# Using a Carbon Tax to Meet US International Climate Pledges

Yunguang Chen and Marc A.C. Hafstead

## Abstract

The United States recently ratified the Paris Agreement, under the UN Framework Convention on Climate Change (UNFCCC), in which it pledged to reduce greenhouse gas emissions by 26–28 percent, relative to 2005, by 2025. In the absence of policy efforts beyond those currently in place or already proposed by the Obama administration, the United States would likely fall well short of its promises. However, a federal economy-wide carbon tax on US carbon dioxide emissions could significantly contribute to the additional reductions necessary to fulfill our international climate commitments. Using a detailed multisector computable general equilibrium (CGE) model, we predict the carbon price paths that would be necessary to meet the 28 percent emissions target and show the economic costs of such carbon-pricing policies. We then demonstrate how both the price paths and associated costs change if action is delayed.

**Key Words:** carbon tax, climate, emissions targets

**JEL Classification Numbers:** Q50, Q58, H23

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Yunguang Chen and Marc A.C. Hafstead*

## 1. Introduction

In December 2015, 195 countries entered into a global agreement to reduce greenhouse gas emissions and limit global warming. The Paris Agreement set a goal to limit warming to 1.5–2 degrees Celsius, relative to preindustrial levels. As part of the negotiations, most countries submitted intended nationally determined contributions (INDCs), which are actions each country pledges to make after 2020 to contribute to reductions in global greenhouse gas emissions. As countries ratify and officially join the agreement, those INDCs become nationally determined contributions (NDCs), and countries are expected to submit updated NDCs every five years as part of the Paris Agreement.[1]

For its part, the United States ratified the agreement through executive action by President Obama on September 3, 2016. Through ratification, the United States thus is committed to reduce emissions by 26–28 percent from 2005 levels. The White House (2015) believes that its "steady efforts to reduce emissions will deliver ever-larger carbon pollution reductions … and provide a firm foundation to meet the new US target."

According to the latest Inventory of U.S. Greenhouse Gas Emissions and Sinks from the US Environmental Protection Agency (EPA), the United States produced 7,379 million metric tons (mmt) of carbon dioxide equivalent ($CO_2e$) greenhouse gases in 2005, and land use, land use changes, and forestry removed 699 mmt $CO_2e$ from the atmosphere (referred to as sinks), for a total level of net emissions of 6,680 mmt $CO_2e$. In 2014, the latest year for which data are available, net emissions were 6,108 mmt $CO_2e$, an 8.6 percent decline relative to 2005. Therefore, the United States must reduce emissions by a further 17.4–19.4 percent relative to 2005 emissions to satisfy its international climate commitments.[2] Under current law, assuming the Clean Power Plan is upheld in the court system, 2025 US greenhouse gas emissions are

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[1] On October 5, 2016, more than 55 countries representing at least 55 percent of global greenhouse emissions had ratified the agreement. As a result of this key threshold for ratification, the Paris Agreement entered into force on November 4, 2016.

[2] There are no legal repercussions in the Paris Agreement if countries fail to meet their NDCs.

projected to be 14 percent below 2005 levels (DOS 2016). The Clean Power Plan itself contributes to 4.1 percent of those emissions reductions (EIA 2016).

To help achieve further reductions, the administration has proposed several regulatory measures, including heavy-duty fuel economy standards, energy efficiency regulations for both buildings and appliances, new standards for addressing methane ($CH_4$) emissions from landfills and the oil and gas sector, and EPA's Significant New Alternatives Policy (SNAP) to reduce hydrofluorocarbons (HFCs). The US Department of State expects additional reductions of at least 349 mmt $CO_2e$ by 2025 from these proposed policies. If these new regulations become law, the US emissions levels in 2025 are expected to be 19 percent below 2005, still well short of the 26–28 percent target (DOS 2016).

$CO_2$ emissions contribute to 80.9 percent of gross greenhouse gas emissions (ignoring sinks), and the combustion of fossil fuels is responsible for almost 94 percent of all $CO_2$ emissions. Clearly, the United States must reduce its use of fossil fuels if it is to meet its climate goals, and basic economics suggests this can be achieved by raising the prices of fossil fuels. A tax on fossil fuels in proportion to their carbon content, a carbon tax, is an instrument for reducing carbon dioxide emissions from the combustion of fossil fuels. A carbon tax provides a price signal that encourages reductions in both total demand for energy (through improved efficiency and conservation) and the carbon intensity of energy (through fuel switching from coal to natural gas or renewable energy). A carbon tax also raises revenue that can be used, among other things, to reduce taxes on labor and capital. However, a carbon tax in the United States would require an act of Congress, and its political feasibility remains low.

This paper examines how a federal carbon tax can be used to meet the United States' international climate commitments. Using a numerical model of the US economy, we find the carbon tax paths that would enable the United States to meet its 28 percent target. These "2025 carbon tax" price paths will vary by the growth rate of the tax over time, the method of revenue recycling, and the year in which the policy is implemented. All of the policies will achieve 28 percent reductions in net greenhouse gas emissions in 2025, but with different economic costs. Moreover, the path of emissions between 2017 and 2025 will depend on the price path, with important consequences for the cumulative $CO_2$ emissions reductions between 2017 and 2025.

Our analysis yields three key findings. First, the size of the 2025 carbon taxes and their corresponding economic costs are modest. For taxes that recycle revenue through lump-sum rebates to households, we find that a constant economy-wide carbon tax of $21.22 (in 2013$)

starting in 2017 satisfies the 28 percent goal at a cost of $34.16 per ton (using equivalent variation welfare measure of cost) and a reduction in real GDP of 0.35 percent in 2025.

Second, we find that the method of revenue recycling significantly affects the costs of the 2025 carbon tax policies. For example, the costs (welfare losses per ton reduced) of the economy-wide carbon tax fall 31 and 75 percent under individual income tax or corporate income tax cuts relative to lump-sum rebates. However, the form of revenue recycling does not significantly affect the price paths. The constant economy-wide carbon tax level must be $21.22 with lump-sum rebates or $21.32 and $21.95 if the policy uses revenues to cut individual income taxes or corporate income taxes.

Finally, we show that the cost of delaying the implementation of a carbon tax is high. Delaying implementation until 2020 raises the costs of using an economy-wide carbon tax to meet the 2025 targets by 12 percent relative to implementing the policy in 2017. Delaying until 2023 increases the costs relative to 2017 by over 29 percent.

To our knowledge, this is the first paper to solve numerically for the carbon price paths necessary to meet US international climate commitments with a general equilibrium model. Our results suggest that economy-wide carbon tax rates below $22, implemented in 2017, can reduce greenhouse gas emissions to the levels promised in the NDC. Further, we demonstrate that each year of delay increases both the level of the carbon taxes needed to achieve the promised reductions and the associated costs of meeting the emissions target with a carbon tax. The rest of the paper is organized as follows. Section 2 presents a brief sketch of the model. Section 3 explains the business-as-usual assumptions for both $CO_2$ and non-$CO_2$ greenhouse gases, and Section 4 discusses the policy simulations. Section 5 provides sensitivity analysis, and the final section concludes.

## 2. A Numerical Model

To assess how a federal carbon tax can meet the United States' international climate commitments, we use a variant of the Goulder-Hafstead Energy-Environment-Economy (E3) computable general equilibrium model to simulate a business-as-usual reference case and various carbon tax policy cases for the US economy.[3] The E3 model is an intertemporal general equilibrium model of the US economy with international trade. The US economy is modeled as a

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[3] The full E3 model includes endogenous domestic oil productivity and perfect foreign oil substitution. Neither of these components is important for results between the years 2017 and 2025. Therefore, we simplify the model by assuming exogenous domestic oil productivity and imperfect (Armington) foreign oil substitution.

collection of representative agents: firms representing 35 distinct industries, a single representative household, and a single representative government. The model captures the interactions among these agents and solves for market-clearing prices in each period. Beginning in the benchmark year 2013, the model is solved at annual intervals. For the purposes of this exercise, we primarily focus on impacts through the year 2025.

Two features of the model distinguish it from similar dynamic environment-related CGE models that also make it well suited for the analysis of federal carbon taxes. First, the model combines a relatively detailed representation of domestic energy supply and demand with a detailed treatment of the US tax system. The detailed treatment of both the energy system and the tax system allows the model to consider critical interactions between climate policy and the fiscal system. These interactions fundamentally shape the impacts of climate policies and in particular determine the costs of climate policies such as the 2025 carbon taxes.

Second, the model recognizes the adjustment costs associated with the installation or removal of physical capital. These costs affect the pace of the economy's response to new environmental policies and are critical to the size of the 2025 carbon tax levels. Because of adjustment costs, the economy cannot instantly reallocate structures and equipment in response to a tax on fossil fuels. As a result, higher 2025 carbon tax rates are required than if there were no adjustment costs.

Carbon taxes are introduced in the model as a tax on the purchase of fossil fuels, both domestic and imported, in proportion to the carbon in each fuel. The tax also covers domestic emissions from the combustion of imported refined products (e.g., gasoline), where the purchase of the fossil fuel occurs abroad through tariffs on the imports of refined products. This specification covers 99.99 percent of all domestic emissions from the combustion of fossil fuels.

All carbon taxes considered in the model are revenue-neutral. Lump-sum rebates are modeled as reductions in lump-sum taxes paid by the household. We also consider cuts in payroll taxes, individual income taxes, and corporate income taxes.

For a complete description of the model, the data sources, and the key parameters of the Goulder-Hafstead E3 model, please see Goulder et al. (2016) and Goulder and Hafstead (2013).

## 3. Greenhouse Gas Emissions in the Reference Case

Carbon dioxide emissions from the combustion of fossil fuels are represented as the product of fossil fuel inputs into production times $CO_2$ emissions coefficients.[4] We choose the coefficients so as to match data on emissions from energy consumption by industry source in the benchmark year 2013, using data on emissions by source from the Energy Information Administration (EIA). Given the reference case time path for fossil fuel inputs, the model produces a reference case path of $CO_2$ emissions from fossil fuel combustion.

The reference case is calibrated to approximate the emissions forecast from EIA's *Annual Energy Outlook* (AEO) 2016 reference case without the Clean Power Plan (CPP).[5] Although EPA has issued its final ruling on the CPP, and the CPP is included in projections for 2025 greenhouse gas emissions levels by the US Department of State (more on this below), we exclude the CPP from our reference case projections for a number of reasons. First, the US Supreme Court has stayed the rule until the legal proceedings against the plan have been fully resolved. Second, states are responsible for choosing policies to meet state-specific goals, and it is not clear what policies they will choose. Finally, policymakers could choose to remove the CPP as part of a carbon tax, and if the CPP is not removed as part of a federal carbon tax policy, it is reasonable to assume that most carbon taxes would render the plan nonbinding.

Figure 1 displays the level of total emissions for both the E3 model and the AEO's no-CPP reference case between 2014 and 2040.[6] Emissions of $CO_2$ from combustion in the E3 model reference case are approximately 118 million tons higher in 2025 than under AEO forecasts (a 2 percent difference), with the disparities primarily from higher emissions from coal-fired electricity generation in the E3 model.

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[4] This method assigns emissions to purchasers of fossil fuels. In many instances, purchasers of fossil fuels also burn those fuels (coal generators). In other circumstances, purchasers of fossil fuels may not combust the fuel (petroleum refiners). This method simplifies emissions accounting while also covering all emissions derived from the purchase of fossil fuels, including combustion-related process emissions, and downstream combustion of secondary products.

[5] We calibrate the model to match fossil fuel price forecasts, productivity changes by electricity generation type, changes in preferences for natural gas generation over coal generation, and changes in demand for energy by households, the government, and industry (a proxy for energy efficiency).

[6] The EIA's data on emissions from combustion of fossil fuels differs from data in EPA's Inventory of Greenhouse Gas Emissions and Sinks. The difference between the two numbers is due to emissions from international bunker fuels and emissions from US territories. The EIA includes international bunker fuels and excludes emissions from US territories relative to EPA. Because the international climate commitments use EPA's inventory report as official levels of emissions, we convert the model's emissions from combustion based on EIA emissions levels to EPA equivalents by assuming the ratio of EIA to EPA emissions is fixed over time.

**Figure 1. Energy-Related Carbon Dioxide Emissions Projections, 2013–2040, E3 and AEO2016 No-CPP Reference Case**

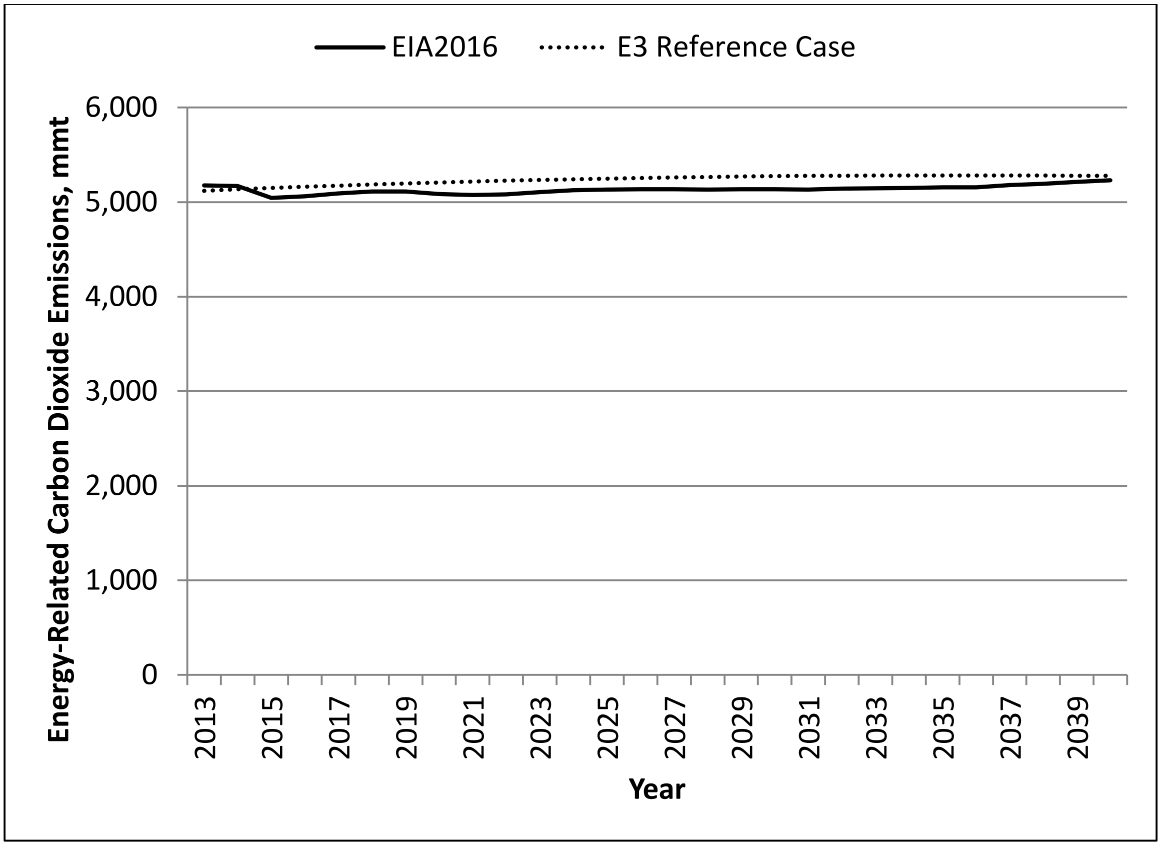

Table 1 displays historical and projected emissions for noncombustion $CO_2$ emissions and other greenhouse gases and sinks under current law and under proposed regulations. For noncombustion $CO_2$ emissions, we assume that the rate of change in emissions between 2005 and 2014 continues between 2014 and 2025. There are no proposed regulations to regulate noncombustion $CO_2$ emissions. For other greenhouse gases and sinks, we use projections for these emissions from the *Second Biennial Report of the United States* to the UNFCCC published by the US Department of State under both current law and proposed regulations (DOS 2016).[7] Proposed regulations that reduce non-$CO_2$ greenhouse gases include new standards for addressing methane emissions from landfills and the oil and gas sector, as well as EPA's Significant New Alternatives Policy (SNAP) to reduce hydrofluorocarbons. For projections of

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[7] The Department of State's biennial report was published in December 2015. In April 2016, EPA significantly revised its historical emissions inventories especially for methane, hydrofluorocarbons, and sinks. State projections of 2025 emissions levels are adjusted to account for the adjustment in historical emissions levels.

changes in sinks or removals of emissions from the atmosphere or from changes in land use and forestry, we use an average of the low and high sequestration estimates.

Table 1 also displays official projections of combustion-related $CO_2$ emissions and total net greenhouse gas emissions. Under current law, including the CPP, total emissions are expected to be 14 percent below 2005 levels in 2025. If proposed regulations are included, emissions in 2025 are expected to be 19 percent below 2005 levels.

For E3 business-as-usual reference case projections for total greenhouse gases, we use the same level of noncombustion $CO_2$ emissions, non-$CO_2$ emissions, and sinks from the state projections with proposed measures included. Combustion-related $CO_2$ emissions differ substantially because we use E3 reference case emissions levels that do not include the CPP or reductions from proposed regulations. Therefore, the E3 model predicts emissions in 2025 that are only 13 percent below 2005 levels in the absence of a carbon tax. Assuming that noncombustion $CO_2$ emissions, non-$CO_2$ emissions, and sinks are unaffected by the carbon tax, our projections indicate that combustion-related $CO_2$ emissions must be 4,263 mmt in 2025 to match the 28 percent target. This represents a 25.8 percent reduction in combustion-related $CO_2$ emissions relative to 2005 levels. The next section presents our results of the carbon tax paths that achieve these emissions targets.

**Table 1. Historical and Projected Greenhouse Gas Emissions, mmt $CO_2e$**

| | | | Current law[b] | Additional regulations[c] | E3 reference case[d] | E3 28% reductions by 2025 |
|---|---|---|---|---|---|---|
| | Historical emissions[a] | | Projected emissions | | | |
| **Greenhouse gases** | **2005** | **2014** | **2025** | | | |
| Energy-related carbon dioxide ($CO_2$) | 5,747 | 5,208 | 4,973 | 4,859 | 5,249 | 4,263 |
| Non-energy-related carbon dioxide ($CO_2$)[e] | 376 | 348 | 332 | 332 | 314 | 314 |
| Methane ($CH_4$) | 717 | 731 | 765 | 683 | 683 | 683 |
| Nitrous oxide ($N_2O$) | 398 | 404 | 381 | 340 | 340 | 340 |
| Hydrofluorocarbons (HFC) | 120 | 167 | 244 | 131 | 131 | 131 |
| Perfluorocarbons (PFC) | 7 | 6 | 5 | 5 | 5 | 5 |
| Sulfur hexofluoride ($SF_6$) | 14 | 7 | 9 | 9 | 9 | 9 |
| **Total emissions** | 7,379 | 6,871 | 6,709 | 6,359 | 6,731 | 5,745 |
| **Land use, land use changes and forestry sequestration**[f] | –699 | –763 | –935 | –935 | –935 | –935 |
| **Total net emissions** | 6,680 | 6,108 | 5,774 | 5,424 | 5,796 | 4,810 |
| **Emissions relative to 2005** | n/a | –8.6% | –13.6% | –18.8% | –13.2% | –28.0% |
| **Energy-related $CO_2$ emissions relative to 2005** | n/a | –9.4% | –13.5% | –15.5% | –8.7% | –25.8% |
| **Energy-related $CO_2$ emissions relative to 2013** | n/a | 1.0% | –3.6% | –5.8% | 1.8% | –17.4% |

[a] Historical emissions are from EPA (2016)

[b] Current law emissions are from DOS (2016), adjusted for 2016 inventory revisions, includes Clean Power Plan

[c] Additional regulations emissions are from DOS (2016), using conservative estimates, adjusted for 2016 inventory revisions

[d] E3 reference case energy-related $CO_2$ emissions from E3 model, non-energy-related $CO_2$ emissions assume same rate of reductions between 2005–2014 and 2014–2025, State Department additional regulation projections for non-$CO_2$ GHGs

[e] State Department projections (current law and additional regulations) for total $CO_2$ emissions disaggregated using 2014 emissions shares

[f] Land use, land use changes, and forestry sequestration projections are a simple average of low and high sequestration projections, adjusted for 2016 inventory revisions

## 4. Simulation Results

To achieve the 2025 emissions target, an economy-wide carbon tax could start high and rise at a low (or zero) growth rate, or the tax could start low and rise at a high rate. The policy implementation year could also vary, and the tax revenue could be recycled through different channels. Each tax path and revenue-recycling plan that meets the 2025 target, however, will have substantially different impacts on emissions and costs in the years before 2025. To highlight this, we consider three different carbon tax growth rates: 0, 3, and 6 percent. First, we solve for the initial price in 2017 such that emissions in 2025 exactly meet the 28 percent greenhouse gas target (holding fixed the tax rate after 2025). Later, we solve for policies that introduce the carbon tax after 2017. In all cases, we consider four revenue-neutral methods of returning the revenue to the private sector: lump-sum rebates, payroll tax cuts, individual income tax cuts, and corporate income tax cuts.

### *4.1. Carbon Price and Emissions Paths*

Figure 2 displays the 2025 carbon tax price path for policies with lump-sum rebates starting in 2017. A constant economy-wide tax of $21.22 (in 2013$) is enough to meet the 2025 target. Alternatively, a tax of $16.87 rising at 3 percent per year in real terms or a tax of $13.50 rising at 6 percent per year would also achieve the 28 percent target for 2025. In 2025 and beyond, the prices are roughly similar, though we note that lower growth rate paths lead to slightly higher tax levels in 2025. While these policies achieve the same 2025 target, the level of emissions over the time interval 2017–2025 will vary considerably.

Figure 3 displays the time path of energy-related carbon dioxide emissions relative to 2005 for the three economy-wide carbon tax paths with lump-sum rebates. In the first year of the policy, a carbon tax of $21.22 with zero growth will achieve energy-related CO2 emissions reductions of about 22 percent (relative to 2005), rising to 25.8 percent in 2025 as the economy adjusts to the tax. The policy that starts at $13.50 and rises at 6 percent per year in real terms, however, will achieve reductions of only slightly less than 19 percent in 2017.

And although emissions under the high growth rate policy converge to the zero growth rate policy by 2025, the cumulative emissions under the two different policies are quite different. Table 2 displays the cumulative (undiscounted) emissions reductions in the years 2017–2025. The 0 percent growth rate policy removes 8,173 million metric tons of CO2 from the atmosphere, whereas the 6 percent policy removes 7,111 million metric tons, a difference of 13 percent. Thus, while targets in benchmark years may be an effective method of demonstrating intent to reduce emissions to the international community, different policies that meet the same benchmark targets may have very different impacts on the level of total emissions and ultimately the climate. As a result, policymakers and climate negotiators might consider changing the framing of nationally determined contributions away from benchmark year targets to cumulative emissions targets over a given time interval to more effectively commit to reducing climate change.

**Figure 2. 2025 Carbon Tax Paths, 2017–2035**

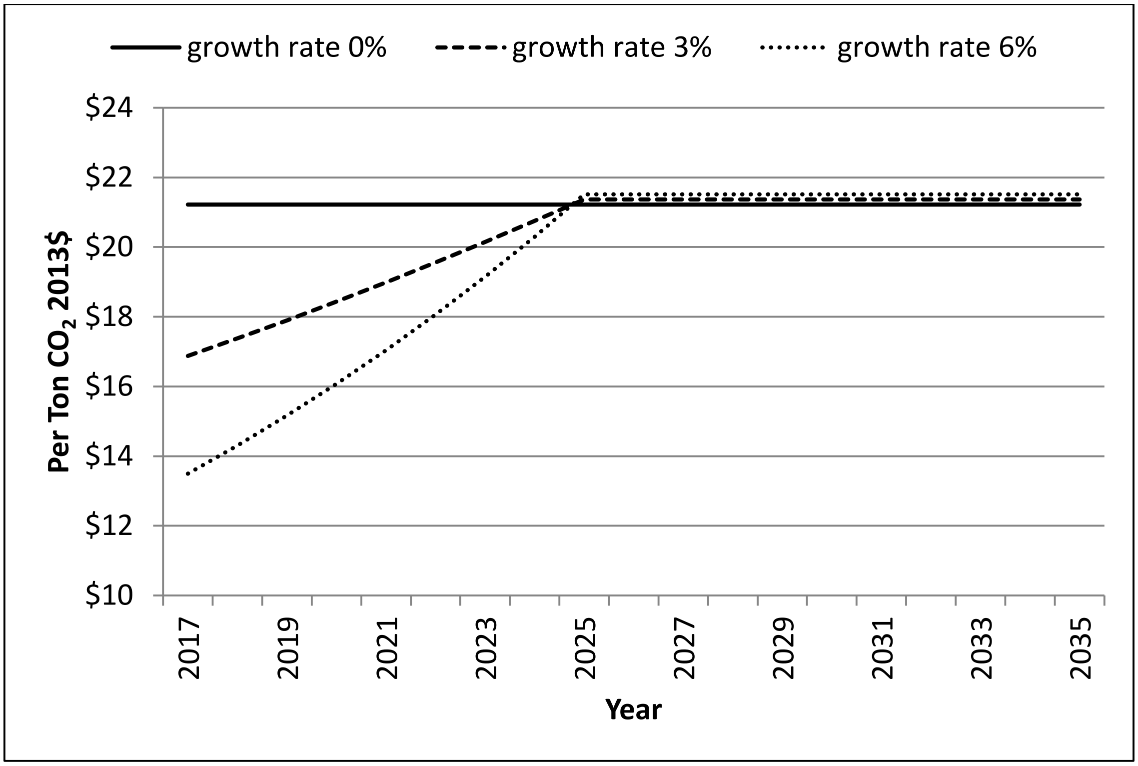

**Figure 3. Energy-Related $CO_2$ Emissions Reductions Relative to 2005, 2017–2035**

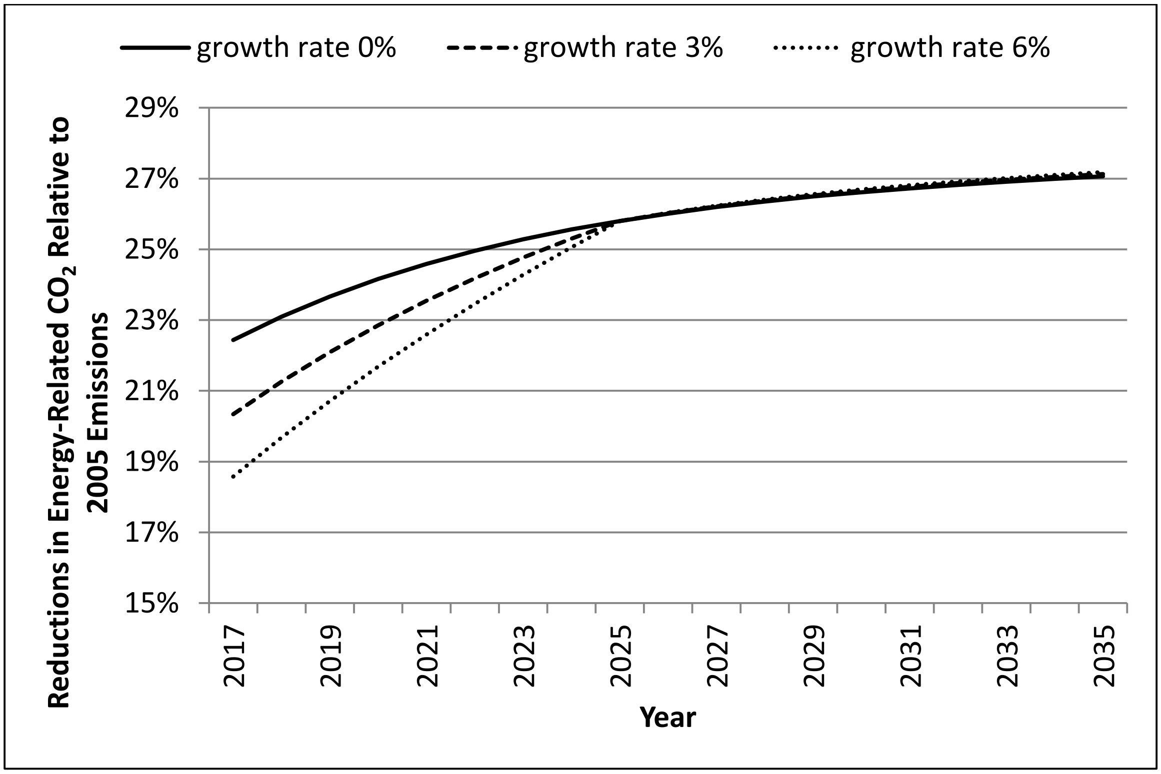

**Table 2. Carbon Prices and Cumulative Emissions Reductions, by Growth Rate and Revenue-Recycling Method**

| | Initial carbon price in 2017 (2013$/ton) | | | Cumulative emissions reduction 2017–2025 (mmt) | | |
|---|---|---|---|---|---|---|
| | Gr 0% | Gr 3% | Gr 6% | Gr 0% | Gr 3% | Gr 6% |
| Lump-sum rebate | $21.22 | $16.87 | $13.50 | 8,173 | 7,610 | 7,111 |
| Payroll tax cut | $21.28 | $16.92 | $13.53 | 8,176 | 7,611 | 7,112 |
| Personal income tax cut | $21.32 | $16.95 | $13.56 | 8,181 | 7,616 | 7,116 |
| Corporate income tax cut | $21.95 | $17.43 | $13.94 | 8,255 | 7,678 | 7,169 |

Table 2 also demonstrates the difference in the tax rates required to hit the 2025 target given different uses of the carbon revenue (referred to as revenue recycling). A revenue-neutral policy with lump-sum rebates (i.e., a tax and dividend type policy) will require a lower price path than revenue-neutral carbon taxes that use the revenues to finance cuts in other preexisting taxes. Cuts in distortionary taxes such as payroll taxes, individual income taxes, or corporate taxes provide a boost to the economy. This boost increases consumption, investment, and most important, emissions (relative to a lump-sum rebate policy), and therefore higher tax rates are needed to offset these extra emissions and still meet the 2025 target. Corporate income taxes are the most distortionary tax in the E3 model, and therefore they require the largest increase in the tax (again, relative to lump-sum rebates). However, the differences in price paths among different recycling options are modest. For example, the constant tax would need to be increased from $21.22 to $21.95 if carbon revenues were used to finance corporate income tax cuts, an increase of about 3 percent. Overall, regardless of the recycling option, a relatively modest carbon tax can meet the United States' most ambitious commitment for emissions in 2025. Also, because of the slightly higher prices needed to meet the 2025 target, revenue-neutral carbon taxes that use the revenues to finance cuts in payroll taxes, individual income taxes, or corporate taxes have slightly higher cumulative emissions reductions over the years 2017–2025.

### *4.2. Economic Costs*

The economic costs of meeting the target depend on what price path is chosen, how the revenues are recycled, and the year in which the policy is implemented. Figure 4 displays the costs of the lump-sum rebate policies with 0, 3, and 6 percent growth rates, respectively. Because the 0 percent growth rate policy requires a higher initial tax rate, the GDP costs are highest in the years 2017–2025 under the 0 percent growth rate policy and lowest under the 6 percent growth rate policy. After 2025, when the tax rates are constant, the policies each have approximately the same GDP impacts, but note that the impacts continue to grow over time as impacts on investment in the early periods lead to reduced consumption in the future. In 2025, under each of the three growth rate policies, real GDP is approximately 0.35 percent less than if no policy had been implemented.[8]

In the previous section, we showed that the price paths for meeting the 2025 goals are similar under alternative recycling schemes. However, the method of revenue recycling is very important for the overall costs of the policy, as previously noted by Goulder (1995), Goulder et al. (2010), Parry and Williams (2010), and Goulder and Hafstead (2013). Figure 5 shows the GDP costs under lump-sum rebates, payroll taxes, individual income taxes, or corporate taxes for a policy with a 3 percent growth rate. Revenue-recycling methods that cut other distortionary taxes significantly lower the negative impact on GDP. In 2025, the GDP losses under payroll tax and individual income tax cuts are about 0.29 and 0.28 percent, compared with 0.35 percent under lump-sum recycling. The GDP losses are minimized the most over the long term under corporate income tax recycling, which has the most positive impact on investment. A tax that finances corporate income tax reductions has a GDP cost of 0.2 percent in 2025 and a cost that stabilizes earlier and at a lower level than the other policies.

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[8] The GDP loss is relative to a no-CPP reference case. These losses should not be interpreted as the costs of a carbon tax relative to the cost of the CPP. Also, inclusion of the CPP would still result in emissions greater than the 2025 target. Thus it would not be meaningful to compare a carbon tax that achieves the target with the CPP, which does not achieve the targets.

**Figure 4. Real GDP Losses (as a Percentage of Reference Case GDP), 2017–2035, Lump-Sum Rebates, by Growth Rate**

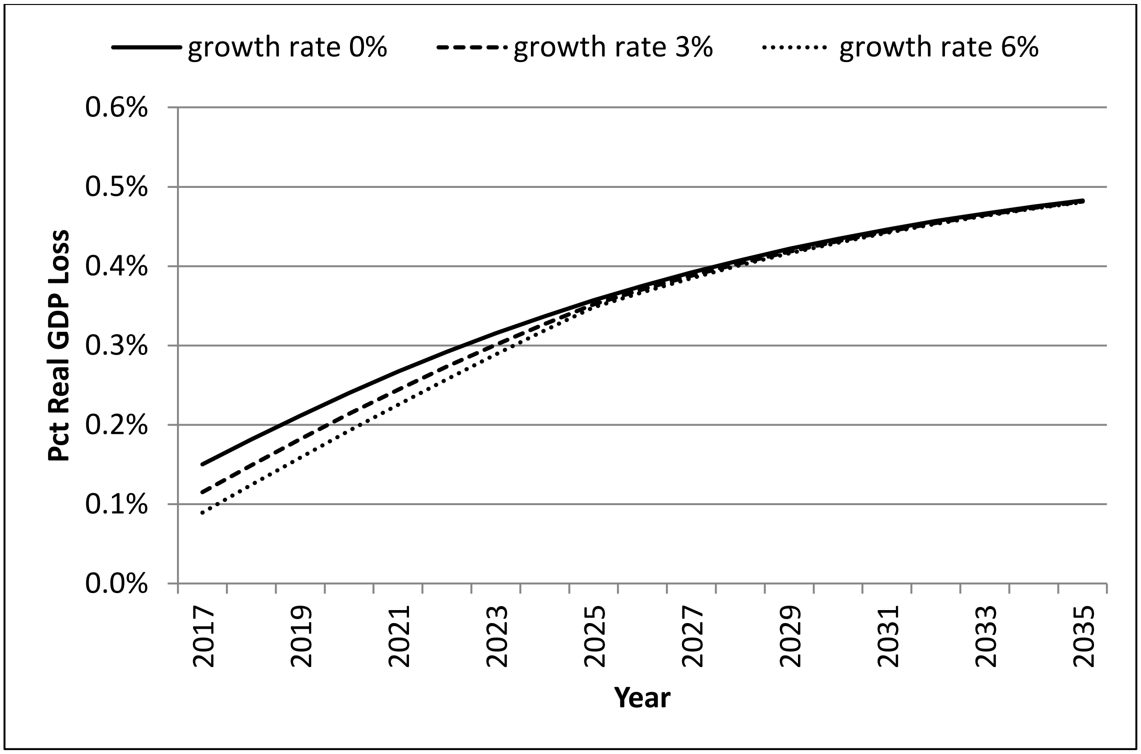

**Figure 5. Real GDP Losses (as a Percentage of Reference Case GDP), 2017–2035, by Revenue-Recycling Method**

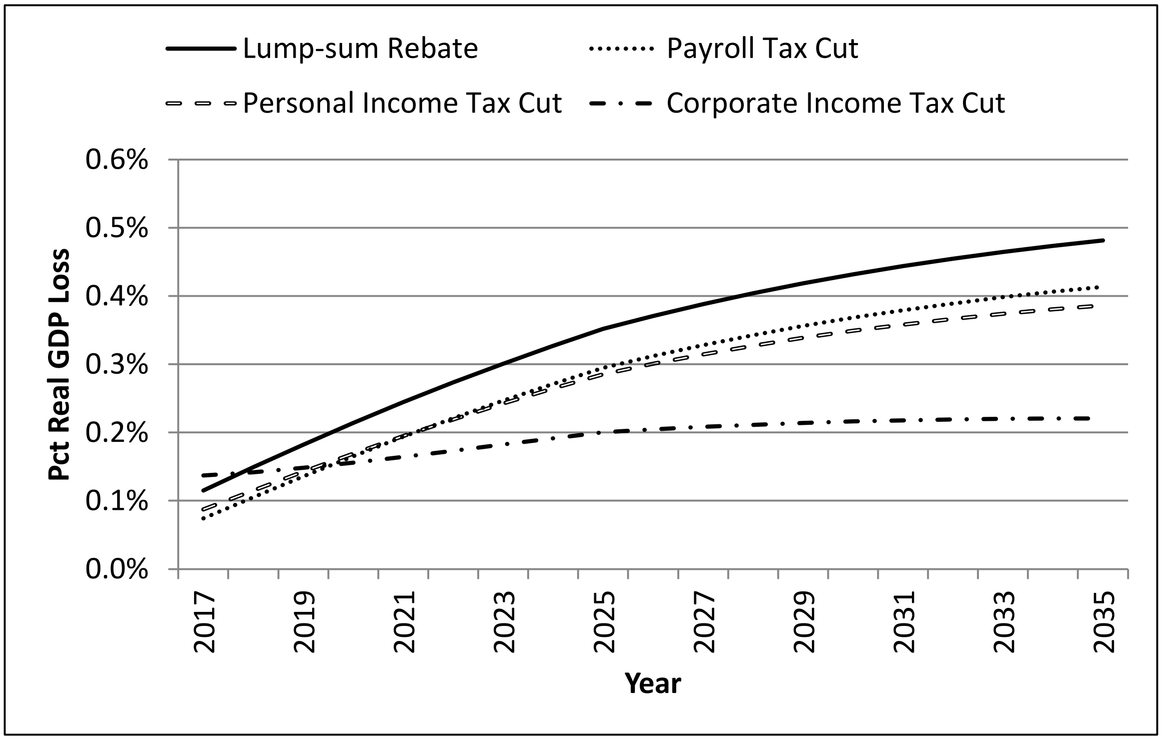

Table 3 displays two alternative cost measures for the four recycling options and the three growth rate options. The first measure calculates the present value of GDP losses over the interval 2017–2025 (as a percentage of the present value of reference case GDP). Over this time period, corporate income tax cuts are the least costly, and again lump-sum rebates remain the most costly form of recycling. GDP is a common, though imprecise, measure of economic well-being.[9] For this reason, we also report the impacts on the welfare (equivalent variation) of the representative household in the E3 model, the most complete measure of the policy's impact on household well-being over the entire length of the policy (we assume the tax is permanent). The welfare cost per ton reduced of the lump-sum rebate policies are between $34.26 and $34.35 per ton, below the expected damages from emissions as measured by the social cost of carbon of $45 per ton. Payroll tax cuts, individual income tax cuts, and corporate income tax cuts reduce the welfare costs by approximately 19, 31, and 75 percent, respectively. In all cases, the growth rate over the time period 2017–2025 has minimal impacts on the welfare costs of the policy, reflecting the nearly identical impacts of each policy after 2025.

**Table 3. Economic Costs by Growth Rate and Revenue-Recycling Method**

| | GDP loss, present value 2017–2025, relative to BAU | | | Welfare cost (-EV) per ton reduced (policy lifetime) | | |
|---|---|---|---|---|---|---|
| | Gr 0% | Gr 3% | Gr 6% | Gr 0% | Gr 3% | Gr 6% |
| Lump-sum rebate | 0.26% | 0.24% | 0.22% | $34.16 | $34.24 | $34.35 |
| Payroll tax cut | 0.21% | 0.19% | 0.17% | $27.51 | $27.67 | $27.85 |
| Personal income tax cut | 0.21% | 0.19% | 0.17% | $23.65 | $23.85 | $24.07 |
| Corporate income tax cut | 0.19% | 0.17% | 0.15% | $8.61 | $8.99 | $9.38 |

### *4.3. Delaying Policy*

So far, we have assumed that the carbon tax is introduced and implemented in 2017. Given the state of politics in the United States, it is unlikely that a carbon tax will become law in 2017, but lawmakers would still have time to introduce a policy before 2025 to meet the targets. How would delaying the policy impact the price path necessary to meet the 28 percent target,

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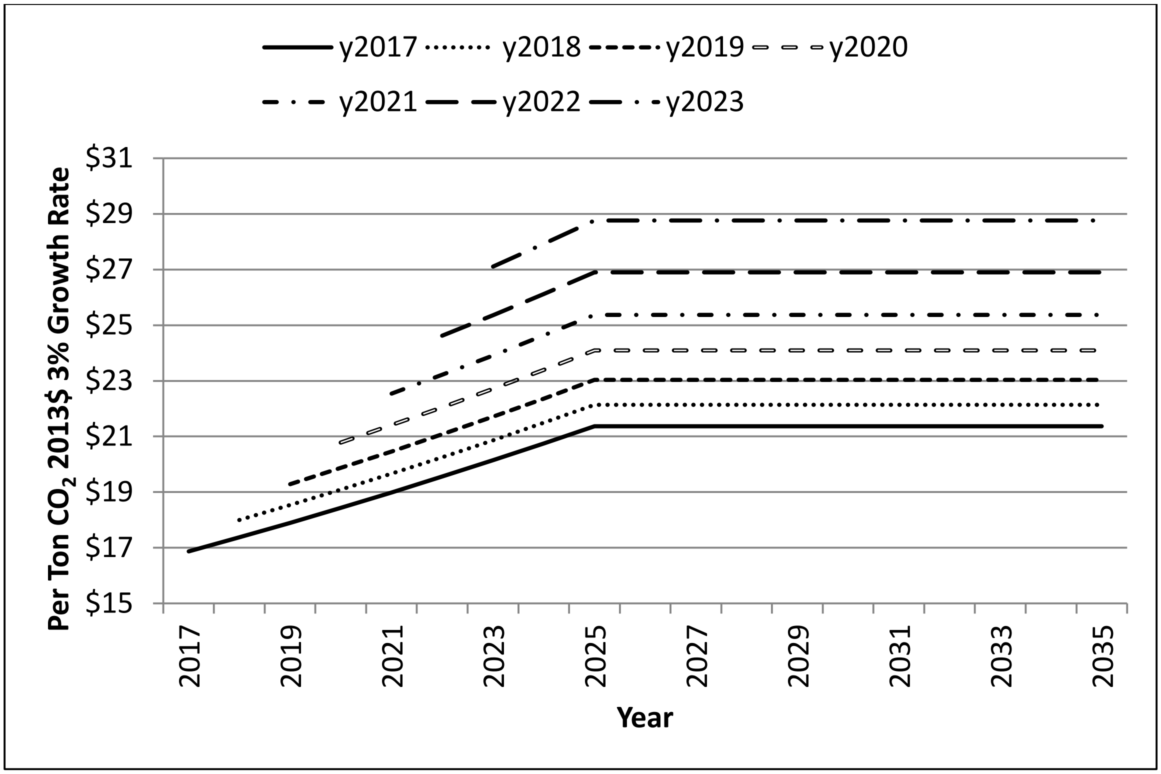
[9] GDP fails to measure the value of both leisure and non-market time. Meals purchased at restaurants are included in GDP but meals cooked at home are not included (aside from the value of ingredients purchased from the market). Most studies find that a carbon tax would induce workers to work slightly less, resulting in more leisure. The GDP measure ignores this value of leisure and therefore GDP would overestimate the cost of the policy.

and how would the costs change? Figure 6 displays carbon tax price paths with a 3 percent growth rate for policies starting between 2017 and 2023.

**Figure 6. 2025 Carbon Tax Paths, 2017–2035, Lump-Sum Rebates, by Implementation Year, 3% Growth Rate**



With each year of delay, both the initial price and the price in 2025 that meet the 28 percent target are increasing, making it more costly to meet the international commitment.[10] Each year of delay adds between 4 and 5 percent to the overall lifetime cost of lump-sum rebate policies. Table 4 displays the welfare costs per ton by year of implementation and growth rate. In addition to making it more costly to meet the 2025 target, each year of delay also reduces the total level of energy-related $CO_2$ emissions over the time interval. In fact, waiting until 2023 leads to approximately 5 billion additional energy-related $CO_2$ emissions between 2017 and 2025 than if the policy were immediately in 2017. Again, this demonstrates the dichotomy between benchmark year (i.e., 2025) targets and cumulative emissions reductions. Benchmark year targets can be achieved in many different ways that have vastly different levels of cumulative emissions reductions in the years prior to the benchmark year.

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[10] We assume that the policies implemented after 2017 are unanticipated. To the extent that delayed policies are anticipated, the costs would be lower.

**Table 4. Prices, Cumulative Emissions Reductions (mmt Energy-Related $CO_2$), and Welfare Cost, Lump-Sum Rebates, by Implementation Year and Growth Rate**

| | Initial carbon price in year y (2013$/ton) | | | Cumulative emissions reduction 2017–2025 (mmt) | | | Welfare cost (-EV) per ton reduced (policy lifetime) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gr 0% | Gr 3% | Gr 6% | Gr 0% | Gr 3% | Gr 6% | Gr 0% | Gr 3% | Gr 6% |
| y2017 | $21.22 | $16.87 | $13.50 | 8,173 | 7,610 | 7,111 | $34.16 | $34.24 | $34.35 |
| y2018 | $22.02 | $18.00 | $14.79 | 7,312 | 6,860 | 6,457 | $35.40 | $35.45 | $35.54 |
| y2019 | $22.96 | $19.29 | $16.29 | 6,451 | 6,100 | 5,783 | $36.75 | $36.79 | $36.84 |
| y2020 | $24.05 | $20.78 | $18.04 | 5,586 | 5,325 | 5,087 | $38.24 | $38.26 | $38.30 |
| y2021 | $25.35 | $22.54 | $20.11 | 4,715 | 4,533 | 4,365 | $39.91 | $39.91 | $39.93 |
| y2022 | $26.90 | $24.62 | $22.59 | 3,832 | 3,717 | 3,610 | $41.78 | $41.77 | $41.78 |
| y2023 | $28.76 | $27.11 | $25.59 | 2,930 | 2,869 | 2,812 | $43.91 | $43.90 | $43.89 |

## 5. Alternative Policy Design and Sensitivity Analysis

In this section, we test the robustness of our results to changes in key parameters of the E3 model and examine how assumptions about non-$CO_2$ greenhouse gas emissions affect the carbon price path we found in the previous section.

To test whether our results rely on key parameter assumptions, we consider the cost of meeting the 28 percent target when we vary these key parameters. The elasticity of demand for generation in our model determines how flexible the power sector is in providing electricity from different types of generators.[11] Our central case parameter value is 3, a value chosen to generate power sector outcomes similar to those from the highly disaggregated Haiku power sector model from Resources for the Future. A higher (lower) elasticity makes it easier (harder) for the utility to substitute across generator types. As a result, both the price path and the economic costs are lower (higher) when the generator elasticity is increased (decreased). However, the price paths remain generally similar to the benchmark path found in the previous section.

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[11] The E3 model includes three types of generators: coal-fired, other fossil (primarily natural gas), and nonfossil. A retail transmission and distribution utility purchases the electricity and delivers it to households, industries, and the government.

## Table 5. Carbon Prices and Emissions Reductions by Growth Rate and Alternative Policy or Parameter Specifications

| | | Initial carbon price in 2017 (2013$/ton) | | | Cumulative emissions reduction 2017–2025 (mmt) | | |
|---|---|---|---|---|---|---|---|
| | | Gr 0% | Gr 3% | Gr 6% | Gr 0% | Gr 3% | Gr 6% |
| Base case: Economy-wide, lump-sum rebate | | $21.22 | $16.87 | $13.50 | 8,173 | 7,610 | 7,111 |
| Generator elasticity | 2 | $24.21 | $19.24 | $15.39 | 8,725 | 8,123 | 7,587 |
| | 4 | $19.26 | $15.32 | $12.26 | 7,747 | 7,214 | 6,744 |
| Elasticity of labor supply | 0.1 | $21.23 | $16.87 | $13.50 | 8,162 | 7,599 | 7,101 |
| | 0.5 | $21.22 | $16.87 | $13.50 | 8,183 | 7,619 | 7,120 |
| Adjustment cost | 2 | $17.03 | $13.60 | $10.93 | 7,760 | 7,259 | 6,814 |
| | 14 | $24.46 | $19.39 | $15.47 | 8,569 | 7,954 | 7,411 |
| New reference case: no additional regulations | | $37.68 | $29.90 | $23.89 | 11,925 | 11,166 | 10,486 |

## Table 6. Economic Costs by Growth Rate and Sensitivity Scenarios (Lump-Sum Rebates)

| | | GDP loss, present value 2017–2025, relative to BAU | | | Welfare cost (-EV) per ton reduced (policy lifetime) | | |
|---|---|---|---|---|---|---|---|
| | | Gr 0% | Gr 3% | Gr 6% | Gr 0% | Gr 3% | Gr 6% |
| Base case: economy-wide | | 0.26% | 0.24% | 0.22% | $34.16 | $34.24 | $34.35 |
| Generator elasticity | 2 | 0.29% | 0.27% | 0.25% | $38.94 | $39.03 | $39.15 |
| | 4 | 0.24% | 0.22% | 0.20% | $31.28 | $31.35 | $31.45 |
| Elasticity of labor supply | 0.1 | 0.21% | 0.19% | 0.18% | $26.83 | $26.89 | $26.97 |
| | 0.5 | 0.30% | 0.28% | 0.26% | $40.75 | $40.85 | $40.98 |
| Adjustment costs | 2 | 0.23% | 0.22% | 0.20% | $30.87 | $31.01 | $31.16 |
| | 14 | 0.27% | 0.24% | 0.22% | $36.84 | $36.88 | $36.96 |
| New reference case: no additional regulations | | 0.49% | 0.45% | 0.41% | $44.02 | $43.98 | $44.02 |

The elasticity of labor supply determines how much the household changes its labor supply in response to a change in the real wage. The E3 model uses a central value of 0.3 for the compensated elasticity of labor supply, a value within the range of estimates from the literature.[12] Higher (lower) values for the compensated elasticity of labor supply imply that the labor tax distortions are larger (smaller). As a result, higher (lower) labor supply elasticities generate

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[12] McClelland and Mok (2012) provide a general review of recent labor supply estimates.

larger (smaller) tax interaction effects, and the economic costs are larger (smaller). However, changing the elasticity of labor supply has almost zero impact on the price path required to achieve the 2025 target.

Adjustment costs are a key feature of the E3 model and will affect the pace of the response to the carbon tax. Older estimates (e.g., Summers 1981) implied high adjustment costs, while newer papers (e.g., Cooper and Haltiwanger 2006) argue for very small aggregate adjustment costs. Our central case value of 7 splits the difference between the older and newer estimates. Higher (lower) adjustment costs require higher (lower) prices to meet the 2025 target at a greater (lower) cost to the economy.

In all cases, changes to key parameters do not fundamentally alter our conclusions, with a constant tax of $19–$25 necessary to achieve the 2025 target. Given the uncertainty in the true values of these parameters, however, policymakers may want to consider implementing a tax at the higher end of the interval, as it is preferable to risk overperforming and reducing emissions more than the target than to risk underachieving and missing the target.

Finally, in our central case simulations, we assumed that non-$CO_2$ greenhouse gas emissions would decrease because of proposed regulations as predicted by the US Department of State. As a result, meeting the 28 percent greenhouse gas target required reductions in energy-related $CO_2$ emissions of only 25.8 percent. If, on the other hand, the proposed regulations on methane and HFCs were not implemented, and non-$CO_2$ greenhouse gas emissions evolved as under current law (see Table 1), the United States would require a 33.2 percent reduction in energy-related $CO_2$ emissions. Our final simulation finds the price paths required to meet the target if no additional regulations on non-$CO_2$ greenhouse gas emissions were implemented. In this case, we find that the price path must be much higher. A constant tax would have to be $37.68 without these additional regulations on non-$CO_2$ greenhouse gas emissions, and the welfare cost would increase over 28 percent relative to the benchmark with the additional regulations.

## 6. Conclusions

The United States has committed to reduce its greenhouse gases by 26–28% relative to 2005 by 2025 through the Paris Agreement. Under current law and proposed regulations, it is unlikely that the United States will reach this target. A substantial proportion of greenhouse gas emissions are in the form of carbon dioxide emissions from burning fossil fuels, and a revenue-neutral federal economy-wide carbon tax is a viable option for the United States to meet its international climate commitments. We show that a modest economy-wide carbon tax with lump-sum rebates can achieve the 2025 greenhouse gas target of 28 percent emissions reductions (relative to 2005) at a relatively low cost. A constant tax of $21.22 (in 2013$) beginning in 2017 can meet the 2025 target with a present value GDP loss of 0.26 percent (relative to no carbon tax) from 2017 to 2025, removing over 8 billion tons of carbon dioxide from the atmosphere over the same interval. The welfare cost of such a policy is $34 per ton reduced, well below the estimated global benefits of $45 per ton, the central estimate for social cost of carbon dioxide. The United States can still meet its 2025 targets if it delays implementing a carbon tax, but delaying results in higher carbon prices, higher costs, and less overall emissions reductions. For example, implementing a constant carbon tax in 2023 to meet the 2025 targets requires a price of $28.76 (in 2013$), increases the welfare cost per ton reduced by 29 percent relative to implementation in 2017, and removes less than 3 billion tons of $CO_2$ from 2017 to 2025.

Our results also demonstrate that the method of returning the revenues to the households does not significantly affect the price paths needed to meet the 2025 targets, but it does significantly impact the costs of the policy. Using the revenues to finance cuts in payroll taxes, personal income taxes, or corporate income taxes would reduce the welfare costs by about 19, 31, and 75 percent, respectively, relative to a lump-sum rebate (cap and dividend) policy. The method of revenue recycling will also impact the distribution of impacts across households (see, e.g., Williams et al. 2014), but that is beyond the scope of this paper.

The carbon taxes considered in this study were only designed to meet the 2025 target, with no consideration of impacts on emissions beyond 2025. Indeed, with constant prices after 2025, we find that emissions reductions (relative to 2005) do not increase significantly after 2025. If the United States as a country committed to further reductions in emissions after 2025 (and the United States has a long-standing goal, but not commitment, to reduce emissions in 2050 by 80 percent relative to 2005), then carbon taxes that continue to increase after 2025 would be required. Of course, the necessary price paths, and associated costs, would be dependent on the precise targets, as well as on future technology and economic activity.

Finally, our findings are sensitive to the paths of non-$CO_2$ greenhouse gases. If proposed regulations to reduce methane and HFC emissions are not implemented, much greater reductions in energy-related carbon dioxide are necessary to meet the 2025 target. The required carbon tax would be much higher, $37.68, and the overall welfare cost would increase about 30 percent relative to the cost with the proposed regulations. Given that the target for 2025 is for all greenhouse gases, reducing all types of emissions would be more efficient than just reducing energy-related carbon dioxide emissions.

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