three different cost-containment mechanisms.

We show that the first two policies, the Obama administration and Waxman-Markey discussion draft targets, produce modest long-term effects on U.S. gross domestic product (GDP) and consumption. The two approaches produce slightly higher overall costs and quite different emissions trajectories than the cost-minimizing alternatives. Compared with the linear emissions trajectories, the cost-minimizing approaches result in relatively steep cuts in the early years, less steep declines in the middle years, and steeper cuts from about 2035 to 2050. The accumulated effect on GDP of each of the four carbon controls through 2050 is roughly equivalent to reaching 2050's reference GDP in 2051 rather than 2050.

Finally, our results also show that adding a price ceiling or price collar can provide security against future events that would adversely affect an emissions permit market without unduly compromising the policy's effectiveness in reducing emissions. The report concludes that a policy similar to the Obama proposal, augmented by a price collar or safety value, could achieve very significant long-term reductions in emissions while imposing a firm upper bound on compliance costs.

1. Introduction

The U.S. Congress continues to debate a potential cap-and-trade program for the control of greenhouse gas (GHG) emissions. The economic effects of such a bill remain in dispute, with some arguing that a cap-and-trade program would create jobs and improve economic growth and others arguing that the program would shift jobs overseas and hit households with large energy price increases. This report applies a state-of-the art economic model to the question and offers insights to policymakers about how to the design the program to lower the costs of achieving long run environmental goals. It also explores the effects of two ways to control the stringency of the program: setting a price ceiling[1] and setting both a price floor and a price ceiling (called a price collar).

A cap-and-trade bill would limit greenhouse gas emissions from specified sources and enforce the limit by requiring firms to surrender allowances to cover their regulated emissions. The government would issue a declining number of allowances each year according to the limits specified by law (the “cap” part of cap-and-trade). Firms could trade allowances so that those with lower abatement costs could reduce emissions and sell excess allowances to firms with higher abatement costs (the “trade” part of cap-and-trade). Thus the program allows market forces to steer abatement to the most cost effective approaches, lowering the overall cost of achieving the environmental goal.

1.1 Policy Scenarios and Legislation

Earlier research has shown how important the details of a cap-and-trade program can be in influencing its environmental and economic performance.[2] Of first order importance is the stringency of the program: the degree to which it reduces emissions in a particular year or over a specified time period, such as 2012 to 2050. However, policies that are equally stringency can have significantly different costs depending on how they are implemented. In this paper, we examine two prominent target proposals that are similar in stringency and achieve ambitious long run goals. We compare them with alternative policies that allow modest variations in the timing or magnitude of reductions. Although we do not analyze specific draft bills in detail, we explore the relationship between short run, long run, and cumulative emissions targets and the economic effects of the policy over time. This gives important insights into the broad design of policy.

The policy scenarios we analyze in this study differ from complete representations of climate legislation in several ways. First, our analysis covers only fossil fuel-related carbon dioxide emissions. Second, we exclude both domestic and international offsets, which could lower overall costs by allowing regulated U.S. firms to comply with their obligations by purchasing abatement credit in sectors outside the U.S. cap-and-trade regime. Third, we do not analyze the banking and borrowing provisions in draft legislation. For example, the Waxman-Markey bill that was reported out of the House Committee on Energy and Commerce allows firms to bank allowances for future periods in unlimited amounts and to borrow from allocations in future periods with strict limitations. Such flexibility could, under certain allowance price trajectories, allow firms to smooth and possibly lower overall costs.[3] We also do not include in our analysis any ancillary policies designed to spur energy efficiency, promote renewable technologies, or the like. Another departure from actual legislation is that we assume the federal government auctions all the allowances and spends the revenue. Other approaches, such as providing free allowances to firms, or using auction revenue to provide rebates to households or reduce marginal tax rates, could affect the cost and other consequences of the policy. Finally, we exclude the administrative costs of monitoring and reporting emissions and providing regulatory oversight of allowance trading.

---

[1] The economic theory behind combining a tradable permit system with a price ceiling was developed by Roberts and Spence (1976). Including a price ceiling as part of a climate change policy was first proposed by McKibbin and Wilcoxen (1997) and Kopp, Morgenstern and Pizer (1997). For a detailed discussion see McKibbin and Wilcoxen (2002a).

[2] See for example: Paltsev, S., J. Reilly, H. Jacoby, A. Gurgel, G. Metcalf, A. Sokolov and J. Holak (2009).

[3] This is partly explored below in the policy we describe as a Hotelling rule.

Importantly, this is not a cost-benefit analysis. Although we consider the emissions reductions from different policy approaches, we make no attempt to monetize the benefits that would derive from mitigating the risk of climate disruption. Rather, we examine the relationships between emissions reductions and cost across different pathways to similar long run objectives.

1.2 Policies Based on Annual Targets

The first policy we examine is a declining series of annual emissions targets consistent with a proposal by the Obama administration. Emissions in 2020 and 2050 would be reduced by 14 percent and 83 percent, respectively, from 2005 emissions levels.[4] The president has not specified targets for specific years before 2020 and between 2020 and 2050, so we assume a linear path of emissions reductions from 2012 to 2020, and then another linear path of reductions (with a slightly different slope) from 2020 to 2050. We refer to this as the "OA" policy.

The second policy we consider sets year-by-year reduction targets for 2020, 2030, and 2050 of 20, 40, and 83 percent, respectively, relative to 2005 emissions. These targets were first proposed by Representatives Waxman and Markey in their April 2009 discussion draft (DD) bill before the Energy and Commerce Committee of the House of Representatives.[5] Subsequent versions of the legislation included less stringent targets, but we analyze the initial draft targets here because they likely represent the upper bound on reductions for the year 2020 that this Congress will consider. Again we assume linear paths of emissions reductions from 2012 through the targets in the later years. We refer to this as the "DD" policy.

1.3 Policies Based on Cost Minimization

We compare the results for OA and DD policies to two other approaches that meet comparable long run goals but do not impose year-by-year emissions targets. In both of these alternative approaches, allowance prices rise 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. If firms have perfect foresight and full flexibility in banking and borrowing allowances, then the real price of allowances will grow at the real risk-free interest rate. Intuitively, if the allowance price rises any faster than the interest rate, investors could make a profit by banking allowances and selling them later. If the price rises more slowly than the interest rate, firms could profit by borrowing allowances from future years. Together, these incentives mean that firms will use banking and borrowing to shift allowances between periods until an equilibrium is reached in which the price of an allowance rises at the long run real interest rate, which we assume is 4 percent.

A Hotelling path also 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 marginal cost of doing so is less than the cost of an allowance. In equilibrium, therefore, the cost of the last unit abated in each year will be equal to the allowance price and hence will rise at the interest rate. An immediate implication is that the 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. Under those circumstances, any reallocation of abatement from one period to another would raise the present value abatement cost.

The first Hotelling path we consider, called "Hotelling 2050" or H50, achieves the same long run annual

---

[4] White House Office of Management and Budget (2009) p. 21
[5] Waxman-Markey (2009).

emissions target as the OA policy (83 percent below 2005 emissions by 2050) via an allowance price path that rises at the interest rate, but does not necessarily match OA emissions in earlier years. Results from Section 3 show this approach results in higher cumulative emissions than the OA scenario. However, reductions relative to business as usual appear early on as the economy adjusts at least cost towards the long run target. The second Hotelling path, called “Hotelling Cumulative” or HC, would achieve the same cumulative emissions as OA, but again with an allowance price path rising at the interest rate. As a result, it would minimize the overall cost and would distribute emissions reductions over the years from 2012 to 2050 differently. This path would emerge under the OA policy if firms had full flexibility in banking and borrowing allowances during that period. Table 1 summarizes the scenario targets for the U.S.

Table 1. Alternative U.S. Reduction Targets To 2050

1.4 Outline of the Study

Section 2 provides a summary of the modeling approach. Section 3 describes the policy scenarios, outcome variables, and assumptions in the study, including assumptions about carbon policy in the rest of the world. Section 4 reports the results for the four policy approaches in detail. The analysis shows the economic and environmental effects of incrementally tighter targets and compares them to the results from the cost minimizing scenarios. Section 5 reports the results of imposing constraints on allowance prices. A summary and conclusion appears in Section 6.

2. Modeling Approach

The G-Cubed model is an intertemporal computable general equilibrium (CGE) model of the world economy (also known as a dynamic stochastic general equilibrium – or DSGE – model in the macroeconomics and central banking literature). A brief technical discussion of the model appears in Appendix A of this paper.

For this study, we apply a version of the model that includes the nine geographical regions listed in Table 2. The United States, Japan, Australia, the European Union, and China are each represented by a single modeled region. The model aggregates the rest of the world into four composite regions: 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. A central strength of including numerous regions is that the model can describe how policies in one country can affect other countries through trade, financial flows, and currency values. Complex global relationships can sometimes create unintended consequences that would be hard to analyze without modeling such linkages.

Table 2. Regions in the G-Cubed Model

The version of G-Cubed[6] we use in this study decomposes each region’s economy into 12 production sectors and another sector that produces a composite capital good. The sectors are shown in Table 3 below. This decomposition allows insights into how economic growth and climate policy may shift energy consumption, capital investment, and employment across and within different parts of the economy. G-Cubed is one of the few models that can examine the effects of U.S. climate policy on employment in different economic sectors under the assumption that labor markets do not always clear in the short run and economic shocks can lead to sustained periods below or above full employment. The Keynesian feature of sticky nominal wage adjustment,

---

[6] Full documentation of the version (GGGV88E) used in this report can be found at www.gcubed.com.

along with the presence of money in the model and a central bank that targets both inflation and output growth, gives the G-Cubed model distinctly realistic short run macroeconomic dynamics.

Table 3. Sectors in Each Region

2.1 Emissions Sources and Sectors

The sources of greenhouse gas emissions in the version of G-Cubed used in this study include only CO_2 emissions from the energy sector, including combustion of coal, natural gas, and oil. This includes 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 2007, and over 80 percent of total U.S. greenhouse gas emissions on a CO_2-equivalent basis.[7] In addition, the increase in net growth in all U.S. GHG emissions from 2000 to 2007 came almost entirely from increases in CO_2 from energy-related fossil fuel combustion. In fact, fossil energy CO_2 emissions grew by 174 million metric tons from 2000 to 2007, but were offset by declines in other emissions for a net growth in all U.S. GHG's of 142 million metric tons of CO_2 equivalent ($MMTCO_2E$).

We assume the policy targets apply exclusively to the energy sector and exclusively to CO_2. For example, if the target specifies a reduction of 14 percent below 2005 emissions levels by 2020, then we compute a scenario in which CO_2 emissions from the energy sector in 2020 are 14 percent lower than emissions from those same sources in 2005. Including other GHG sources in the analysis would result in potentially lower marginal abatement costs, but higher overall levels of abatement, with unclear net effect on costs relative to the results we present below.

2.2 Environmental and Economic Outcomes

To assess how climate policy might affect outcomes of interest, we compare the values of economic variables in the policy scenario to their values in the reference scenario. We generally represent the outcome as a percentage change from reference. For example, we measure the overall cost of climate policy as the percent reduction (relative to reference) in the present discounted value of household consumption.

G-Cubed includes a number of variables of key interest to policymakers, including CO_2 emissions, GDP, employment, personal consumption, investment, real interest rates, exchange rates, inflation, and international trade and financial flows. G-Cubed is one of the few CGE models that can examine the effects of U.S. climate policy on employment in specific economic sectors. In G-Cubed, wages adjust slowly to changes in relative prices, so unemployment can occur in the short to medium run. Labor supply is mobile between sectors, but immobile between regions.

2.3 Reference Scenario

One of the most important factors in modeling a cap on carbon emissions is the model's assumptions (or in the case of G-Cubed, its endogenous projections) about future emissions and economic activity in the absence of the cap. This is called the reference scenario, and it is a major factor in explaining why different economic models produce different estimates for the cost of a particular climate bill; the lower emissions are in the reference scenario, the less abatement is needed to hit a particular cap.

---

[7] U.S. Environmental Protection Agency (2009) p. ES-4, Table ES-2. Figures do not account for carbon stored in terrestrial carbon sinks.

In this study, we first construct a reference 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 reference 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. We then include the climate policies announced by various governments to create the reference scenario in which the U.S. policy decisions are framed.

Figure 1 below shows two key variables in the reference scenario for the U.S. The solid blue curve shows historical levels of real U.S. GDP through 2008, and the dashed blue curve leading from it is the reference scenario's projected real GDP from 2010 to 2050. We solve the model from 2002 under a range of assumptions about technical change, productivity growth by sector, and population growth by country. We report the model results from 2010 to emphasize economic growth after the 2009 recession.[8] The red curves show historical (solid) and projected (dashed) energy-related CO_2 emissions for the U.S. over the same periods. In our reference scenario, emissions grow about 0.7 percent per year from 2010 to 2050, a rate significantly lower than economic growth (about 2.8 percent per year). Thus this reference scenario continues the long historical decline in the emissions intensity of the U.S. economy.

Figure 1. Historical and Projected U.S. Real GDP and Energy-Related CO2 Emissions

2.4 Actions by Other Countries

The primary purpose of this paper is to isolate the effects of a cap-and-trade program on the U.S. economy holding the actions of other countries constant. Given that many other countries currently or plan to have economy-wide climate measures, it is important to include those efforts in the model while analyzing the effects of U.S. policy. Thus we must make assumptions about the nature and scale of those commitments.

OECD Countries

Other developed countries are likely to take on binding quantitative emissions reductions goals, and indeed some countries have already announced their proposed cuts for 2020.[9] Throughout the analysis, we assume that every OECD country achieves an 83 percent reduction in its emissions (relative to its 2005 levels) by 2050. These assumptions are summarized in Table 4.

Table 4. Other OECD Country and Regional Targets

Non-OECD Countries

We assume that each of the non-OECD regions in the study (China, the Former USSR, Other LDC's, and OPEC) take on obligations somewhat later than the OECD countries and in the form of a price on carbon rather than a quantitative cap. We assume they take on no climate policy until 2025, at which time they each take a real price on carbon of $30 (in 2002 U.S. dollars). Each year, real carbon prices in these regions rise by 4

---

[8] For modeling of the 2009 recession, see McKibbin and Stoeckel (2009).

[9] The Australian government issued a white paper describing its proposed targets: http://www.climatechange.gov.au/whitepaper/summary/index.html. EU climate policy documents can be found at http://ec.europa.eu/environment/climat/pdf/future_action/citizen_summary_en.pdf.

percent, the real rate of interest in the model. Although prior to 2025 the late entrants have no price on carbon, price expectations reduce emissions below their reference levels before 2025.

Effects of International Action on the U.S. Reference Case

When all other countries take on an abatement commitments and the U.S. does not, then emissions and economic variables in the U.S. are different than in the case shown above where all countries take on no special climate commitments. For example, if the U.S. is the only country not to impose a price on carbon, it can benefit from lower fossil energy prices and more competitive production costs. Figure 2 below shows the reference scenarios for the U.S. in a world in which all countries take no action (No Action Anywhere scenario) and in the world in which all countries except the U.S. take the actions described above but the U.S. does not (No U.S. Action scenario).

Figure 2. Reference U.S. CO_2 Emissions With and Without International Action

U.S. reference emissions are not influenced greatly by action abroad. In discussing the effects of U.S. policy on U.S. emissions and economic variables in Section 3, we emphasize the results of the U.S. policy scenario relative to the case in which all other countries act but the U.S. does not. This isolates the effect of the U.S. taking action, holding the climate policy actions of other countries constant.

2.5 Other Assumptions

How the government uses revenue from auctioning allowances can have important consequences for the effects of the policy. In this report we assume that the revenue expands government spending across sectors in proportion to historical spending. Thus we hold the fiscal deficit constant. We also assume no banking or borrowing, nor offsets or international trade in emission permits. Including these policy provisions would also change the quantitative outcomes but not the basic insights from this analysis.

3. Results

By slowing the growth of atmospheric concentrations of greenhouse gases, these policies can reduce the risk of economic and ecological damage from climate disruptions and ocean acidification. Some of these benefits could derive indirectly by reducing climate feedbacks, for example by limiting increases in natural emissions sources that result from warming. In this study, however, we do not attempt to monetize these effects. Instead, we simply measure the atmospheric benefit of each policy by computing the overall reduction in cumulative emissions it generates relative to the emissions in the reference scenario.

Figure 3 shows U.S. CO_2 emissions levels for the four policy scenarios. Each is consistently below the orange emissions curve, which shows U.S. emissions when other countries take action but the U.S. does not. Comparing the OA and HC trajectories, which produce identical cumulative emissions, shows that OA departs from cost-minimization by allowing relatively more emissions in the very short and very long runs (before 2020 and after 2045), but compensates with larger reductions in the middle of the period. Roughly speaking, the reductions under OA begin more gradually than the cost-minimizing path but then accelerate more rapidly. In addition, the cost-minimizing path requires significantly larger cuts in the very long run in order to achieve the same cumulative reduction as OA. Annual and cumulative reductions under each policy are summarized in Table 5.

Figure 3. Annual U.S. CO_2 Emissions for Policy Scenarios and Reference Case

Table 5. Effect of Policies on Annual and Cumulative Emissions

The market price of allowances gives firms the incentive to abate their emissions up to the point where the incremental cost of emissions abatement is equal to the price of an allowance.[10] This incentive applies whether or not the firms already have sufficient allowances (for example, via free allocations from the government) because firms can make additional profit by selling excess allowances if their abatement costs are lower than the allowance price. Thus the allowance price (alternatively called the price on carbon) reflects the abatement cost of the last ton of reductions necessary to meet the constraint. The total cost of abatement is the sum of all the individual tons of abatement, most of which come at lower cost than the last ton.

Figure 4 below shows how the price of allowances evolves from 2010 to 2050 under the four policy scenarios. Consistent with the reductions in Figure 3, the Hotelling paths have sharply higher initial prices than the year-by-year policies OA and DD. This suggests that if allowed, firms would choose to bank in the early years of the OA and DD policies because the real price of allowances is climbing faster than the real interest rate. Firms could profit by purchasing allowances in the early years and selling them later. However, the differential shrinks over time as the OA and DD targets become tighter. Between about 2020 and 2040, the price under the OA and DD policies exceeds both Hotelling prices. Finally, in the last decade of the policy, the HC price once again exceeds the OA and DD prices. In this period the price of allowances in the OA and DD policies is rising more slowly than the 4 percent real annual increase of the Hotelling curves. This suggests that in those scenarios, if allowed firms would wish to draw down stocks of banked allowances because gains from holding them longer would be lower than potential gains from alternative investments.

Figure 4. Allowance Price 2010 To 2050 under Four Policy Scenarios

In addition to the total cost of abatement, the positive price on carbon emissions can produce other costs to the economy that lower the welfare of households. Energy is an input to all sectors of production. A higher carbon price results in higher energy prices and therefore higher prices throughout the economy. This reduces the amount of consumption achievable for a given level of spending by households. The rise in energy prices does not necessarily result in sustained inflation in the economy as long as the central bank does not accommodate the price increase. However, this results in higher interest rates during the transition which raises mortgage costs and reduces the welfare of borrowers.

One way to measure the overall drop in welfare created by the policy is to compute the present discounted value of the stream of real personal consumption over the time frame of the analysis. Given the long time horizon of the policies considered here, the discount factor has a significant effect on the calculation so we present results for two different rates. The first (2.2 percent) reflects the real rate of time preference in the model, and the second (4 percent) represents the long run real interest rate. Table 6 reports, for each policy, the welfare cost as measured by the present discounted value of the resulting drop in personal consumption from 2010 to 2050.

---

[10] In any one year, the marginal cost of abatement may be different than the allowance price if firms can bank and/or borrow allowances over time.

Table 6. Reduction in Discounted Consumption Due to Each Policy

The total value of allowances distributed in a given year is the allowance price times the cap for that year. Figure 5 below shows that the overall allowance value varies a great deal over the 2010 to 2050 time frame, starting low, peaking between 2025 and 2035, and dropping considerably by 2050. Although the price of individual allowances climbs steadily through 2050, the declining number of allowances eventually drives the total value of allowances down.

Figure 5. Allowance Values under Four Policy Scenarios

Figure 6 shows the effects of the policies on real U.S. GDP. The dark blue curve at the left of the diagram shows historical GDP and the orange dashed curve shows future growth under the reference scenario. The four scenarios representing alternative U.S. climate policies are slightly lower than the reference case by the year 2050. In that year, the percent reduction in the level of GDP relative to the baseline, 2.5 percent, is about equal to the 2.4 percent annual rate of GDP growth. That is, the accumulated effect of carbon controls through 2050 is roughly equivalent to reaching 2050's reference GDP in 2051 rather than 2050. The four control trajectories are essentially indistinguishable from one another and are also difficult to distinguish from the reference case through about 2025.

Figure 6. U.S. GDP under Four Policy Scenarios

At the industry level, all four control policies principally affect the energy sectors. Figure 7 shows the percentage change in purchaser's prices in 2015 relative to the reference scenario. Energy prices rise considerably as a result of the carbon price shown in Figure 4. The largest increase occurs in the coal industry because the carbon content of coal per unit of energy is substantially higher than other fossil fuels. The increase in coal prices, in turn, raises the cost of electricity and drives up its price. The price of crude oil also rises under each of the policies, which raises the price of refined petroleum products. Outside the five energy sectors the price effects are quite small because energy is only a small share of costs in those sectors. As a result, an increase of 10 to 15 percent in electricity or refined petroleum prices only raises downstream prices by a fraction of a percent. Figure 8 shows percentage changes in output in 2015 relative to the reference scenario. Apart from the coal sector, the output effects are roughly proportional to the changes in prices shown in Figure 7. Coal, however, falls less than in proportion because demand for it is relatively inelastic.

Figure 7. Effects on Purchaser's Prices in 2015

Figure 8. Effects on Production in 2015

Table 7 summarizes the 2015 results in Figure 7 and Figure 8 and also provides results for the percent change in employment in each sector relative to the reference scenario. The employment results are generally similar to the effects on sector-level output. Depending on the policy, employment in the coal and crude oil sectors falls by 11 to 21 percent in 2015. The effect is smallest for OA and largest for HC. The reductions in other energy sectors are much smaller, as are the effects in non-energy sectors. Employment in services rises slightly. The employment results are determined partly by the change in demand for the output of the sector and partly by the change in the wage relative to the before-tax price of the sector's output. This is important in the coal sector, where the price of coal before including the cost of carbon allowances actually falls relative to the baseline even thought the tax-inclusive price of coal is rises. As a result, from an employer's perspective the real wage in the coal sector (the nominal wage relative to the output price) actually rises, which reduces further the demand for labor in that sector.

Table 7. Effects of Each Policy on Individual Sectors in 2015

Table 8 shows sector-level results for 2025 as percent changes from the reference scenario in the same year. By 2025, the greater mid-term stringency of OA and DD causes the increase in energy prices and decrease in energy output to be larger in magnitude than under the H50 and HC policies. The effects on employment are also larger in magnitude, with more workers moving out of most energy sectors and into agriculture, non-durable manufacturing and services. Natural gas utilities are an interesting exception: demand remains relatively strong as electric utilities shift from coal to gas, and employment rises slightly as gas producers shift slightly toward more labor-intensive practices.

Table 8. Effects of Each Policy on Individual Sectors in 2025

Figure 9 shows the change in the U.S. trade balance over time for each policy relative to the reference scenario. A negative value indicates that the policy moves the trade balance towards deficit and a positive value indicates movement towards surplus. There are a number of ways to interpret the trade balance. The more conventional approach is to note that as the U.S. takes action on emissions which raises the price of energy, U.S. exports, particularly energy intensive exports become less competitive on world markets which implies that exports should decline relative to imports and the trade balance therefore worsen. In the initial years this is largest for the cost-minimizing HC scenario since the initial energy price rise is largest for this policy. An alternative way to understand the results is to note that the current account is the net of aggregate saving and investment decisions in the economy. With a given level of payments servicing net external debt, it is the outcome of saving and investment decisions that determines the trade balance and the change in the price of energy determines the composition of the trade balance.

Figure 9. Effect of Alternative Policies on the U.S. Trade Balance

The change in the real effective exchange rate is shown in Figure 10. The real effective exchange rate is the price of U.S. goods relative to a basket of foreign goods expressed in U.S. dollars. A rise in this ratio relative to the reference scenario is an appreciation of the real effective exchange rate. The rise in carbon prices tends to raise the price of U.S. goods. The U.S. dollar exchange rate does not offset this and thus the appreciation of the real effective exchange rate reflects the rise in the relative price of U.S. goods as a result of the rise in energy prices.

Figure 10. Effect of Alternative Policies on U.S. Real Effective Exchange Rate

4. Alternative Scenarios: A Price Ceiling Policy and a Price Collar

Our analysis suggests that the OA and DD policies would impose relatively modest costs on the U.S. economy. However, legislators in Congress may be concerned that macroeconomic shocks or unexpected difficulties in bringing new low-carbon technology to market could cause costs to be considerably higher. To address that concern, they could include a predictable and transparent mechanism to contain the costs of the program. In this section, we examine two cost containment mechanisms: a price ceiling policy that allows the government to sell additional emissions allowances at a pre-set price each year, limiting how high market permit prices would go, and a price collar that includes a price floor as well as a price ceiling.

4.1 Price Ceiling Policy

The price ceiling approach we examine is an extension of the OA policy and is drawn in part from McKibbin and Wilcoxen (1997, 2002b, and 2007). Under a price ceiling, the government would issue or auction the permits allowed under OA. In addition, it could sell an arbitrary number of additional emissions permits at a stipulated price. This price could be higher than the market price policymakers expect to emerge given the caps that they set, so that it would have no effect if their expectations are correct. The additional permits would be good only in the year sold and could not be banked. The potential sales of new permits at the ceiling price would establish a gradually-rising ceiling on the marginal cost of abatement and the market price of emissions permits. Because the real price of the ceiling rises at the real interest rate, firms would not buy large volumes of extra allowances expecting a large return on selling them later. Because the policy allows emissions to increase if costs turn out to be very high, it is sometimes described as a “safety valve.” [11]

A price ceiling truncates the downside risk to the U.S. economy of imposing the emissions cap. It protects households and firms from both unanticipated spikes in the allowance price and chronic stringency in excess of that intended by policymakers. In the event of unexpected stringency, it offers an orderly relaxation of the target to a feasible level, thus precluding a disruptive and abrupt change in policy that would be more likely than the ceiling to undermine long run environmental goals. Further, by preventing such disruption a price ceiling can bolster incentives to invest in abatement; even while it truncates the upside potential of allowances prices, it increases investors’ confidence that the program will endure through severe economic fluctuations. The price ceiling also limits the competitive pressures energy-intensive trade-exposed U.S. firms may experience relative to firms in countries that do not place an equivalent price on carbon. Other cost containment mechanisms, such as domestic and international offsets and an allowance reserve auction offer different advantages and disadvantages. However, unlike those other approaches, the price ceiling transparently and with certainty limits the economic risk of the program and makes clear exactly what circumstances would allow emissions to increase.

Although many of the advantages of a price collar relate to reducing uncertainty in the allowance price, it is worth exploring how the floor and ceiling may bind under expected conditions and what their effects may be on emissions and costs. Accordingly, we present below the results for a policy in which the ceiling price starts at $30 (2008 dollars) in 2012 and rises at 4 percent per year in real terms. For comparison, we also provide results for a second price ceiling starting at $35. Figure 11 shows the allowance prices that would occur under the two alternative price ceiling policies. The dark green curve shows the price of a ton of carbon dioxide under the OA policy. It is the same curve that appears in green in Figure 4. The orange curve, labeled “Ceiling 30,” shows the price under the policy with an annual ceiling price that starts out at $30. The blue curve, “Ceiling 35,” starts at $35 in 2012 but is otherwise an identical scenario. Under both price ceiling polices, the price of allowances remains below the ceiling during the first few years. Between 2020 and 2025, the price reaches the ceiling under both policies but slightly later for Ceiling 35. After binding, the ceiling remains in effect until about 2040 for

---

[11] In the literature and in policy debates outside the United States, this is also called a “hybrid approach” because it is a carbon trading system but with unlimited carbon permits issued when the market price or permits reaches the price cap. The additional emissions are effectively subject to a tax equal to the price cap.

Ceiling 35 or a couple of years later for Ceiling 30. In the last years, the ceiling no longer binds because it rises above the equilibrium price under both policies.

Figure 11. Allowance Price per Ton of CO_2 under Price Ceiling Policies

Figure 12 shows the percentage reduction in annual U.S. CO_2 emissions for the two ceiling policies and the OA policy relative to the reference scenario. Emissions under both ceilings fall rapidly and are coincident with the OA path until almost 2020. After that, emissions under either ceiling fall somewhat less than they do under the OA policy. However, the differences are relatively modest. In 2030, for example, the reduction under OA is 45 percent relative to the reference case while the reductions are 34 and 40 percent under Ceiling 30 and Ceiling 35, respectively. In both price-ceiling cases, emissions are reduced substantially relative to reference, but a little less than under the hard annual targets of the OA policy.

Figure 12. Reductions in U.S. CO_2 Emissions under Price Ceiling Policies

Figure 13 shows the effects of both price ceiling policies and the OA policy on cumulative emissions. All three policies achieve significant—and very similar—emission reductions relative to the reference scenario. Under OA, cumulative emissions from 2010 to 2050 equal 154 billion metric tons of CO_2; under the Ceiling 35 policy cumulative emissions are 3 percent higher than the OA policy at 159 billion metric tons; under Ceiling 30, emissions are 11 percent higher at 171 billion metric tons. Relative to cumulative emissions in the reference case, the reductions due to OA, Ceiling 35, and Ceiling 30 are 47 percent, 45 percent and 41 percent, respectively. This demonstrates that over the long run, an appropriately chosen price ceiling can reduce compliance cost risks without compromising the outcome that matters most for the climate: cumulative emissions.

Figure 13. Cumulative U.S. CO_2 Emissions under Price Ceiling Policies

4.2 Price Collar

A price collar imposes a price floor along with a price ceiling. By preventing the policy from being either unexpectedly lax or unexpectedly stringent, a collar protects investors in green technologies and households alike. The price floor preserves strong incentives to abate, even in the context of abundant low cost abatement opportunities or unexpectedly slow economic growth. The version of the Waxman-Markey bill that the House of Representatives passed in June 2009, includes a price floor starting at $10 in 2012, increasing by 5 percent per year over inflation. The bill imposes the floor through a reserve price on allowances allocated through auctions.[12] We modeled a price collar with the floor beginning at $10 and rising at 4 percent per year. We find that the allowance price results are essentially identical to the Ceiling 35 curve in Figure 11. The price floor binds only in the first couple of years.

To better illustrate how a price floor might bind, this section presents the results of a collar having a price floor and ceiling that are $20 and $35 respectively per ton of CO_2 emissions in 2012, and both rise at 4 percent

---

[12] This approach does not guarantee that secondary market prices are above the price floor. However, for the secondary market price to drop below the price floor, there would have to be such a flush supply of allowances that it eliminates demand for auctioned allowances at the reserve price. This is unlikely under the measures in the draft legislation.

annually. Figure 14 shows the allowance prices that emerge in the scenarios. As before, the OA policy is shown in dark green. The price floor is shown by the lower dashed curve beginning at $20 in 2012 and the ceiling is shown by the higher dashed curve beginning at $35 in 2012. The dashed orange curve labeled “Price” shows the price trajectory with the price collar in place.

If firms are allowed to bank allowances, the price floors we modeled are significantly less likely to bind. For example, allowance prices in the HC50 scenario, depicted in Figure 4, begin above $24 per ton. This suggests that firms would bank in those early years in sufficient quantities that they drive the market price of allowances higher than a $10 or $20 price floor.

Figure 14. Allowance Price per Ton of CO_2 under Price Collar Policy

The price floor binds from 2012 and 2014, during which time the government would remove some permits from the market. From 2015 through 2022, the permit price stays within the collar and the OA and “Price” paths coincide. By 2023, however, strong demand for permits causes the allowance price to reach the ceiling and the government offers additional permits at the ceiling price. By 2041, however, the price ceiling exceeds the market price, and the government stops selling extra permits. Emissions from then on remain at the annual cap.

Figure 15 shows annual U.S. CO_2 emissions for the policy scenarios relative to the reference scenario. Emissions under the collar are slightly below the OA Target path until 2015. After that they remain at the target level until 2022 when the price rises enough to hit the ceiling. As with the ceiling policies, emissions fall somewhat less when the ceiling is in effect than they do under the hard annual targets of the OA policy. In 2030, for example, the reduction under the OA policy is 45 percent relative to the reference case while under the collar it falls by 40 percent.

Figure 15. Reduction in U.S. CO_2 Emissions under Price Collar Policy

Figure 16 shows the effects of the collar on the cumulative emissions path. As with the ceiling policies, the price collar achieves nearly the same reduction in cumulative emissions as the OA policy. In this case, cumulative emissions are similar to the Ceiling 35 policy but slightly lower due to the price floor and total 158 billion metric tons, or about 2.5 percent above OA alone. Either a ceiling policy or a price collar can provide cost containment without unduly compromising the environmental goals of the policy.

Figure 16. Cumulative U.S. Emissions of Carbon Dioxide, Price Collar

5. Conclusion

The results presented above indicate that the U.S. can reduce cumulative carbon dioxide emissions over 2010-2050 by 112 to 141 billion metric tons, or by 40 to 50 percent relative to business as usual, at a present value cost in forgone consumption of $0.6 to $2 trillion 2008 dollars. By 2050, each of the policies we analyze here would reduce U.S. GDP relative to the baseline by about 2.5 percent, which is essentially the same as the 2.4 percent baseline rate of GDP growth. That is, the accumulated effect of carbon controls through 2050 is roughly equivalent to reaching 2050’s reference GDP in 2051 rather than 2050.

The scenarios that achieve the targets proposed by the Obama administration and the targets included in an early version of the Waxman-Markey bill produce similar outcomes. The Obama target scenario has slightly higher emissions but also has slightly lower costs. At a 4 percent discount rate, the two policies are $200 to $400 billion more costly in present value than the cost minimizing approaches, out of a total cost of around $1 trillion 2008 dollars.

Finally, our results also show that adding a cost containment measure, such as a price ceiling or a price collar, can provide security against future events that would adversely affect an emissions permit market without unduly compromising the policy’s expected effectiveness in reducing emissions. A policy that seeks the long run environmental objectives of the Obama proposal or the Waxman-Markey discussion draft targets, if augmented by a price collar or price ceiling, could very significantly cut emissions over the long run while firmly limiting compliance costs.

6. References

Australian Government (2008) *Carbon Pollution Reduction Scheme: Australia's Low Pollution Future*: White Paper, Australian Government Printing Office, Canberra. Available at http://www.climatechange.gov.au/whitepaper/summary/index.html

Blanchard O. and S. Fischer (1989) *Lectures on Macroeconomics* MIT Press, Cambridge MA.

Henderson, D.W., and W.J. McKibbin (1993) “A Comparison of Some Basic Monetary Policy Regimes for Open Economies: Implications of Different Degrees of Instrument Adjustment and Wage Persistence,” *Carnegie-Rochester Conference Series on Public Policy*,39, pp 221-317.

Hotelling, Harold (1931) “The Economics of Exhaustible Resources,” *Journal of Political Economy*, Vol. 39:137-175.

Kopp, R., R. Morgenstern and W.A. Pizer (1997), “Something for Everyone: A Climate Policy that Both Environmentalists and Industry Can Live With,” *Weathervane*, Resources for the Future, Washington, September 29.

McKibbin, W.J., Morris, A. and P.J. Wilcoxen (2009) “Expecting the Unexpected: Macroeconomic Volatility and Climate Policy”, in J Aldy and R. Stavins (eds*) Implementing Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World,* Cambridge University Press (forthcoming).

McKibbin W.J, D. Pearce and A. Stegman (2007) “Long Term Projections of Carbon Emissions” *International Journal of Forecasting*, vol. 23, pp637-653

McKibbin W. J. and A. Stoeckel (2009), “The Global Financial Crisis: Causes and Consequences,” mimeo Australian National University.

McKibbin W.J. and D. Vines (2000) “Modeling Reality: The Need for Both Intertemporal Optimization and Stickiness in Models for Policymaking” *Oxford Review of Economic Policy*, Vol. 16, No 4.

McKibbin, W.J. and P.J. Wilcoxen (1997), “A Better Way to Slow Global Climate Change,” *Brookings Institution Policy Brief*, No. 17, June.

McKibbin W.J. and P.J. Wilcoxen (1998) “The Theoretical and Empirical Structure of the G-Cubed Model” *Economic Modelling* , 16, 1, pp 123-148.

McKibbin, W.J. and P.J. Wilcoxen (2002a), “The Role of Economics in Climate Change Policy,” *Journal of Economic Perspectives*, 16(2), pp. 107-129, Spring.

McKibbin, W.J and P.J. Wilcoxen (2002b) *Climate Change Policy after Kyoto: A Blueprint for a Realistic Approach*, Brookings Institution

McKibbin W.J. and P.J. Wilcoxen (2007) “A Credible Foundation for Long Term International Cooperation on Climate Change” in Joseph Aldy and Robert Stavins (eds), Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World, Cambridge University Press, pp. 185-208.

McKibbin W.J. and P.J. Wilcoxen (2008) *Building on Kyoto: Towards a Realistic Global Climate Change Agreement*, The Brookings Institution, June.

Obstfeld M. and K. Rogoff (1996) *Foundations of International Macroeconomics*, MIT Press, Cambridge MA.

Paltsev, S., J. Reilly, H. Jacoby, A. Gurgel, G. Metcalf, A. Sokolov and J. Holak, (2007) “Assessment of U.S. Cap-and-Trade Proposals,” MIT Joint Program on the Science and Policy of Global Change, Report Series #146, 66 pages. Available at http://globalchange.mit.edu/pubs/abstract.php?publication_id=718

U.S. Environmental Protection Agency (2009) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*, April. Available at: http://www.epa.gov/climatechange/emissions/downloads09/ExecutiveSummary.pdf

Waxman-Markey (2009) *Discussion Draft: Titles III and IV* http://energycommerce.house.gov/Press_111/20090331/acesa_discussiondraft.pdf

White House Office of Management and Budget (2009) *Jumpstarting the Economy and Investing for the Future*, White House Office of Management and Budget, Fiscal Year 2010 document, February 26. Available at: http://www.whitehouse.gov/omb/assets/fy2010_new_era/Jumpstarting_The_Economy.pdf

Appendix A. The G-Cubed Model

The theoretical structure of G-Cubed is outlined in McKibbin and Wilcoxen (1998).[13] A number of studies—summarized in McKibbin and Vines (2000)—show that the G-Cubed modeling approach has been useful in assessing a range of issues across a number of countries since the mid-1980s.[14] The model is based on explicit intertemporal optimization by the agents (consumers and firms) in each economy.[15] In contrast to static CGE models, time and dynamics driven by short term rigidities are of fundamental importance in the G-Cubed model.

In order to track the macro time series data, the behavior of agents is modified to allow for short run deviations from optimal behavior either due to myopia or to restrictions on the ability of households and firms to borrow at the risk free bond rate on government debt. For both households and firms, deviations from intertemporal optimizing behavior take the form of rules of thumb, which are consistent with an optimizing agent that does not update predictions based on new information about future events. These rules of thumb are chosen to generate the same steady state behavior as optimizing agents so that in the long run there is only a single intertemporal optimizing equilibrium of the model. In the short run, actual behavior is assumed to be a weighted average of the optimizing and the rule of thumb assumptions. Thus aggregate consumption is a weighted average of consumption based on wealth (current asset valuation and expected future after tax labor income) and consumption based on current disposable income. Similarly, aggregate investment is a weighted average of investment based on Tobin's q (a market valuation of the expected future change in the marginal product of capital relative to the cost) and investment based on a backward looking version of Q. Finally, there is an explicit treatment of the holding of financial assets, including money. Money is introduced into the model through a restriction that households require money to purchase goods.

The model also allows for short run nominal wage rigidity (by different degrees in different countries) and therefore allows for significant periods of unemployment depending on the labor market institutions in each country. This assumption, when taken together with the explicit role for money, is what gives the model its "macroeconomic" characteristics. (Here again the model's assumptions differ from the standard market clearing assumption in most CGE models.)

The model distinguishes between the stickiness of physical capital within sectors and within countries and the flexibility of financial capital, which immediately flows to where expected returns are highest. This important distinction leads to a critical difference between the quantity of physical capital that is available at any time to produce goods and services, and the valuation of that capital as a result of decisions about the allocation of financial capital. In climate policy this effect is important since climate policies affect expected future returns to capital differently in different sectors.

As a result of this structure, the G-Cubed model contains rich dynamic behavior, driven on the one hand by asset accumulation and, on the other by wage adjustment to a neoclassical steady state. It embodies a wide range of assumptions about individual behavior and empirical regularities in a general equilibrium framework. The interdependencies are solved out using a computer algorithm that solves for the rational expectations equilibrium of the global economy. It is important to stress that the term 'general equilibrium' is used to signify that as many interactions as possible are captured, not that all economies are in a full market clearing equilibrium at each point in time. Although it is assumed that market forces eventually drive the world economy to a neoclassical steady state growth equilibrium, unemployment does emerge for long periods due to wage stickiness, to an extent that differs between countries due to differences in labor market institutions.

---

[13] Full details of the model including a list of equations and parameters can be found online at: www.gcubed.com

[14] See McKibbin and Vines (2002)

[15] See Blanchard and Fischer (1989) and Obstfeld and Rogoff (1996).

Table 1. Alternative U.S. Reduction Targets to 2050

		Target Relative to 2005 Emissions			**Cumulative 2012-2050 Emissions Target**
		2020	2030	2050	
Policy	**OA**	-14%	Interpolated	-83%	Not specified, but bounded by the sum of annual targets
	DD	-20%	-40%	-83%	Not specified, but bounded by the sum of annual targets
	H50	None	None	-83%	None
	HC	None	None	None	The sum of annual emissions for 2012 to 2050 under OA

Table 2. Regions in the G-Cubed Model

Number	**Region Name**	**Region Description**
1	USA	United States
2	Japan	Japan
3	Australia	Australia
4	Europe	European Union
5	ROECD	Rest of the OECD, i.e. Canada and New Zealand
6	China	China
7	OPEC	Oil Exporting Developing Countries
8	EEFSU	Eastern Europe and the former Soviet Union
9	LDC	Other Developing Countries

Table 3. Sectors in Each Region

Number	**Sector Description**
1	Electric Utilities
2	Gas Utilities
3	Petroleum Refining
4	Coal Mining
5	Crude Oil and Gas Extraction
6	Mining
7	Agriculture, Fishing and Hunting
8	Forestry and Wood Products
9	Durable Manufacturing
10	Non-Durable Manufacturing
11	Transportation
12	Services
13	Capital Producing Sector

Figure 1. Historical and Projected U.S. Real GDP and Energy-Related CO_2 Emissions

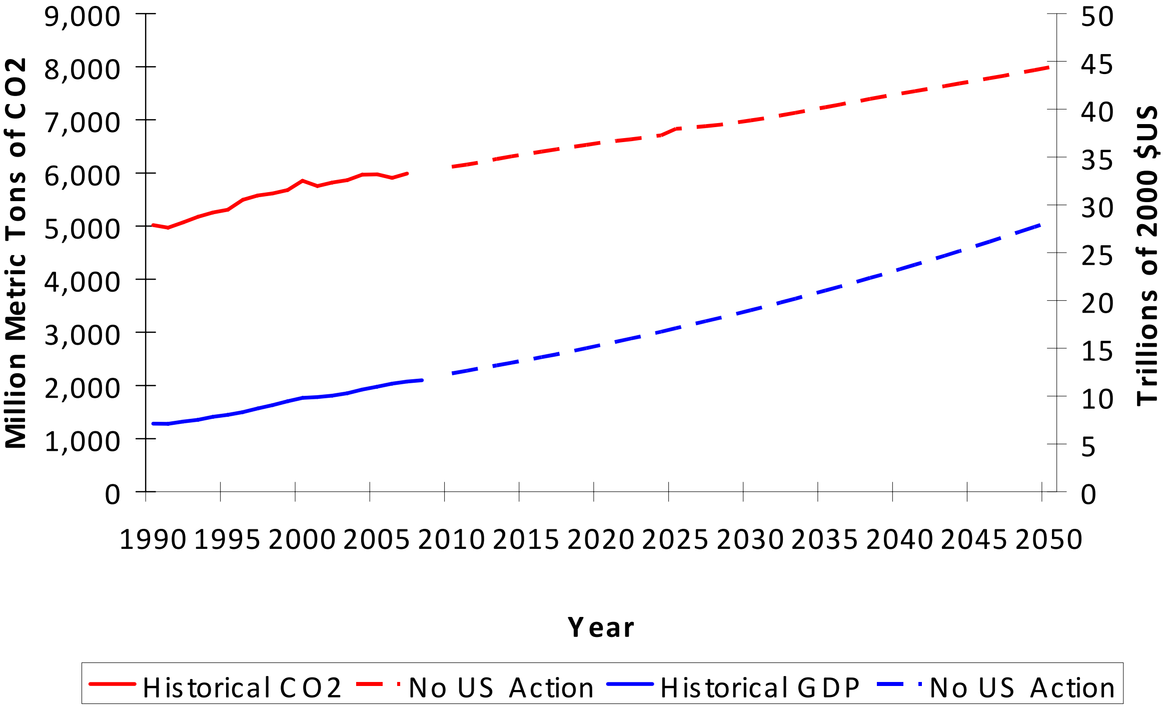

Table 4. Other OECD Country and Regional Targets

Country	Target for 2020	Target for 2050
Australia	4% below 1990 levels	-83% below 2005 levels
Japan	14% below 2005 levels	
European Union	20% below 1990 levels	
Other OECD	14% below 2005 levels	

Figure 2. Reference U.S. CO_2 Emissions With and Without International Action

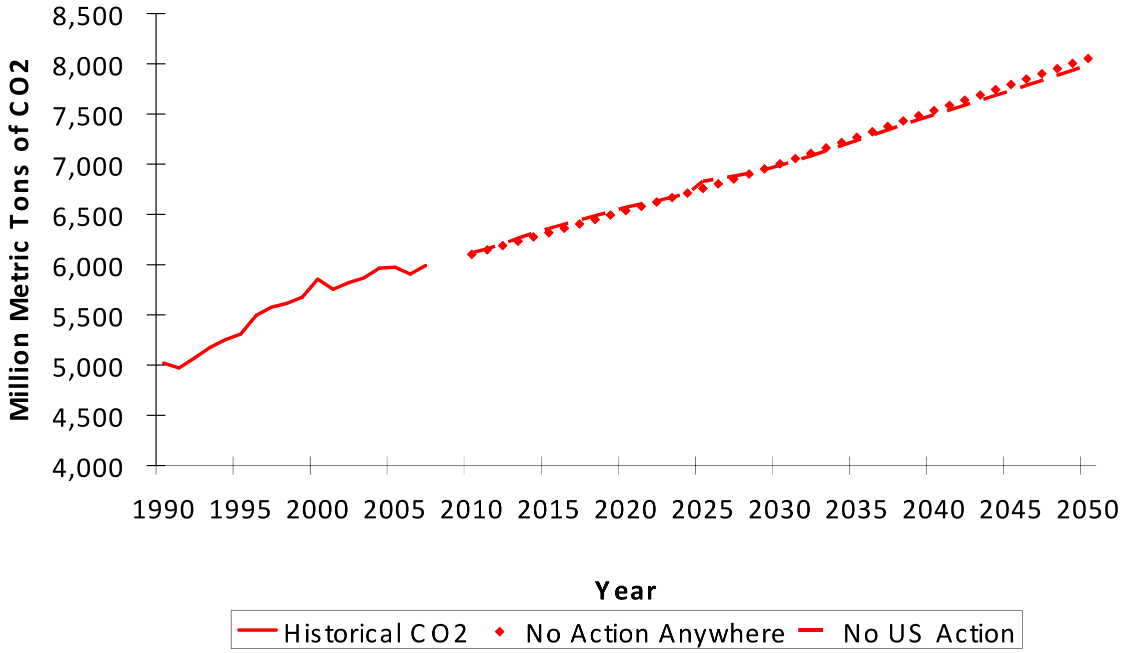

Figure 3. Annual U.S. CO_2 Emissions for Policy Scenarios and Reference Case

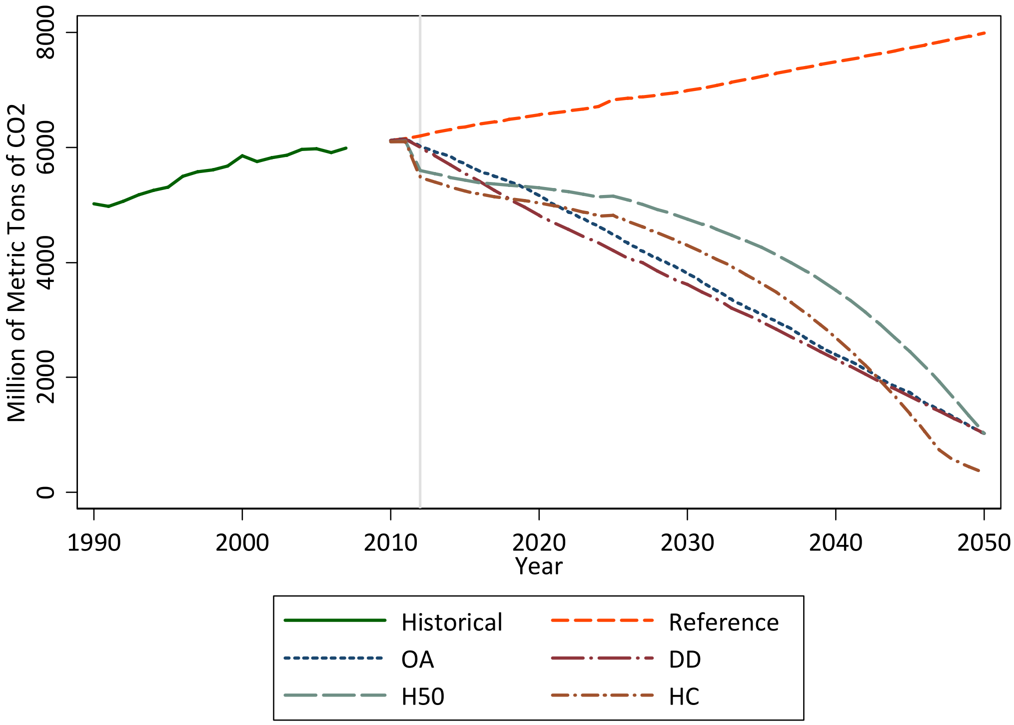

Table 5. Effect of Policies on Annual and Cumulative Emissions

All values are in billions of metric tons of CO_2

		Annual Reduction Relative to Reference Case				Cumulative 2010-2050	
		2020	**2030**	**2040**	**2050**	**Emissions**	**Reduction**
Policy	**OA**	1.4	3.2	5.1	7.0	154	134 (47%)
	DD	1.7	3.4	5.2	7.0	148	141 (49%)
	H50	1.3	2.2	4.0	7.0	176	112 (39%)
	HC	1.5	2.7	4.8	7.6	154	134 (47%)

Figure 4. Allowance Price 2010 to 2050 under Four Policy Scenarios

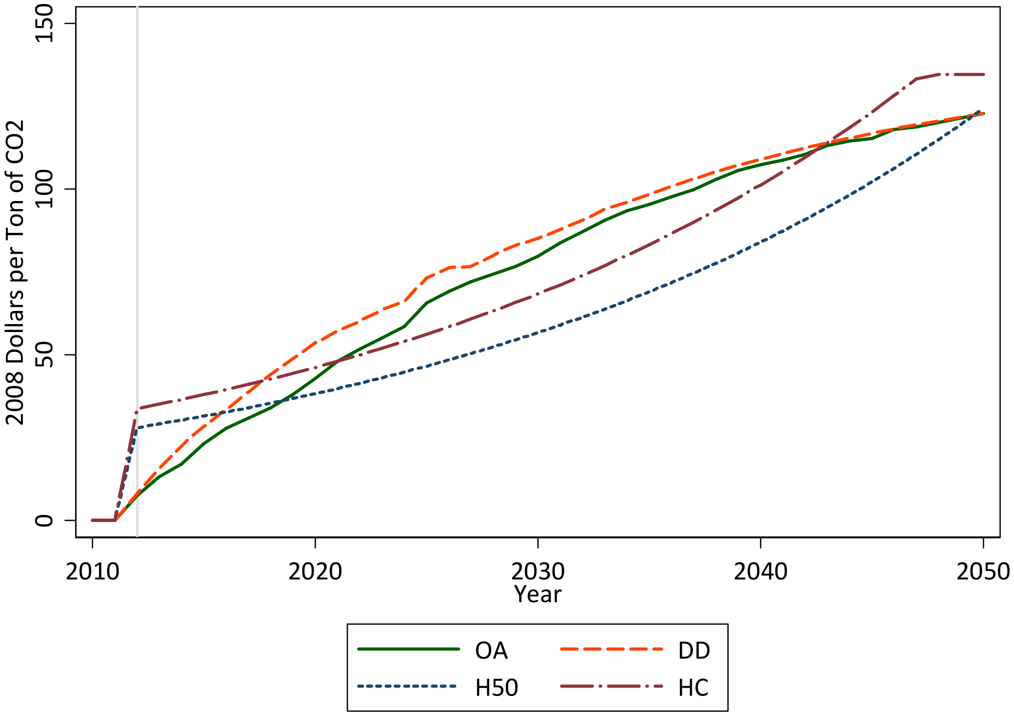

Table 6. Reduction in Discounted Consumption Due to Each Policy

		2.2% discount rate		4.0% discount rate	
		Percent	**Present Value**	**Percent**	**Present Value**
Policy	**OA**	-0.45%	$1.9 trillion	-0.36%	$1.1 trillion
	DD	-0.49%	$2.0 trillion	-0.39%	$1.3 trillion
	H50	-0.28%	$1.1 trillion	-0.23%	$0.6 trillion
	HC	-0.38%	$1.6 trillion	-0.31%	$0.9 trillion

Figure 5. Allowance Values under Four Policy Scenarios

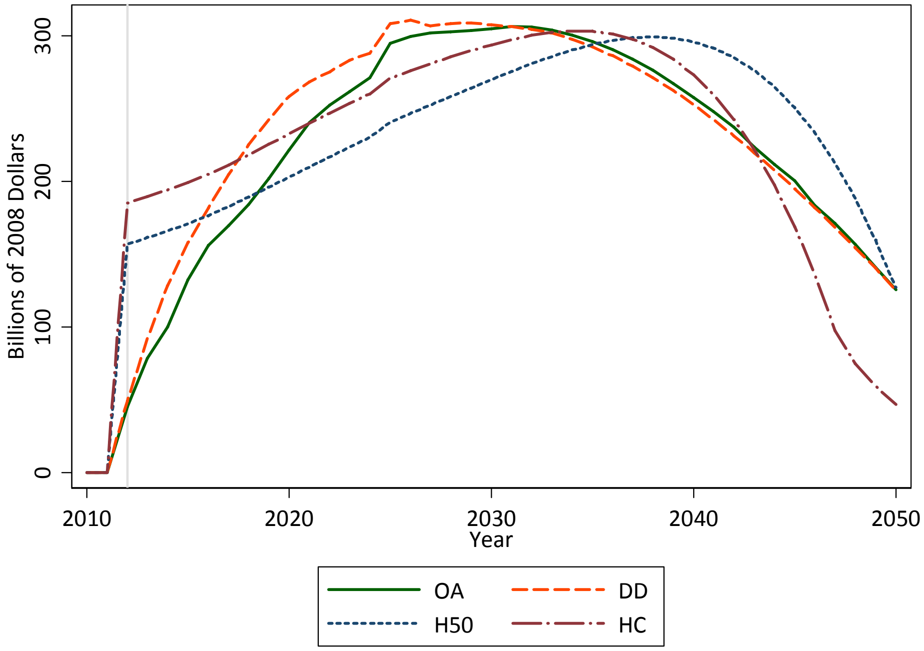

Figure 6. U.S. GDP under Four Policy Scenarios

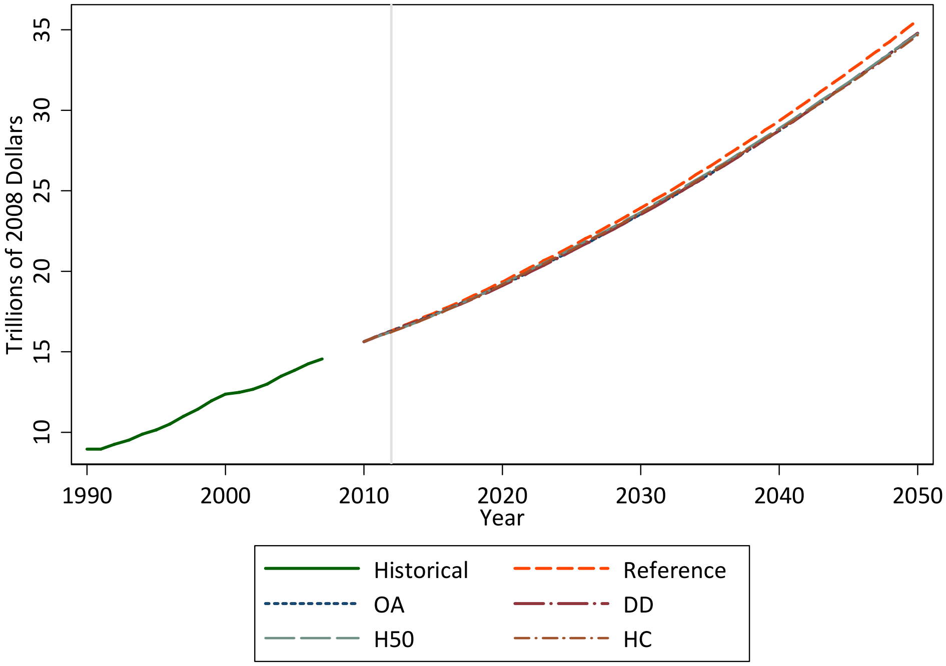

Figure 7. Effects on Purchaser's Prices in 2015

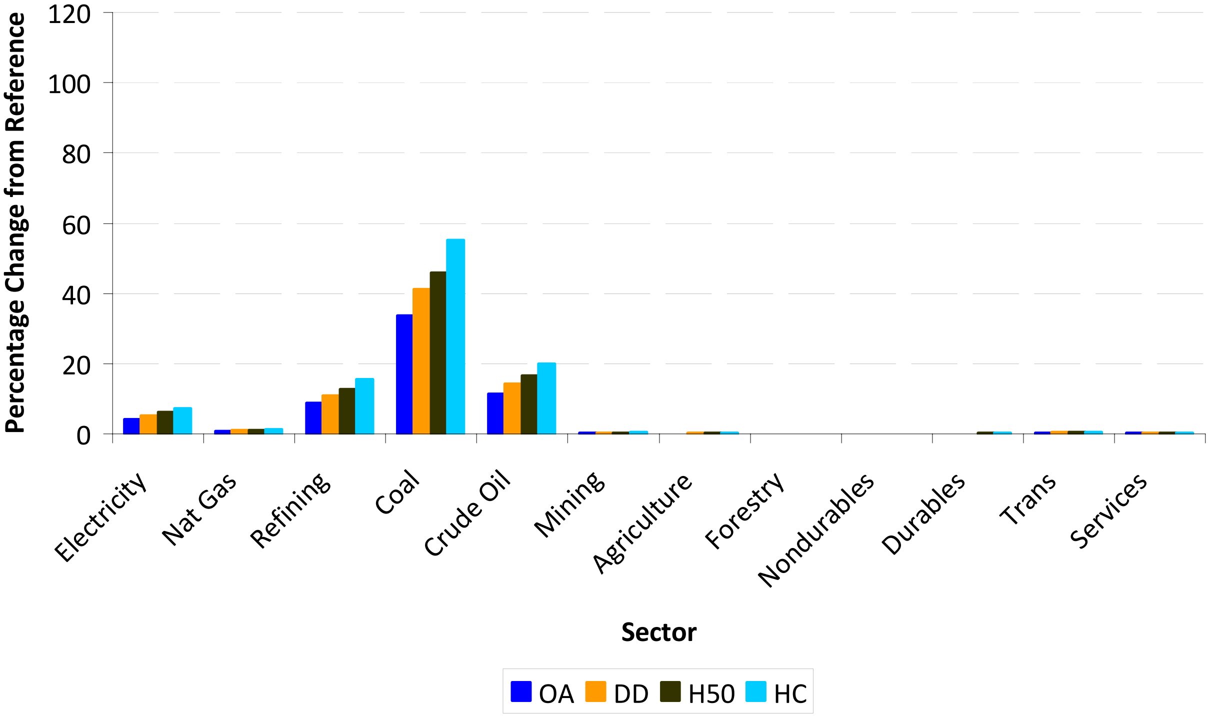

Figure 8. Effects on Production in 2015

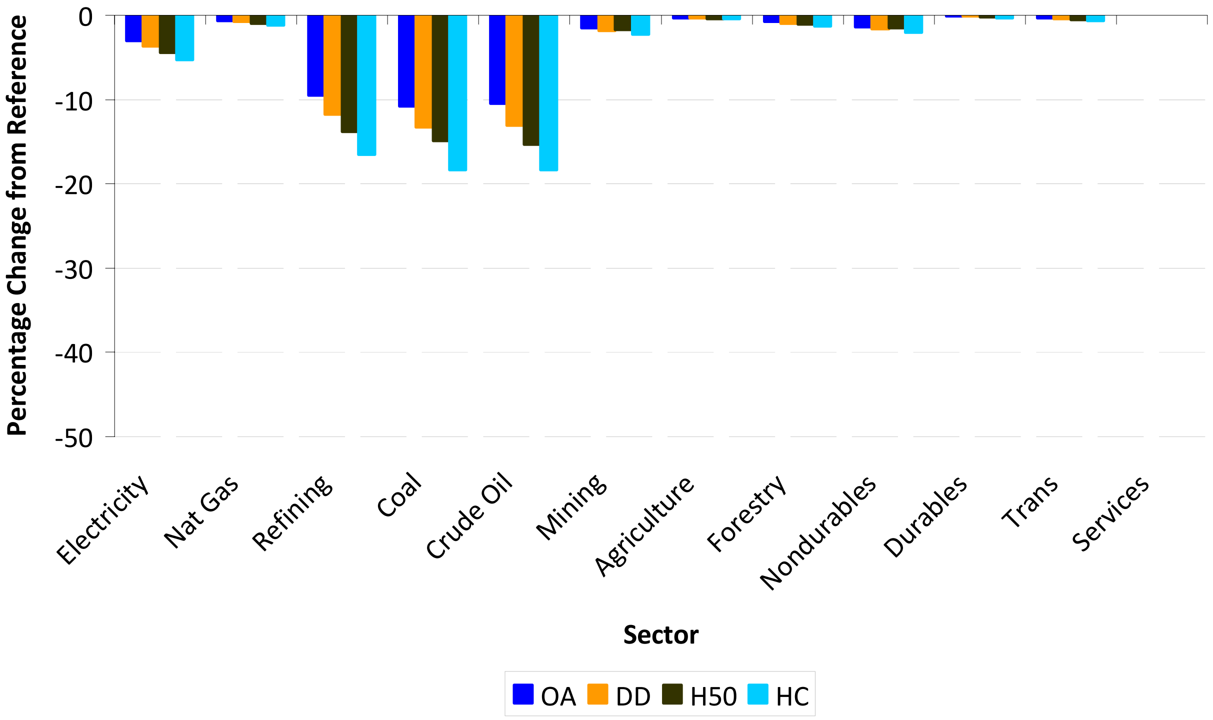

Table 7. Effects of Each Policy on Individual Sectors in 2015

Values are percentage changes relative to the reference scenario.

	Sector	Price (%)				Output (%)				Employment (%)			
		OA	DD	H50	HC	OA	DD	H50	HC	OA	DD	H50	HC
1	Electric Utilities	4.2	5.2	6.1	7.4	-3.0	-3.7	-4.4	-5.3	-3.3	-4.1	-4.8	-5.9
2	Gas Utilities	0.7	0.9	1.1	1.3	-0.6	-0.8	-1.0	-1.1	-0.2	-0.3	-0.3	-0.4
3	Petrol. Refining	8.8	10.9	12.8	15.7	-9.5	-11.8	-13.8	-16.5	-3.9	-4.8	-5.6	-6.6
4	Coal Mining	33.7	41.3	45.9	55.3	-10.8	-13.3	-14.9	-18.3	-12.6	-15.4	-16.9	-20.8
5	Crude Oil & Gas	11.4	14.2	16.6	19.9	-10.5	-13.0	-15.3	-18.3	-10.6	-13.1	-14.8	-17.7
6	Mining	0.2	0.2	0.4	0.5	-1.5	-1.9	-1.8	-2.3	-1.5	-1.8	-1.5	-2.0
7	Agriculture	0.1	0.1	0.2	0.3	-0.3	-0.3	-0.4	-0.5	-0.2	-0.2	-0.1	-0.1
8	Forestry & Wood	-0.3	-0.3	-0.2	-0.3	-0.8	-1.0	-1.1	-1.3	-1.0	-1.2	-1.2	-1.4
9	Durables	-0.5	-0.6	-0.3	-0.3	-1.4	-1.7	-1.5	-2.0	-1.5	-1.8	-1.6	-2.1
10	Non-Durables	0.1	0.1	0.3	0.3	-0.1	-0.1	-0.2	-0.3	-0.1	-0.1	-0.1	-0.1
11	Transportation	0.4	0.4	0.5	0.6	-0.3	-0.4	-0.5	-0.6	-0.2	-0.3	-0.3	-0.4
12	Services	0.2	0.2	0.3	0.3	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1

Table 8. Effects of Each Policy on Individual Sectors in 2025

Values are percentage changes relative to the reference scenario.

	Sector	Price (%)				Output (%)				Employment (%)			
		OA	DD	H50	HC	OA	DD	H50	HC	OA	DD	H50	HC
1	Electric Utilities	12.7	14.2	9.1	11.0	-10.1	-11.3	-7.2	-8.7	-23.9	-26.6	-16.9	-20.4
2	Gas Utilities	2.0	2.3	1.5	1.8	-1.9	-2.1	-1.3	-1.6	0.3	0.5	0.3	0.4
3	Petrol. Refining	27.1	30.3	18.0	22.5	-32.3	-36.1	-23.1	-27.8	-13.8	-15.4	-10.1	-12.0
4	Coal Mining	96.4	107.4	68.7	82.8	-35.7	-39.7	-24.1	-30.0	-39.4	-43.4	-25.8	-32.0
5	Crude Oil & Gas	35.0	39.1	24.8	30.0	-36.4	-40.6	-26.1	-31.5	-32.9	-36.7	-23.3	-28.0
6	Mining	0.9	1.0	0.4	0.6	-2.3	-2.4	-1.2	-1.6	-1.3	-1.2	-0.5	-0.8
7	Agriculture	0.5	0.5	0.2	0.3	-0.7	-0.7	-0.5	-0.6	0.7	0.9	0.4	0.6
8	Forestry & Wood	-0.3	-0.3	-0.5	-0.5	-1.0	-0.9	-0.2	-0.3	-0.5	-0.3	0.1	0.0
9	Durables	-0.7	-0.7	-0.7	-0.8	-1.6	-1.6	-0.3	-0.7	-1.6	-1.5	-0.3	-0.7
10	Non-Durables	0.5	0.6	0.1	0.2	-0.4	-0.5	-0.2	-0.3	0.1	0.2	0.1	0.2
11	Transportation	0.8	0.9	0.5	0.6	-0.7	-0.7	-0.4	-0.5	-0.1	-0.1	0.0	0.0
12	Services	0.3	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.4	0.5	0.3	0.4

Figure 9. Effect of Alternative Policies on the U.S. Trade Balance

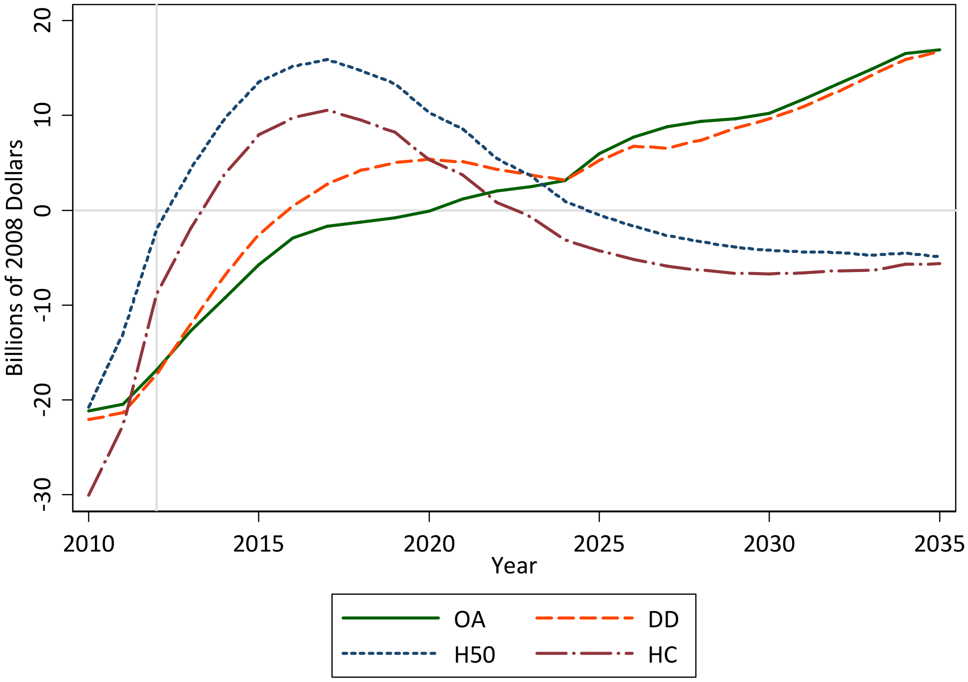

Figure 10. Effect of Alternative Policies on U.S. Real Effective Exchange Rate

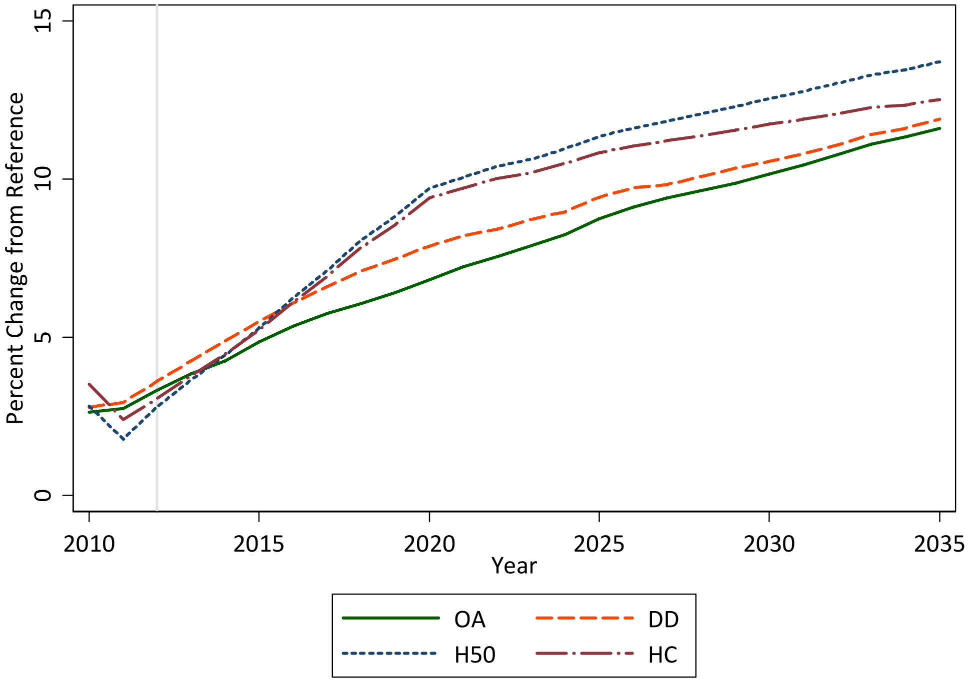

Figure 11. Allowance Price per Ton of CO_2 under Price Ceiling Policies

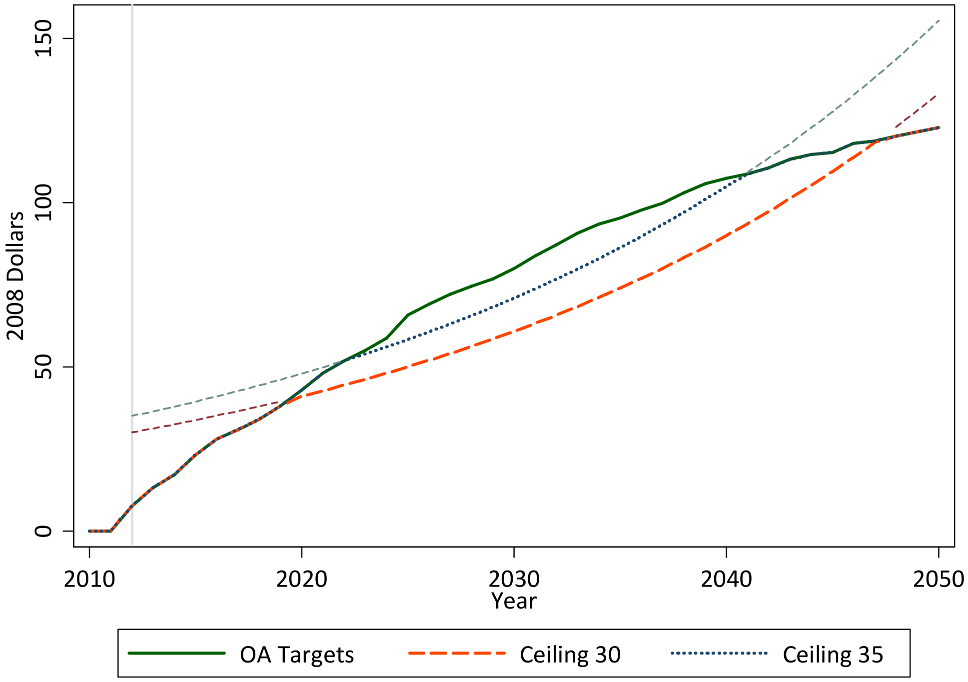

Figure 12. Reductions in U.S. CO_2 Emissions under Price Ceiling Policies

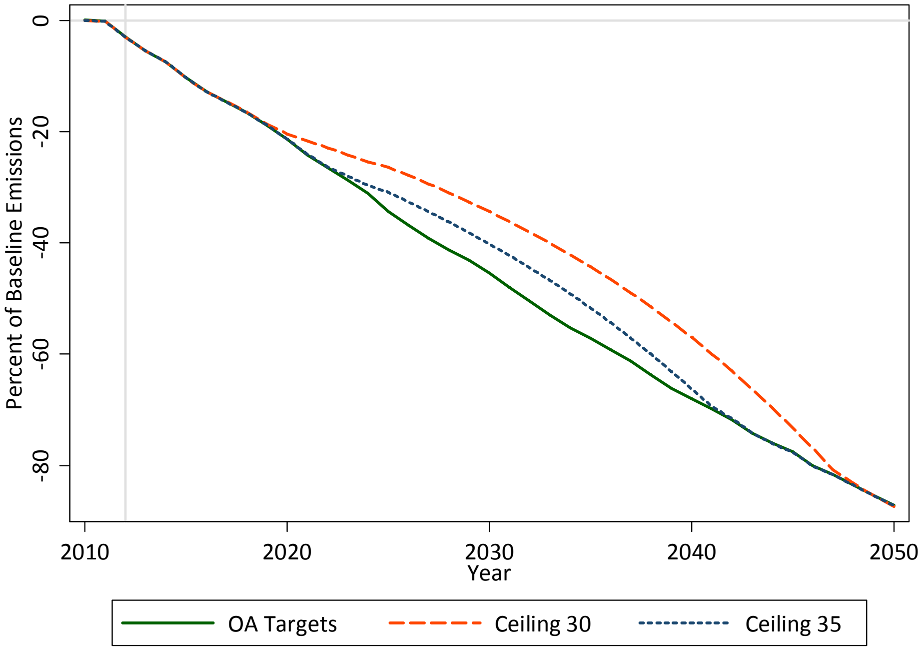

Figure 13. Cumulative U.S. CO_2 Emissions under Price Ceiling Policies

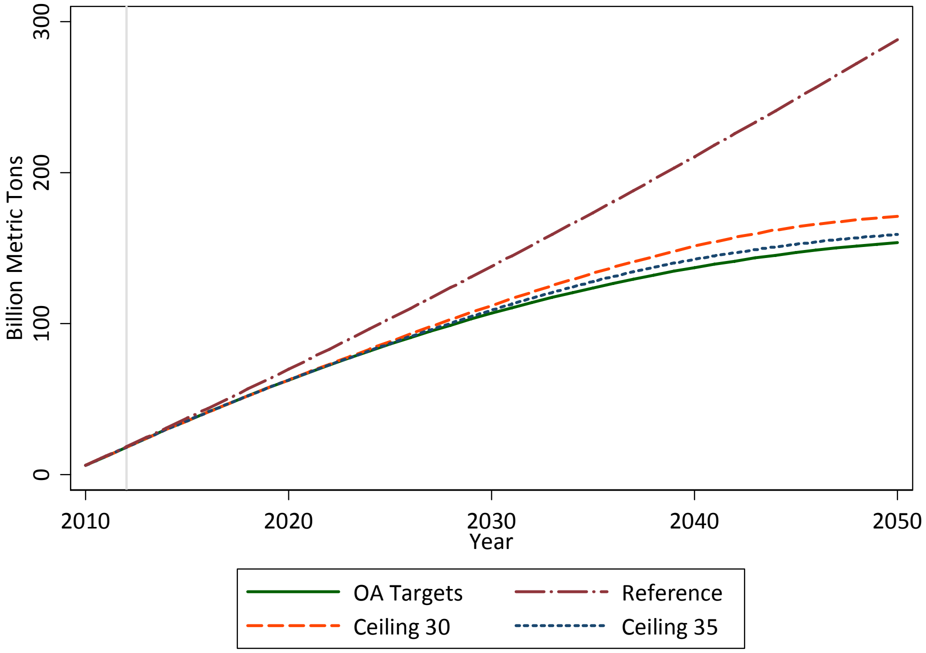

Figure 14. Allowance Price per Ton of CO_2 under Price Collar Policy

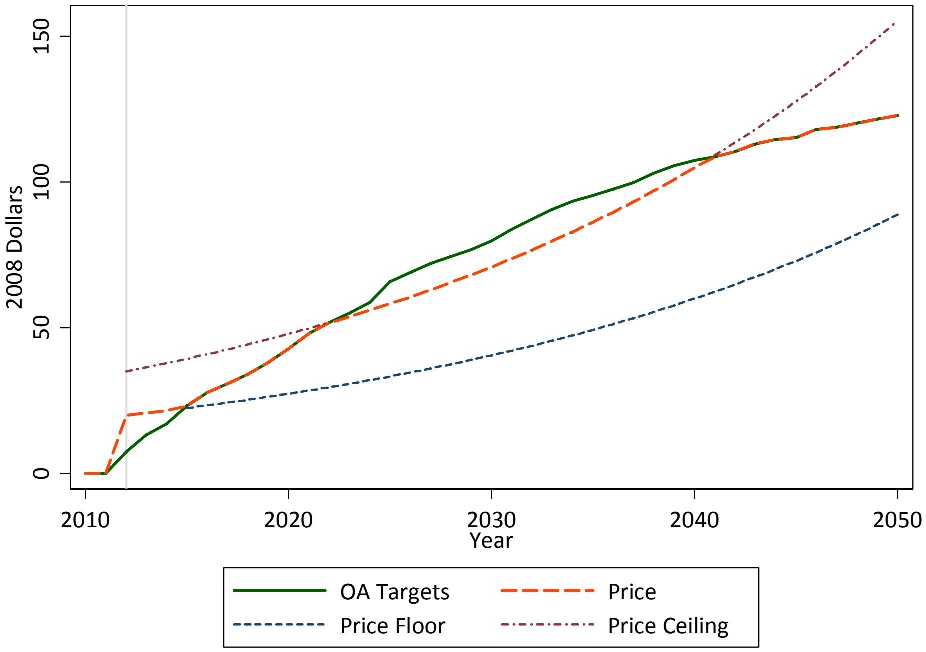

Figure 15. Reduction in U.S. CO_2 Emissions under Price Collar Policy

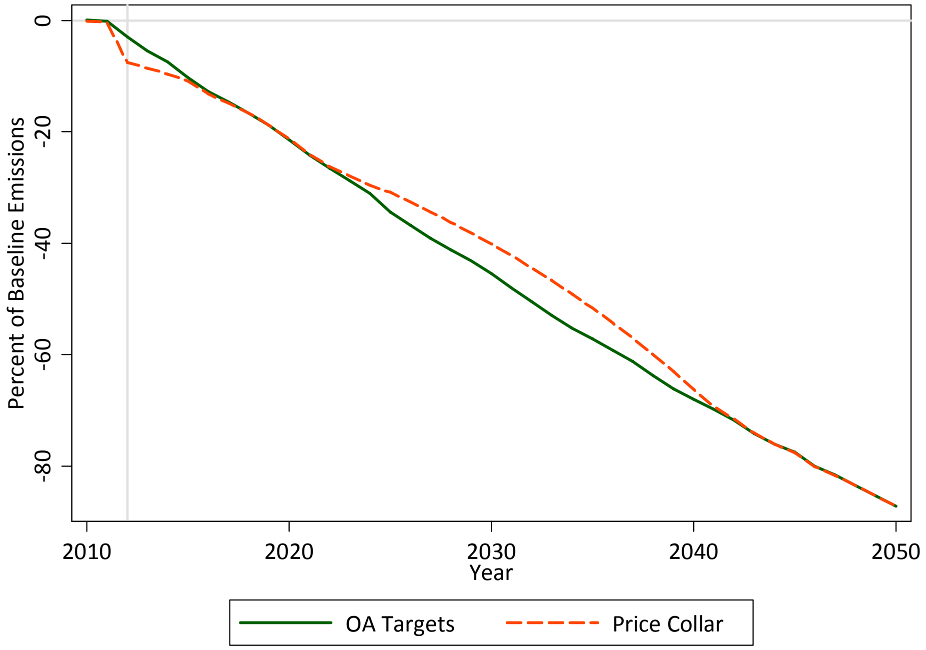

Figure 16. Cumulative U.S. CO_2 Emissions under Price Collar Policy