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THE EFFECTS OF CARBON TAX POLICIES ON THE US ECONOMY AND THE WELFARE OF HOUSEHOLDS

AN INDEPENDENT REPORT PREPARED BY THE BAKER INSTITUTE FOR PUBLIC POLICY AT RICE UNIVERSITY FOR COLUMBIA SIPA CENTER ON GLOBAL ENERGY POLICY

BY JOHN W. DIAMOND AND GEORGE R. ZODROW

JULY 2018

EDITED BY NOAH KAUFMAN, COLUMBIA SIPA CENTER ON GLOBAL ENERGY POLICY

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EXECUTIVE SUMMARY

The potential for utilizing a federal carbon tax to address the risks of climate change has been discussed in U.S. policy debates on both sides of the aisle. Under a carbon tax, consumers and producers would account for the costs of climate change in their decision making. The policy would reduce greenhouse gas emissions without sacrificing the efficiency of private markets.

This paper, part of the Carbon Tax Research Initiative of Columbia University's SIPA Center on Global Energy Policy, comprises the second element of a two-part analysis of the effects of a federal carbon tax. It provides an up-to-date (inclusive of the Tax Cuts and Jobs Act of 2017) analysis of the short-run and long-run macroeconomic effects and intergenerational and intragenerational distributional effects of a federal carbon tax in the United States. The analysis simulates the effects of various carbon taxes using the Diamond-Zodrow (DZ) dynamic overlapping generations computable general equilibrium model under a variety of assumptions regarding tax rates and with three revenue-neutral uses for carbon tax revenue:

1. **Payroll Tax Reduction**: All the revenue from the carbon tax is used to reduce the employee portion of the payroll tax;

2. **Equal Per-Household Rebates**: All the revenue from the carbon tax is used to finance equal per-household rebates; and

3. **Debt Reduction**: All revenue from the carbon tax is used to reduce the national debt for a period of 10 years and then used to finance equal per-household rebates.

Results for a benchmark carbon tax that starts at $50/ton are summarized as follows:

- When revenues are used to reduce payroll taxes, the carbon tax initially has slightly negative effects on gross domestic product (GDP), but these effects rapidly turn positive and, in the long run, GDP increases by nearly 0.5 percent. Total investment, consumption, and labor supply increase in the long run as well. When revenues are used for debt reduction, long-run GDP and investment increase, while consumption and labor supply fall. In contrast, when revenues are used to provide equal rebates to all households, the carbon tax has more negative effects: both initially and in the long run, GDP decreases by about 0.4 percent, while consumption, labor supply, and the capital stock decline modestly as well.

- Across the income distribution, a carbon tax coupled with payroll tax reductions would initially have roughly proportional effects on all households with respect to their lifetime incomes—except for a relatively small burden on the lowest-income households and a relatively large burden on the highest-income households. In the long run, this carbon tax policy is regressive across much of the income distribution, but the largest proportional burden is borne by the highest earners. In contrast, when carbon tax revenues are used to finance per-household rebates or debt reduction followed by per-household rebates, carbon taxes are progressive, both initially and (even more so) in the long run. Under these policies, lower-income households gain because the carbon tax revenues (after a ten-year period of debt reduction in the latter case) are distributed equally on a per-household basis.

This paper follows a long literature assessing the economic impacts of carbon pricing and the potential for such policies to increase societal welfare, even before accounting for the benefits of emissions reductions (known as achieving a second or “double dividend,” in addition to the “first dividend” of an improvement in environmental quality). Our results suggest a double dividend is perhaps more achievable than previous studies have indicated, and we identify unique features and drawbacks of the DZ model that may be causing these differences. In particular, the finding that a carbon tax with debt reductions followed by rebates can increase GDP growth while disproportionately benefiting low income households is new to the literature.

INTRODUCTION

Recent tax policy debates in the United States have included discussions of implementing a carbon tax—that is, a tax on emissions of carbon dioxide or carbon dioxide equivalent greenhouse gas emissions. Carbon taxes did not play a role in the recent tax reform debate in the United States; they were not included in the recently enacted Tax Cuts and Jobs Act and seem unlikely to be considered seriously in the formulation of tax policy in the near future. Nevertheless, there is still considerable interest in carbon taxes in many quarters. Indeed, a group of influential policy makers that includes former treasury secretaries James Baker and George Shultz and Harvard economists Martin Feldstein and Greg Mankiw (Baker et al. 2017) has formulated a "conservative case" for a carbon tax and offered a proposal under which carbon tax revenues would be rebated on an equal per capita basis. Similarly, Brill (2017) includes a collection of articles that provides a "conservative dialogue" that examines pro-growth methods of implementing a carbon tax policy to replace current environmental regulations. In addition, some observers have argued that the need to finance the large deficits associated with the newly passed tax law—estimated to be on the order of $1.0–$1.5 trillion over the next 10 years (Joint Committee on Taxation 2017) and perhaps $2.0 trillion if individual and business tax provisions currently scheduled to expire are extended—may strengthen the case for eventual future enactment of a carbon tax (Gleckman 2017; Mathur and Morris 2017b).

In the academic literature, a carbon tax is viewed as an example of a Pigouvian tax—a tax designed to offset the negative externalities of carbon dioxide emissions associated with climate change. The primary advantage of the Pigouvian approach is that it results in consumer prices that reflect the social costs of production, including external costs, so that consumers and producers take such costs into account in their private decision making. As a result, assuming that the carbon tax is set accurately to reflect the true marginal social cost of carbon, the market equilibrium with carbon taxes retains the efficiency properties associated with private markets, assuming that the other conditions for the efficiency of private markets are satisfied. Additional "command and control" regulations on carbon emissions, such as limits on individual emission sources or mandated emission-reducing technologies, which are often administratively cumbersome, distortionary, and unnecessarily costly, are not required.[1] Moreover, firms face the correct price incentives to find new and innovative ways to reduce the carbon intensity of their production processes.

In theory, the tax rate under a carbon tax should equal the social cost of carbon (SCC) emissions, the best estimate of the marginal social damages that result from greenhouse gas emissions along an "optimal" global emissions path. The calculation of this SCC is both difficult and controversial—including the contentious issue of whether the measure of costs should include worldwide costs or simply domestic costs—and estimates vary widely. For example, Marron, Toder, and Austin (2015) report that in one set of estimates, the SCC, measured in dollars per metric ton of CO_2 equivalents, ranges from slightly below zero[2] to more than $100, with a central tendency of roughly $42 per metric ton.[3] This uncertainty naturally complicates the setting of the level of a carbon tax. Nevertheless, it is not a compelling argument against the use of such a tax. Indeed, Baker et al. (2017) argue that, "Mounting evidence of climate change is growing too strong to ignore," so such a plan is desirable because "the risks associated with future warming are too big and should be hedged. At least we need an insurance policy." We do not attempt to estimate the SCC in this paper or address any of the issues that make such estimates controversial; instead, we analyze the macroeconomic and distributional effects of a federal carbon tax under a variety of assumptions regarding the tax rates and uses of tax revenues (often referred to as "revenue recycling" options).

Our paper, part of the Carbon Tax Research Initiative of Columbia University's SIPA Center on Global Energy Policy, comprises the second element of a two-part analysis of the effects of a federal carbon tax. In the first part, Larsen, Moran, Herndon and Marsters (2018) of the Rhodium Group (RHG) analyzes the price effects of various potential carbon taxes within the context of a highly disaggregated model of the US economy that includes considerable detail on energy production and usage. In particular, RHG uses the National Energy Modeling System (NEMS), developed by the US Energy Information Administration, which provides a detailed representation of the energy and carbon intensity of production in the United States across a wide variety of business sectors. RHG version of this model, RHG-NEMS, is utilized to estimate (among many other outputs) the effects of the carbon tax on the prices of a group of 15 major consumer goods.[4] The RHG-NEMS also estimates carbon tax revenues under the various reform options.

These price and revenue effects are key inputs into our analysis, which simulates the macroeconomic and distributional effects of carbon taxes using the Diamond-Zodrow (DZ) dynamic overlapping generations computable general equilibrium (CGE) model, which is designed to estimate the short- and long-run macroeconomic and the intergenerational and intragenerational distributional effects of tax reforms in the United States (Zodrow and Diamond 2013). Our model is much more highly aggregated than RHG's model, as it has only four consumer goods with four corresponding production sectors; in addition, our model does not include energy inputs in the four production sectors or an explicit energy-production sector. Accordingly, we use the carbon-tax-induced consumer price effects calculated by RHG and convert them into the analogous price increases for the four consumer/producer goods in our model. Given the degree of aggregation in our model, we cannot adequately capture the distributional effects of these price increases. However, we discuss several other studies that have examined the distributional effects of carbon taxes in models characterized by commodity bundles that vary with income levels, and the implications of these studies for our analysis.

In our benchmark case, we assume that a carbon tax of roughly $50 (in 2016 dollars) per metric ton of CO_2 equivalent is introduced in 2020, increases for 30 years at the path specified by Rhodium Group (RHG) (2018),[5] and is then held constant in real terms beginning in 2050, with the revenues used to finance payroll tax reductions. We also examine the sensitivity of the results to assumptions of a higher initial tax rate (roughly $73 per ton), hereafter referred to as the high carbon tax case, and a lower initial tax rate (roughly $14 per ton), hereafter referred to as the low carbon tax case. In addition, using the benchmark tax rates, we simulate the effects of the carbon tax using revenues for equal per-household rebates, and for reductions in the national debt for a period of 10 years followed by equal per-household rebates.

For each potential carbon tax policy, we simulate its short-run and long-run macroeconomic effects and its distributional effects, both across all living and future generations and across various income groups within each generation. We follow most of the literature in this area by ignoring the benefits associated with reductions in carbon emissions, including improved environmental quality as well as related benefits such as reduced medical expenditures, reduced time lost from work, and the like; that is, the analysis estimates the macroeconomic and distributional effects of only the price changes attributable to the carbon tax and the associated revenue recycling.

Our paper is organized as follows. The following section describes the dynamic overlapping generations CGE model we use to simulate the various carbon tax policies outlined above. Sections III and IV describe the previous literature on the distributional and macroeconomic effects of federal carbon taxes. Section V provides our simulation results for each of the carbon tax policy proposals analyzed, while Section VI summarizes our report. Several appendices provide additional information related to our analysis.

THE DIAMOND-ZODROW MODEL

This section provides a brief description of the model used in this analysis; for more details, see appendix A or consult Zodrow and Diamond (2013). The Diamond-Zodrow (DZ) model is a dynamic, overlapping generations, computable general equilibrium (CGE) model of the US economy that focuses on the macroeconomic, distributional, and transitional effects of tax reforms; to simplify the analysis, we use the closed-economy version of our model.

Using the carbon tax-induced price increases from the RHG-NEMS model as a key input, our model is well suited to simulating in considerable detail the dynamic short-run and long-run macroeconomic effects and intergenerational and intragenerational distributional effects of the implementation of a carbon tax.[6] The DZ model is a micro-based general equilibrium model in which households act to maximize lifetime utility and firms act to maximize profits or firm value, with behavioral responses dictated by parameter values taken from the literature; these responses include changes in consumption, labor supply, and bequest behavior by households and changes in the time path of investment by firms that take into account the costs of adjusting their capital stocks. Households and firms are characterized by perfect foresight and thus do not overreact to the short-run price effects of policy changes as they typically do in models with myopic agents. By construction, the model tracks the responses to a tax policy change every year after its enactment and always converges to a steady-state long-run equilibrium; as a result, we can track both the short-run and long-run responses to a tax policy change.[7] (By comparison, standard macroeconomic models are often dynamically unstable in the medium and long runs.)

The overlapping generations structure of the DZ model enables us to track the effects of policy reforms across generations and across income groups within each generation, rather than simply tracking the effects of reforms in terms of broad aggregate variables. Specifically, each generation includes 12 income groups, which reflect lifetime income deciles in each generation, with the first decile (the lowest lifetime income decile) split into the bottom 2 percent and the remaining 8 percent and the tenth decile split into the top 2 percent and the remaining 8 percent.

The model includes considerable detail on business taxation, including separate tax treatment of corporate and pass-through entities, separate tax treatment of owner-occupied and rental housing, and separate tax treatment of new and old capital (including explicit calculations of asset values). We also model in considerable detail the progressive taxation of labor income for households at different income levels, capture differential taxation of different types of capital income (although we do not model differential capital income taxes across income groups), and model government expenditures, including transfers and the Social Security system.

The model includes four consumer/producer sectors, characterized by profit-maximizing firms and competitive markets. The goods produced by these four sectors are: (1) a composite good C produced by the "corporate" sector, which includes all businesses subject to the corporate income tax; (2) a second composite good N produced by the "noncorporate" sector that encompasses all pass-through entities including S corporations, partnerships, LLCs, LLPs, and sole proprietorships; (3) an owner-occupied housing good H; and (4) a rental housing good R.

On the consumption side, each household has an "economic life" of 55 years, with 45 working years and a fixed 10-year retirement,[8] and makes its consumption and labor supply choices to maximize lifetime welfare subject to a lifetime budget constraint that includes personal income and other taxes and a fixed "target" bequest.

The government purchases fixed amounts of the composite goods at market prices including the carbon tax, makes transfer payments, and pays interest on the national debt; it finances these expenditures with revenues from the corporate income tax, a progressive labor income tax, and flat-rate taxes on capital income. All markets are assumed to be in equilibrium in all periods, and the economy must begin and end in a steady-state equilibrium, with all of the key macroeconomic variables growing at the exogenous growth rate, which equals the sum of the exogenous population and productivity growth rates.

PREVIOUS STUDIES OF THE DISTRIBUTIONAL EFFECTS OF CARBON TAXES

As noted above, the DZ model is characterized by just four consumer/producer sectors, which implies our analysis of the distributional implications of carbon-tax-induced changes in consumer prices is limited to modeling the effects of price changes in those four sectors. As a result, we are unable to adequately examine, for example, whether and the extent to which the burden of carbon taxes is borne disproportionately by lower-income households because their consumption is relatively energy intensive (although we capture this to some extent since consumption of utilities is included in our two housing sectors). This is not as problematic as one might suspect, as several recent studies (discussed in detail in appendix C) suggest that the focus of this study—the use of the revenues from a carbon tax is the key driver in determining the distributional effects of any carbon tax policy; this is especially the case for the studies that are most relevant to our analysis, which are those in which incidence is calculated on a lifetime income basis and transfers are indexed for inflation. Nevertheless, these disaggregated price effects are also important in understanding the distributional effects of carbon tax policies. Accordingly, in this section, we summarize the main results of six recent studies that are representative of a large literature[9] in which researchers capture these price effects by analyzing carbon tax policies using highly disaggregated models with considerable detail on both the carbon intensity of different goods and services, and differences in consumption patterns across income groups. Additional details on these six analyses are provided in appendix C.

Before turning to these studies, however, it is important to note that the incidence or distributional impact of a carbon tax—most commonly described as whether the tax is progressive or regressive[10]—will depend on the measure of taxpaying capacity used in the analysis. The most often used concept is some measure of annual income. However, numerous studies, including Fullerton and Rogers (1993) and Bull, Hassett, and Metcalf (1994), have stressed that annual income tends to overstate the regressivity of consumption-based taxes, such as the carbon tax analyzed in this report, for two reasons—both of which are related to the fact that household consumption is more stable over time than household income. First, household income often fluctuates considerably from year to year. Because households tend to smooth consumption (and thus consumption tax payments) over time by drawing down savings to maintain consumption in low-income years and replenishing savings in high-income years, measuring a consumption tax burden with respect to annual income will systematically overstate the regressivity of the tax. Second, household income fluctuates systematically over the life cycle, with annual income relative to consumption low for the young and the elderly and high for those in their prime earning years—which again implies that with consumption smoothing, measuring the burden of a consumption tax with respect to annual income will overstate the regressivity of the tax. For these reasons, the distributional effects of consumption taxes are sometimes measured with respect to income over a longer time period than a single year, such as a measure of lifetime income—a natural way to measure incidence in our model, given its overlapping generations structure in which households maximize lifetime utility over their life cycles subject to a lifetime income constraint. The differences between studies that measure incidence with respect to annual and lifetime income, as well as alternative methods for approximating lifetime income, will be highlighted in the discussion below.

In addition, it is important to note that all of the studies considered, like most of the studies in this literature, focus solely on the costs of the imposition of a carbon tax (or the costs incurred by businesses under a cap-and-trade system) and explicitly ignore the environmental benefits of a reduction in carbon emissions in calculating both the macroeconomic and the distributional effects of a carbon tax reform. The policies thus will result in aggregate welfare losses, unless the policy generates what is known in the literature as a “double dividend,” a second welfare gain due to the substitution of the carbon tax for some other existing distortionary tax in addition to the first welfare gain due to improved environmental quality—an outcome that is by no means guaranteed.[11] Note, however, that because the reduction in emissions for a particular pattern of carbon taxes is typically similar across all of the policy simulations in any given study, accounting for such benefits would not significantly change the ranking of the various policies examined.

Turning next to the six studies reviewed in detail in appendix C, their main results can be summarized as follows. First, before accounting for the revenue uses and assuming full forward shifting of carbon taxes into consumer prices, carbon taxes are regressive with respect to annual income; in particular, Rosenberg, Toder, and Lu (2018) obtain this result for each of the three carbon tax trajectories analyzed in this report. This regressivity is due primarily to the fact that lower-income households tend to spend a disproportionate share of their income on carbon-intensive products, especially gasoline, electricity, natural gas, and fuel oil. The regressivity of carbon taxes is exacerbated if tax burdens are adjusted for family size using equivalence scales. By comparison, the regressivity of carbon taxes is reduced or eliminated if general equilibrium effects result in reductions in the rate of return to capital that is held primarily by high-income households; indeed, Rausch, Metcalf, and Reilly (2011) suggest that the carbon tax is roughly proportional with respect to annual income in this case.

Second, there are compelling reasons to measure the regressivity of a carbon tax with respect to lifetime rather than annual income, and a carbon tax is less regressive when annual consumption expenditures are used as a proxy for lifetime income (Hassett, Mathur, and Metcalf 2009; Grainger and Kolstad 2010; Cronin, Fullerton and Sexton 2017). On the other hand, Rausch, Metcalf, and Reilly (2011) find that using lifetime income does not reduce the regressivity of a carbon tax when two alternative proxies for lifetime income are used—restricting the sample to heads of households who are between the ages of 40 and 60 and using the educational level of the head of household.

Third, the regressivity of carbon taxes is further reduced under the highly plausible assumptions that government transfers and tax parameters such as income tax brackets are indexed for inflation. Indeed, the analysis of Cronin, Fullerton, and Sexton (2017) suggests that the combination of measuring incidence with respect to annual consumption expenditures as a proxy for lifetime income and taking into account the effects of inflation indexing convert the carbon tax into a moderately progressive tax.

Fourth, all of the studies suggest that the distributional effects of carbon tax policies are determined primarily by the approach used to distribute the revenues raised by the tax.

Carbon tax proposals that recycle revenues in the form of a constant per capita rebate are quite progressive but also relatively inefficient. (This policy is regressive, however, if the lump sum rebate is based on initial levels of capital income rather than distributed equally.) By comparison, policies that use carbon tax revenues to reduce highly distortionary taxes on capital income are relatively efficient but highly regressive, while policies that reduce labor income taxation fall in between these two options, as they are more efficient than the lump sum rebate approach due to their positive effects on labor supply, and they are less regressive than the reduction in capital income taxation since labor income is less concentrated among higher-income households.

Finally, carbon tax policies can be designed to achieve a wide variety of distributional objectives. For example, policies can be targeted to relieve the burden of the tax for the working poor by using the revenues to expand the Earned Income Tax Credit or to provide relief to a wide spectrum of households by reducing payroll taxes and increasing Social Security benefits; indeed, Cronin, Fullerton, and Sexton (2017) show that the latter policy can make the incidence of the carbon tax reform roughly proportional with respect to annual consumption while generating tax reductions for all but the richest consumption decile.[12]

PREVIOUS STUDIES OF THE MACROECONOMIC EFFECTS OF CARBON TAXES

Before proceeding to our simulation results, we briefly discuss the literature on the macroeconomic effects of carbon taxes and relate them to our results. These studies are part of the voluminous literature on the potential for obtaining a double dividend from environmental taxes. This literature investigates whether the use of carbon tax revenues to reduce existing distortionary taxes can generate a welfare improvement (the second dividend from the policy) in addition to the environmental benefits of the policy in the form of reduced emissions (its first dividend).

The literature suggests that when environmental benefits are ignored, environmental taxes may reduce welfare. The basic intuition underlying this result is that a tax on emissions such as a carbon tax effectively creates a system of differential commodity taxes that, neglecting environmental benefits, is likely to distort consumer choices and decrease economic efficiency. If the tax replaces a relatively efficient broad-based tax—such as a tax on all wage income—then the tax substitution is likely to reduce economic welfare. Moreover, an increase in an existing environmental tax on a polluting or so-called dirty good will result in a reduction in tax revenue as consumers substitute away from the taxed dirty good to the untaxed "clean" good (a uniform consumption tax on both goods would not have this effect). As a result, a higher tax on the dirty good is needed to maintain revenue neutrality, consumer prices increase more than after-tax wages fall due to the reduction in the wage tax, the real wage falls, and labor supply declines (assuming a positive labor supply elasticity), causing further inefficiencies. Moreover, the resulting efficiency costs are likely to be significant, as relatively large existing taxes on labor income imply that the labor supply decision is already highly distorted and efficiency costs increase disproportionately with the size of the effective tax rate.

Nevertheless, environmental taxes can be welfare enhancing, even ignoring their environmental benefits, under certain circumstances. Two related scenarios are especially prominent in the literature. First, revenue recycling in the form of reductions in taxes on capital income tends to be especially beneficial, as the resulting increases in investment, capital accumulation, labor productivity, and wages—relative to an initial equilibrium in which saving and investment are inefficiently low due to the distortions imposed by an income tax—may improve economic efficiency sufficiently to result in net gains. Second, economic efficiency may increase if the consumer price changes induced by the environmental tax offset distortions in the initial equilibrium attributable to the existing tax system.[13]

These points are illustrated by several recent CGE studies of the macroeconomic effects of carbon taxes. We focus on Jorgenson, Goettle, Ho, and Wilcoxen (JGHW) (2015), a study that is broadly similar to ours in terms of both general model structure and revenue recycling options considered.[14] JGHW use their Intertemporal General Equilibrium Model (IGEM)—a complex CGE model that has many production and consumption sectors and many representative households, each of which acts to maximize an infinite-horizon utility function—to analyze the macroeconomic effects of carbon taxes at various levels under several revenue recycling options. These options include (among others) reductions in capital income tax rates, reductions in labor income tax rates, lump sum redistributions to households, and reductions in the national debt.

JGHW stress that revenue recycling in the form of capital income tax rate reductions provides the largest economic benefits among the various revenue recycling options they consider, as the resulting reduction in the cost of capital—which is initially inefficiently high due to taxation under the existing income tax system—stimulates investment and gradually increases the capital stock, production, labor productivity, and wages. Indeed, in their simulations, a carbon tax with revenues used to reduce capital taxes is the only approach that results in a positive impact on the present value of future GDP. The other tax and debt reduction options, all of which result in reductions in the present value of future GDP, are ranked as follows: (1) combined labor and capital income tax reductions; (2) labor tax reductions; (3) debt reduction, and (4) lump sum rebates. These results indicate that (1) reducing capital income taxes is preferable on efficiency grounds to reducing labor income taxes, (2) reducing distortionary taxes is preferable to reducing debt, and (3) financing lump sum rebates, which have no benefit in terms of improving economic efficiency, is the least desirable policy in terms of stimulating economic growth.[15]

JGHW also analyze the effects of taxes on a broader measure of well-being that corresponds roughly to changes in aggregate welfare—changes in private consumption and in leisure (which is in the individual utility function but is ignored in GDP) plus changes in public consumption (which is typically held constant). These results are more favorable for the various carbon taxes, as all of the options result in an increase in the present value of this utility-related measure at low carbon tax rates, while reductions in labor income tax rates and, to a greater extent, lump sum rebates result in long-run declines in this measure at higher carbon tax rates. The ranking of revenue recycling options under this measure of well-being that aggregates changes in private plus public consumption plus leisure is: (1) reductions in capital income taxes; (2) reductions in the level of debt; (3) reductions in capital and income tax rates; (4) reductions in labor income tax rates, and (5) reductions in lump sum rebates. Debt reductions fare better with a broader measure of well-being because public consumption expenditures increase as interest payments on the debt are reduced.

By comparison, Tuladhar, Montgomery, and Kaufman (2015) find that neglecting environmental benefits, carbon taxes (imposed at rates of $15 and $25 per ton of CO_2 and increasing at a real rate of 4 percent per year) reduce the welfare of a representative consumer under all the scenarios they consider. Consistent with the results noted above, they find that revenue recycling in the form of reductions in corporate income tax rates results in smaller aggregate welfare losses than reductions in personal income tax rates. They also find that reducing the deficit is a relatively less efficient use of carbon tax revenues in their model, even after taking into account the benefits of the lower interest rates on government borrowing associated with a smaller government debt; note, however, that these results may be understated because they do not consider any benefits of lower interest rates for the private sector. Finally, Tuladhar, Montgomery, and Kaufman (2015) show that lump sum rebates are the least efficient revenue recycling option by a considerable margin.[16]

MACROECONOMIC AND DISTRIBUTIONAL EFFECTS OF OUR CARBON TAX SIMULATIONS

We simulate the macroeconomic and distributional effects of the enactment of a carbon tax under five different scenarios:

1. Payroll Tax Reduction and $50/ton Carbon Tax (denoted A1): All revenue from a carbon tax that starts at $50/ton (in 2016 dollars) in 2020 and increases at about 2 percent per year is used to reduce the employee portion of the payroll tax.

2. Payroll Tax Reduction and $73/ton Carbon Tax (denoted A2): All revenue from a carbon tax that starts at $73/ton (in 2016 dollars) in 2020 and increases at about 1.5 percent per year is used to reduce the employee portion of the payroll tax.

3. Payroll Tax Reduction and $14/ton Carbon Tax (denoted A3): All revenue from a carbon tax that starts at $14/ton (in 2016 dollars) in 2020 and increases at about 3 percent per year is used to reduce the employee portion of the payroll tax.

4. Equal Per-Household Rebate and $50/ton Carbon Tax (denoted B): All revenue from a carbon tax that starts at $50/ton (in 2016 dollars) in 2020 and increases at about 2 percent per year is used to finance equal per-household rebates.

5. Debt Reduction followed by Rebates and $50/ton Carbon Tax (denoted C): All revenue from a carbon tax that starts at $50/ton (in 2016 dollars) in 2020 and increases at about 2 percent per year is used for debt reduction for a period of 10 years and then used to finance equal per-household rebates.

In each case, we compare the macroeconomic and distributional effects of the policy change to the values that would have occurred in the absence of any changes—that is, under a current policy scenario, which includes the effects of the Tax Cuts and Jobs Act enacted in 2017.

Note that we do not consider any scenarios in which carbon tax revenues are used to provide reductions in the corporate income tax rate or investment incentives, as these seem unlikely in light of the recent enactment of the Tax Cuts and Jobs Act. That reform lowered the corporate tax rate to 21 percent and provided for immediate expensing of investment in equipment (temporarily, with a phaseout that begins in 2023 with full elimination by 2027—but with some likelihood of extension) while still allowing interest deductibility under many circumstances—a combination that implies negative marginal effective tax rates (i.e., subsidies) on such investment.[17]

Carbon Tax Revenues Finance a Payroll Tax Reduction

The macroeconomic results for the case in which carbon tax revenues are used to finance proportionate reductions in payroll taxes are shown in tables V.A1–A3. In the benchmark case, shown in Table V.A1, the carbon tax is imposed in 2020 at a rate of about $50 (in 2016 dollars) per metric ton of CO_2 equivalent, increases for 30 years at about 2 percent per year, and then is held constant in real terms beginning in 2050. The tax raises revenue equal to 1.23 percent of GDP in 2020 ($259 billion in 2016 dollars)[18] and 1.48 percent of GDP in the long run.[19] As shown in the table, this revenue enables a reduction in Social Security payroll tax rates of 2.34

percentage points in 2020 (from 15 percent to under 13 percent), 2.34 percentage points in 2029, 2.80 percentage points in 2039, and 3.09 percentage points in the long run.[20] These figures reflect indexing of Social Security benefits in the short run for the price increases associated with the carbon tax; this indexing is phased out over a 30-year period to reflect the fact that in the long run, Social Security benefits are indexed to wages rather than to consumer prices.

Table V.A1: Macroeconomic Effects of Benchmark Carbon Tax with Payroll Tax Reductions
(Percentage changes in variables, relative to steady state with no carbon tax)

Variable %Change in Year:	2020	2024	2029	2039	2069	LR
GDP	−0.12	0.12	0.18	0.26	0.42	0.45
Total Consumption	−0.30	−0.15	−0.08	0.00	0.13	0.16
Corporate Good	0.18	0.32	0.37	0.43	0.53	0.57
Noncorporate Good	−0.60	−0.39	−0.31	−0.09	0.12	0.16
Owner-Occupied Housing	−1.17	−1.03	−0.88	−0.96	−0.93	−0.93
Rental Housing	−1.41	−1.38	−1.22	−1.26	−1.16	−1.13
Total Investment	0.36	1.10	1.03	1.16	1.41	1.40
Total Capital Stock	0.00	0.22	0.42	0.66	1.12	1.22
Total Employment (hours worked)	0.11	0.12	0.12	0.15	0.18	0.18
Payroll Tax Rate (change in % points)	−2.34	−2.22	−2.34	−2.80	−3.07	−3.09

The simulation results indicate that the net effect on GDP of the carbon tax coupled with a payroll tax reduction is initially (in the year after enactment of the reform) slightly negative (−0.12 percent) but rapidly turns slightly positive and ultimately reflects a modest increase of 0.45 percent in the long run. This positive result is attributable to several differences between our model and that used by JGHW (although recall that the JGHW study shows positive effects on welfare for small carbon taxes coupled with reductions in labor income taxes).

First, note that carbon tax-induced price increases in the model are largest for the two housing sectors and smallest for the corporate sector, with an intermediate price increase for the noncorporate sector that is closer to the price increase for the corporate sector. This is broadly consistent with earlier studies (e.g., Grainger and Kolstad 2010 and Rausch, Metcalf, and Reilly 2011, discussed in appendix C) that found relatively large price increases for utilities, which are included in the housing sector in our model. This implies that the carbon tax-induced consumer price increases act to offset existing production distortions in the model, as the corporate sector is more heavily taxed than the noncorporate sector due to the existence of the corporate income tax, and the housing sector—at least the owner-occupied housing sector—is the least heavily taxed sector of all due to the various tax preferences for owner-occupied housing under the income tax, including the exemption of imputed rent, mortgage interest deductibility, and very low effective capital gains tax rates.

Second, the overlapping generations nature of our model implies that we identify gains and losses by generation rather than summing the discounted values of all of the future gains and losses caused by a carbon tax reform into a single aggregate measure of reform-induced welfare changes. In particular, the long run gains in GDP we report are not offset by short run losses (as they would be in a calculation of the present value of all future changes in GDP). Note also that the implementation of the carbon tax imposes windfall losses on the elderly at the time of enactment due to the reform-induced increases in consumer prices, which are only partially offset by the indexation of transfer payments (including Social Security benefits) and not at all offset by the reduction in payroll taxes, because these individuals are retired. Analogous but smaller losses are imposed on those who are near retirement at the time of enactment of the carbon tax. These losses cannot be shifted to future generations because our model assumes a fixed target bequest. As a result, these windfall losses give rise to a one-time revenue increase for the government, which implies somewhat larger future payroll tax reductions that stimulate additional labor supply and increases in production.[21] As discussed further below, these gains are unevenly distributed across income groups, since the higher-income groups are subject to the Social Security earnings cap and thus benefit less than proportionately (and not at the margin) from the reduction in payroll taxes, and finance virtually all of their consumption with funds that are not subject to indexing for carbon tax-induced price increases.

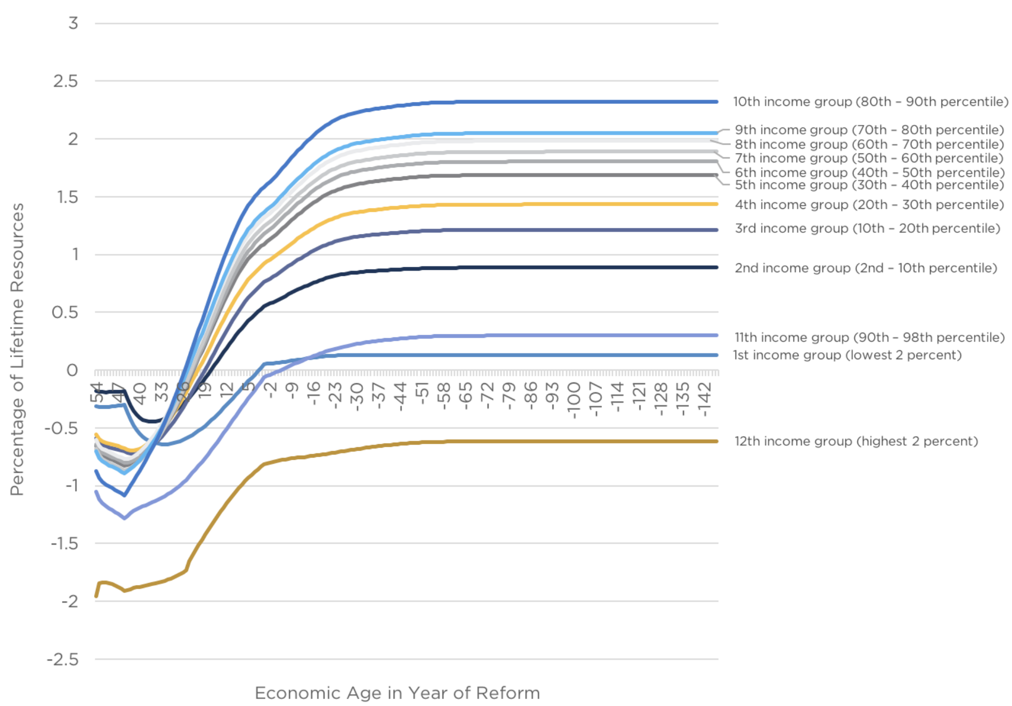
Finally, the high level of aggregation in our model (a total of four consumer/producer sectors and only two nonhousing sectors) implies that the distortionary effects on consumer choices of many of the price differentials attributable to the carbon tax tend to cancel each other out; the only tax differentials we capture are among the corporate and noncorporate sectors and the owner-occupied and rental housing sectors. For the same reason, the revenue costs of the resulting carbon tax-induced reallocations of consumer demand are muted because the tax differentials across the four sectors are smaller than the tax differentials that would arise in a more disaggregated model with numerous untaxed goods. This has the effect of muting the distortionary effects of the carbon tax on both consumption and on labor supply.

Returning to the results in Table V.A1, aggregate consumption in this simulation follows roughly the same pattern as GDP, falling initially (by 0.30 percent) but eventually increasing with a long-run gain of 0.16 percent. The pattern of changes in the components of consumption follows the pattern implied by the carbon tax-induced price changes described above. Specifically, the demands for owner-occupied and rental housing decline the most dramatically (by 1.17 and 1.41 percent initially and by 0.93 and 1.13 percent in the long run), the demand for the noncorporate good initially declines by 0.60 percent while increasing by 0.16 percent in the long run, and the demand for the corporate good increases (by 0.18 percent initially and by 0.57 percent in the long run).

Total investment (including depreciation) increases by 0.36 percent initially and by 1.40 percent in the long run, which reflects modest growth as well as the reallocation of production from housing, where the economic depreciation rate is very small, to the corporate and noncorporate sectors, where economic depreciation and thus replacement investment are larger. The capital stock increases gradually as a result, by 0.22 percent after five years and by 1.22 percent in the long run. Total employment increases by 0.11–0.18 percent (recall that our model assumes full employment so the increase in employment or hours worked reflects additional hours worked by a fixed number of employees rather than new jobs). This reflects the net effect of the changes in after-tax real wages due to the carbon tax, which vary considerably across income groups. Specifically, the after-tax real wage increases for the bottom nine income groups and decreases for the top three income groups.

The distributional effects of the carbon tax proposal across generations and across the 12 income groups are shown in Figure V.A1, which shows the welfare change for each representative household by economic age at the time of enactment and by lifetime income.[22] We utilize an equivalent variation measure, defined as the percentage change in remaining lifetime resources, including the value of leisure but excluding the value of the inheritance/bequest (which is simply transmitted across generations and grows at the exogenous growth rate) that is required in the initial equilibrium for a household to achieve the same level of lifetime utility as under the newly enacted carbon tax. As discussed above, our model does not adequately capture the effects of differences in the consumption of carbon-intensive goods across households of different income levels. However, the general message of the literature on the distributional effects of carbon taxes summarized above is that the way carbon tax revenues are recycled is the key driver of distributional outcomes.

Figure V.A1: Distributional Effects of Benchmark Carbon Tax with Payroll Tax Reductions
(Present value of all future equivalent variations, relative to present value of all remaining lifetime resources)



Source: Diamond-Zodrow model results
Note: Income group percentiles are with respect to a lifetime income distribution.

The results depicted in Figure V.A1 indicate that the carbon tax with revenue recycling in the form of payroll tax reductions (1) redistributes from the old to the young and future generations within each lifetime income group, (2) initially has roughly proportional impacts across the income distribution—except for a relatively low burden on households in the lowest lifetime income decile and a disproportionately large burden on households in the top lifetime income decile, and (3) in the long run is a moderately regressive policy across much of the income distribution, but the largest burden remains on the top lifetime income decile.

Initially, all elderly retired households lose from reform as they face higher carbon tax-induced prices for consumer goods (which are only partially offset by indexation of transfers, including Social Security benefits) but do not benefit from higher after-tax wages attributable to the reduction in payroll taxes. In addition, because interest rates decline slightly with the enactment of the carbon tax reform,[23] elderly households, especially relative wealthy households who have disproportionately large bequests, have to save more to finance their target bequests, which are fixed in nominal terms; they thus have less income to finance consumption during retirement. As a result, the highest three lifetime income groups (groups 10–12) experience the largest reductions in welfare among elderly households at the time of enactment. For example, the oldest retired households in the highest lifetime income group (the 12th group, or the top 2 percent of the lifetime income distribution) suffer a loss equal to nearly 2 percent of remaining lifetime resources, groups 10 and 11 suffer losses of roughly 1 percent of remaining lifetime resources, and the elderly households in the bottom and middle lifetime income groups lose roughly 0.2–0.7 percent of remaining lifetime resources.

These losses tend to diminish with reductions in age at the time of enactment for generations that are in the labor force (those with an economic age of 44 or less, or roughly 65–67 years old or younger) when the carbon tax is enacted. These declining losses reflect four factors. First, households that are not retired at the time of enactment have some time to benefit from the payroll tax reduction, and this effect increases as the age at the time of enactment declines. Second, younger households benefit most from the modest increase in economic growth, including increases in real wages,[24] associated with the reform, an effect that also increases with time and indeed continues, albeit at a modest rate, for roughly 100 years after the time of enactment. Third, as noted above, the reform causes interest rates to decline slightly, which implies that households alive at the time of enactment have to increase their savings to finance their target bequests that are fixed in nominal terms. Younger generations have more time to make this adjustment, so the negative impact on their welfare is smaller. Finally, the decline in interest rates implies that the return to existing assets declines, and the importance of this effect also decreases with declines in age at the time of enactment.

In the long run, this version of the carbon tax is moderately regressive except at the top of the income distribution. For example, the lowest lifetime income group experiences a gain of only 0.1 percent of lifetime resources. Welfare gains increase monotonically from 0.9 percent for the second lifetime income group[25] to 2.3 percent for the tenth lifetime income group. This regressivity reflects the fact that at the margin, the payroll tax reduction results in a disproportionately large increase in after-tax wages for higher-income groups relative to lower-income groups, because the reductions in the payroll tax are equal across the bottom 10 income groups, but marginal income tax rates increase with income. Thus, higher and lower-income groups suffer a proportional loss in income due to the carbon tax-induced price increases, but the higher-income groups have a larger increase in after-tax income due to the payroll tax reduction. Households in the top decile of the income distribution do not fare as well from the reform, as the gain for the 11th lifetime income group is only 0.3 percent of lifetime resources while the 12th lifetime income group experiences a loss equal 0.6 percent of lifetime resources. This occurs for two reasons. First, the top lifetime income group benefits less than proportionately from the reduction in the payroll tax because much of these households' earnings are above the Social Security earnings cap while all of their expenditures are subject to carbon tax-induced price increases. Second, because we assume that the target bequest is fixed in nominal terms, these households receive an inheritance that is smaller in real terms than it would be in the absence of the tax; this effect is disproportionately more important in the top income decile (lifetime income groups 11 and 12). The net result is that all households except the highest income group (the top 2 percent, which comprises lifetime income group 12) benefit from the reform, with the middle and upper income groups (through the ninth decile of the lifetime income distribution) benefiting the most.

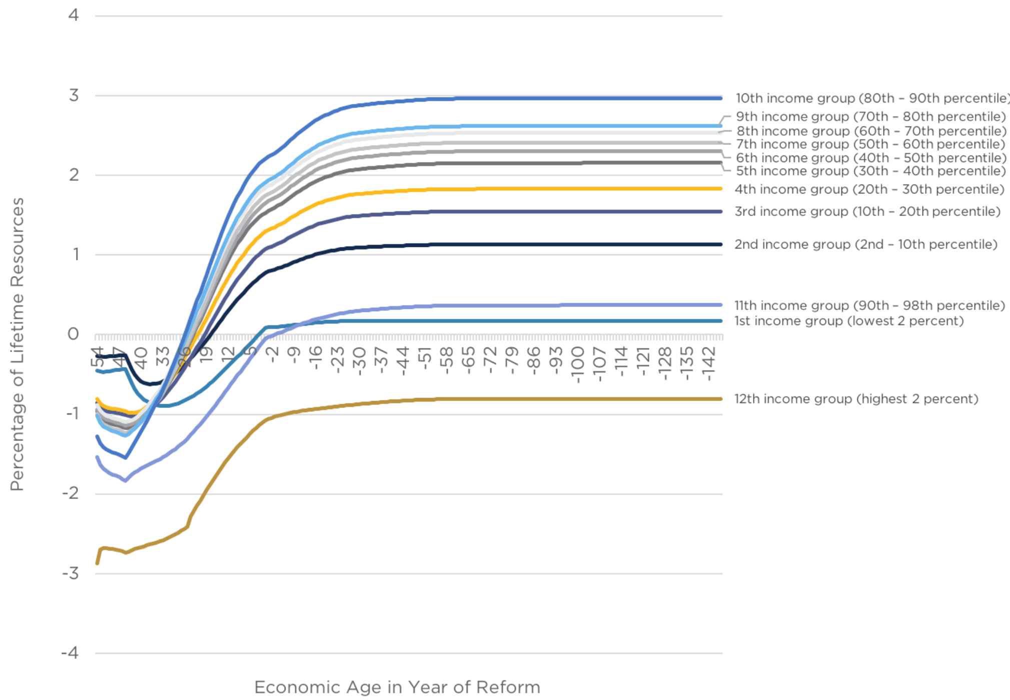
As discussed above, we consider three different carbon tax levels in our analysis. The simulation results for the high tax case are shown in Table V.A2. These results reflect a carbon tax of roughly $73 (in 2016 dollars) per metric ton of CO_2 equivalent that is introduced in 2020, increases for 30 years at about 1.5 percent per year, and then remains constant in real terms; this implies a carbon tax that is nearly 50 percent higher than in the benchmark tax case.

Table V.A2: Macroeconomic Effects of High Carbon Tax with Payroll Tax Reductions
(Percentage changes in variables, relative to steady state with no carbon tax)

Variable %Change in Year:	2020	2024	2029	2039	2069	LR
GDP	−0.17	0.19	0.28	0.40	0.56	0.59
Total Consumption	−0.46	−0.24	−0.09	0.02	0.18	0.22
Corporate Good	0.22	0.46	0.45	0.57	0.63	0.67
Noncorporate Good	−0.86	−0.66	−0.35	−0.14	0.18	0.22
Owner-Occupied Housing	−1.76	−1.43	−1.04	−1.14	−0.98	−0.98
Rental Housing	−2.10	−1.92	−1.51	−1.54	−1.27	−1.25
Total Investment	0.65	1.78	1.55	1.68	1.84	1.83
Total Capital Stock	0.00	0.37	0.69	1.03	1.52	1.62
Total Employment (hours worked)	0.17	0.18	0.16	0.20	0.23	0.23
Payroll Tax Rate (change in % points)	−3.43	−3.13	−3.26	−3.71	−3.97	−3.98

The macroeconomic results for the larger carbon tax are naturally larger than for the benchmark tax. For example, the initial changes in GDP, total consumption, total investment, and total employment are between 42 and 81 percent larger, and the long-run changes in these variables are between 28 and 38 percent larger than in the case of the benchmark carbon tax. Similarly, the associated changes in welfare by age and by income group, shown in Figure V.A2, are also larger for the high carbon tax case. The middle and upper lifetime income groups, other than those in the top income decile, again experience the largest gains. In the long run, the highest income group loses approximately 0.8 percent of remaining lifetime resources as compared to 0.6 percent in the benchmark case, and the other 11 income groups gain between 0.2 and 3.0 percent of remaining lifetime resources as compared to 0.1–2.3 percent in the benchmark case.

Figure V.A2: Distributional Effects of High Carbon Tax with Payroll Tax Reductions
(Present value of all future equivalent variations, relative to present value of all remaining lifetime resources)



Source: Diamond-Zodrow model results
Note: Income group percentiles are with respect to a lifetime income distribution.

The simulation results for the low carbon tax case are shown in Table V.A3. These results reflect a carbon tax of roughly $14 (in 2016 dollars) per metric ton of CO_2 equivalent that is introduced in 2020, increases for 30 years at about 3 percent per year, and then remains constant in real terms; this implies a carbon tax that is 72 percent lower than in the benchmark payroll tax case.

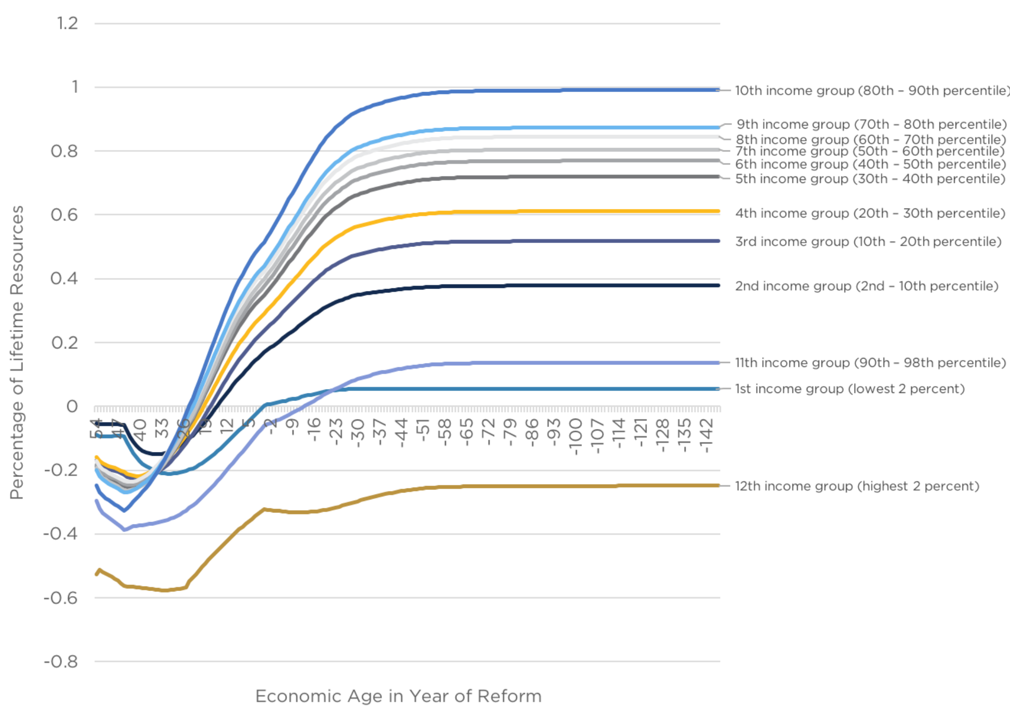
Table V.A3: Macroeconomic Effects of Low Carbon Tax with Payroll Tax Reductions
(Percentage changes in variables, relative to steady state with no carbon tax)

Variable %Change in Year:	2020	2024	2029	2039	2069	LR
GDP	−0.03	0.03	0.04	0.07	0.16	0.18
Total Consumption	−0.07	−0.04	−0.03	−0.01	0.04	0.07
Corporate Good	0.04	0.08	0.11	0.17	0.25	0.28
Noncorporate Good	−0.12	−0.07	−0.07	−0.06	0.01	0.03
Owner-Occupied Housing	−0.30	−0.30	−0.31	−0.44	−0.49	−0.48
Rental Housing	−0.37	−0.42	−0.43	−0.55	−0.59	−0.57
Total Investment	0.06	0.23	0.26	0.33	0.58	0.58
Total Capital Stock	0.00	0.04	0.08	0.14	0.42	0.49
Total Employment (hours worked)	0.02	0.03	0.04	0.06	0.08	0.08
Payroll Tax Rate (change in % points)	−0.67	−0.69	−0.77	−1.08	−1.28	−1.29

The macroeconomic results for the low carbon tax case are of course smaller than for the benchmark tax. For example, the initial changes in GDP, total consumption, total investment, and total employment are between 75 and 83 percent smaller, and the long-run changes in these variables are between 56 and 60 percent smaller than in the case of the benchmark carbon tax.

Similarly, the associated changes in welfare by age and by income group, shown in Figure V.A3, are smaller for the low carbon tax case. The middle and upper lifetime income groups, other than those in the top income decile, again experience the largest gains. Specifically, in the long run, the highest income group loses approximately 0.25 percent of remaining lifetime resources as compared to 0.6 percent in the benchmark case, and the other 11 income groups gain between 0.1 and 1.0 percent of remaining lifetime resources as compared to 0.1 to 2.3 percent in the benchmark case.

Figure V.A3: Distributional Effects of Low Carbon Tax with Payroll Tax Reductions
(Present value of all future equivalent variations, relative to present value of all remaining lifetime resources)



Source: Diamond-Zodrow model results
Note: Income group percentiles are with respect to a lifetime income distribution.

Carbon Tax Revenues Finance Uniform Per-Household Rebates

We next consider the macroeconomic results of the benchmark carbon tax with uniform per-household rebates. For the benchmark case, these rebates are initially $1,751 per household and increase to $2,091 per household by 2029, to $2,945 per household by 2039, and to $5,985 per household by 2069. In contrast to the case of revenue recycling in the form of payroll tax reductions, such lump sum rebates have no incentive effects on labor supply. This policy thus creates carbon tax-induced increases in consumer prices that lead to reductions in real wages that are not offset by the recycling of carbon tax revenues.

Table V.B: Macroeconomic Effects of Benchmark Carbon Tax with Uniform Per-Household Rebates
(Percentage changes in variables, relative to steady state with no carbon tax)

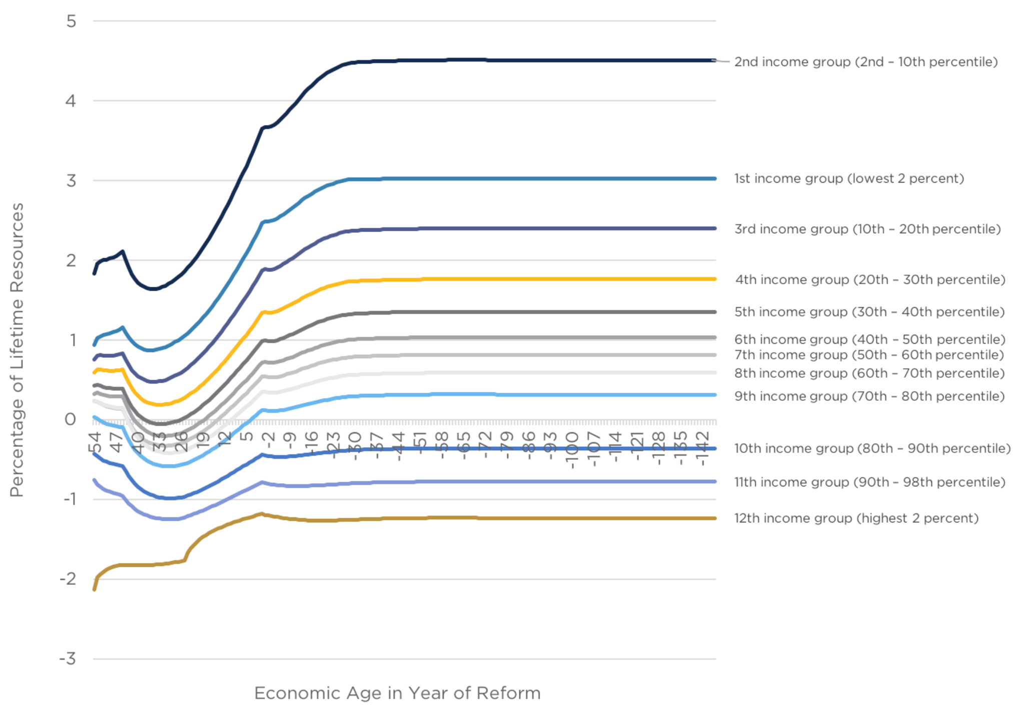
Variable %Change in Year:	2020	2024	2029	2039	2069	LR
GDP	−0.42	−0.31	−0.36	−0.40	−0.37	−0.37
Total Consumption	−0.37	−0.38	−0.45	−0.56	−0.57	−0.57
Corporate Good	0.11	0.09	−0.01	−0.14	−0.19	−0.18
Noncorporate Good	−0.67	−0.62	−0.69	−0.66	−0.59	−0.59
Owner-Occupied Housing	−0.68	−0.42	−0.30	−0.41	−0.11	0.00
Rental Housing	−1.60	−1.76	−1.71	−1.94	−2.04	−2.06
Total Investment	−1.01	−0.32	−0.28	−0.04	0.14	0.12
Total Capital Stock	0.00	−0.16	−0.26	−0.30	−0.07	−0.05
Total Employment (hours worked)	−0.37	−0.34	−0.36	−0.40	−0.46	−0.47

As a result, the macroeconomic effects of the policy are generally negative. In particular, declining real wages imply that aggregate labor supply declines by 0.37 percent initially and by 0.47 percent in the long run. Total investment decreases initially by 1.01 percent but increases slightly—by 0.12 percent—in the long run. This leads to a reduction in the total capital stock of 0.16 percent five years after enactment of the reform and 0.05 percent in the long run. GDP declines initially by 0.42 percent and by 0.37 percent in the long run. Similarly, aggregate consumption declines by 0.37 percent initially and by 0.57 percent in the long run.

The changes in the composition of consumption reflect the price increases in owner-occupied and rental housing relative to nonhousing goods and in the price of the noncorporate good relative to the corporate good. Upon enactment, the consumption of owner-occupied housing declines by 0.68 percent, the consumption of rental housing declines by 1.60 percent, and the consumption of the noncorporate good declines by 0.67 percent, while the consumption of the corporate good increases by 0.11 percent. In the long run, with total consumption declining by 0.57 percent, consumption of each of the individual goods declines or is unchanged.

The distributional effects of this reform are shown in Figure V.B. Uniform per-household rebates disproportionately benefit households with relatively low lifetime incomes, so this carbon tax plan is highly progressive. For example, the second-poorest lifetime income group at the time of enactment experiences a welfare gain of nearly 2 percent of remaining lifetime resources, while the richest lifetime income group experiences a loss slightly greater than 2 percent, with the magnitude of the gain declining uniformly for all households between these two lifetime income groups. In the long run, all lifetime income groups in the bottom eight deciles (groups 1–9) experience gains from reform while the households in the top two lifetime income deciles (groups 10–12) are net losers from reform. For example, in the long run, the second-poorest lifetime income group experiences a welfare gain of 4.5 percent of remaining lifetime resources, while the richest lifetime income group experiences a loss of roughly 1.2 percent. The differences between the various income groups (for all generations) also reflect differing costs of financing the fixed bequest in the presence of the lower interest rates, as described above.

Figure V.B: Distributional Effects of Benchmark Carbon Tax with Uniform Per-Household Rebates
(Present value of all future equivalent variations, relative to present value of all remaining lifetime resources)



Source: Diamond-Zodrow model results
Note: Income group percentiles are with respect to a lifetime income distribution.

The U-shaped patterns in Figure V.B during the transition period for generations that are not retired at the time of enactment reflect the effects of the decline in after-tax real wages. In addition, they reflect the effects of the target bequest and lower interest rates, which cause welfare to decline for those above the economic age of 25 at the time of enactment who have already received their inheritance and must augment it each year after reform in order to achieve their target bequest. This effect is diminished for those who are younger than 25 economic years, since the latter effect is not relevant until they receive their inheritance—they have more years to adjust to the need for reduced consumption to finance the target bequest in the presence of postenactment lower interest rates. Note that the bequest is far more important for the top lifetime income group (the top 2 percent) than for any other group, since these households account for 65 percent of all bequests. Thus, small changes in interest rates in the years after enactment of reform have a disproportionately large impact on the highest income group.

Carbon Tax Revenues Finance Reductions in Debt Followed by Per-Household Rebates

In this final simulation, we examine the effects of a carbon tax under which the revenues are used to reduce the domestically held portion of national debt[26] for a period of 10 years and then finance uniform per-household rebates. This reduces the domestic debt/GDP ratio from 44.5 percent to 31.2 percent and reduces interest rates by roughly 0.5 percentage points (50 basis points). The reduction in the level of debt and in interest payments on the debt frees up savings for investment, which results in gradual increases in the capital stock and labor productivity and creates upward pressure on wages.

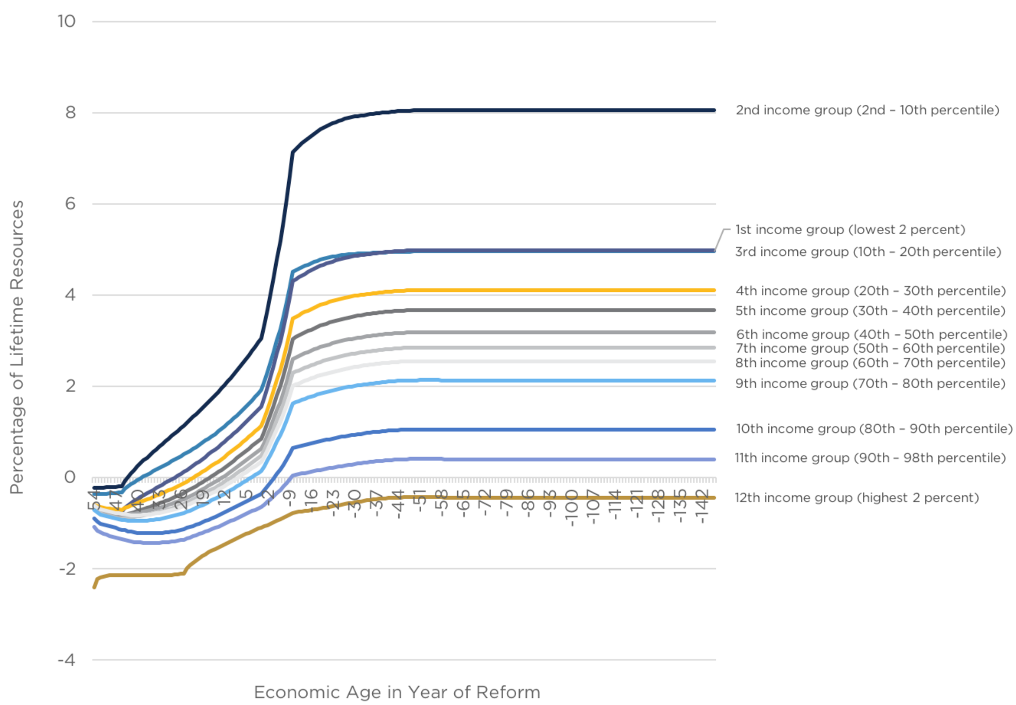
Table V.C: Macroeconomic Effects of Benchmark Carbon Tax with 10-Year Debt Reduction Followed by Uniform Per-Household Rebates (Percentage changes in variables, relative to steady state with no carbon tax)

Variable %Change in Year:	2020	2024	2029	2039	2069	LR
GDP	−0.43	−0.15	−0.04	0.07	0.29	0.30
Total Consumption	−0.72	−0.65	−0.61	−0.54	−0.49	−0.42
Corporate Good	−0.22	−0.16	−0.14	−0.07	−0.02	0.06
Noncorporate Good	−1.01	−0.87	−0.82	−0.59	−0.43	−0.35
Owner-Occupied Housing	−1.33	−1.06	−0.85	−0.70	−0.04	0.33
Rental Housing	−1.97	−2.04	−1.98	−2.15	−2.41	−2.40
Total Investment	0.40	1.72	2.08	2.33	3.13	2.91
Total Capital Stock	0.00	0.28	0.73	1.37	2.58	2.65
Total Employment (hours worked)	−0.30	−0.27	−0.30	−0.39	−0.56	−0.57

The macroeconomic effects of this reform are shown in Table V.C. Relative to the case in which all revenues are used to finance per-household rebates, this policy has more favorable effects on investment, which increases by 0.40 percent initially and by 2.91 percent in the long run, and on GDP, which initially falls by 0.43 percent but eventually increases by 0.30 percent. The capital stock increases by 0.28 percent five years after reform and by 2.65 percent in the long run. However, labor supply still declines, initially by 0.30 percent and by 0.57 percent in the long run, indicating that the negative effects of the carbon tax on the real wage (with revenues beyond the first 10 years of enactment used to finance uniform per-household rebates rather than payroll tax reductions) dominate the positive effects of greater capital accumulation and greater productivity. The net effect is that total consumption declines, initially by 0.72 percent and by 0.42 percent in the long run. The changes in the composition of consumption are similar to those in the previous simulations.[27]

The distributional effects of this policy are shown in Figure V.C. All retired lifetime income groups experience a loss due to the carbon tax-induced increase in consumer prices and the decline in interest rates coupled with a fixed nominal bequest; the latter effect is especially important in the year of enactment for the richest income group, which experiences a reduction in welfare equal to 2.4 percent of remaining lifetime resources, while all other groups suffer losses that range from 0.2–1.1 percent of remaining lifetime resources. These losses are gradually mitigated as the growth benefits of a smaller national debt (including more consumption of leisure) are realized. The policy is highly progressive in the long run, as all lifetime income groups but the wealthiest group benefit from the reform, with the gains declining uniformly beginning with the second lifetime income group. All households benefit from the capital accumulation due to the debt reduction, but the subsequent equal per-household rebates provide a disproportionately large benefit to lower-income groups while the relatively large decline in interest rates disproportionately hurts the wealthy. For example, in the long run, the highest income group suffers a loss of 0.4 percent of lifetime resources, while the second-lowest income group experiences a gain equal to 8.1 percent of remaining lifetime resources.

Figure V.C: Distributional Effects of Benchmark Carbon Tax with 10-Year Debt Reduction Followed by Uniform-Per-Household Rebates (Present value of all future equivalent variations, relative to present value of all remaining lifetime resources)



Source: Diamond-Zodrow model results
Note: Income group percentiles are with respect to a lifetime income distribution.

CONCLUSION

Although the recently enacted Tax Cuts and Jobs Act did not include any carbon tax provisions, numerous discussions of tax policy options in the United States have considered the possibility of implementing a carbon tax. In this analysis we examine the macroeconomic and distributional effects of the implementation of a carbon tax for several levels of the tax under a variety of assumptions regarding recycling of the resulting tax revenues. We simulate these effects using the Diamond-Zodrow (DZ) dynamic overlapping generations computable general equilibrium (CGE) model with 12 lifetime income groups, which is designed to estimate the short-run and long-run macroeconomic effects and the intergenerational and intragenerational distributional effects of tax reforms in the United States.

The results of our simulations can be summarized as follows. The macroeconomic effects of the benchmark carbon tax (which starts at $50/ton) with revenue recycling in the form of payroll tax reductions are generally moderately positive. GDP initially falls slightly but increases shortly after reform with a long-run increase of nearly 0.5 percent, accompanied by long-run increases in investment and in the capital stock of over 1 percent and increases in the labor supply of 0.18 percent. Aggregate consumption follows a similar pattern, with a long-run increase of 0.16 percent.

These results are somewhat more favorable than others found in the double dividend literature, which examines whether the substitution of carbon tax revenues for other distortionary taxes can increase welfare, ignoring the environmental benefits associated with the policy. Using the work of Jorgenson, Goettle, Ho, and Wilcoxen (2015) as representative of that literature, we identify several reasons for these differences, including the high level of aggregation in our model, a pattern of carbon tax-induced price increases that tends to offset existing production distortions, and the overlapping generations structure of our model, which implies that we identify gains and losses by generation rather than aggregating all of the gains and losses caused by a carbon tax reform into a single aggregate measure of reform-induced welfare changes.

In contrast, the macroeconomic effects of the implementation of the benchmark carbon tax rates with revenues used for uniform per-household rebates are generally negative. Under this policy, the carbon tax-induced increases in consumer prices that lead to reductions in real wages are not offset by the recycling of carbon tax revenues, as lump sum rebates have no incentive effects on labor supply. As a result, labor supply and the capital stock decrease, leading to declines in GDP and consumption of 0.4 and 0.6 percent in the long run.

Finally, the macroeconomic effects of the implementation of the benchmark carbon tax when the revenues are used to reduce the national debt for a period of 10 years and then finance uniform per-household rebates are more mixed. The reductions in the level of debt and interest payments on the debt free up savings for investment, which results in gradual increases in investment and in the capital stock, which increases by nearly 3 percent in the long run. However, labor supply declines by more than 0.5 percent in the long run, indicating that the negative effects of the carbon tax on the after-tax real wage (with revenues beyond the first 10 years of enactment used to finance uniform per-household rebates rather than payroll tax reductions) dominate the positive effects of greater capital accumulation and greater labor productivity. The net effect is that while GDP increases by 0.3 percent in the long run, aggregate consumption declines by 0.4 percent. Nevertheless, as discussed below, this policy leads to welfare gains for all lifetime income groups except the highest income group (which experiences a small loss in the long run), as the welfare benefits of increased leisure outweigh the costs of lower consumption.

Turning to distributional effects, we show that the carbon tax with payroll tax revenue recycling (1) redistributes from the old to the young and future generations within each lifetime income group, (2) initially has roughly proportional impacts across the income distribution—except for a relatively low burden on households in the lowest lifetime income decile and a disproportionately large burden on households in the top lifetime income decile, and (3) in the long run is a regressive policy, except at the top of the income distribution. All elderly retired households lose from this reform, as they face higher carbon tax-induced prices for consumer goods but do not benefit from higher after-tax wages attributable to the reduction in payroll taxes. This is especially the case for wealthy households, who, in addition, are disproportionately affected by the need to save more to finance a fixed nominal target bequest. These losses diminish with age for all generations that are in the labor force at the time of enactment of the carbon tax, primarily because such generations benefit from the payroll tax reduction and from the modest economic growth associated with the reform.

The carbon tax with revenue recycling in the form of uniform per-household rebates is quite progressive, as uniform rebates disproportionately benefit households with relatively low lifetime incomes. For example, the second-poorest lifetime income group (which has the largest welfare gains) initially experiences a welfare gain of nearly 2 percent of remaining lifetime resources, while the richest lifetime income group experiences a loss slightly greater than 2 percent. Similarly, in the long run, the second-poorest lifetime income group experiences a welfare gain of 4.5 percent of remaining lifetime resources, while the richest lifetime income group experiences a loss of roughly 1.2 percent.

Finally, the distributional effects of the implementation of the benchmark carbon tax when the revenues are used to reduce the national debt for a period of 10 years and then finance uniform per-household rebates is the most progressive of the three options. All retired lifetime income groups experience a loss due to the carbon tax-induced increase in consumer prices and the decline in interest rates coupled with a fixed nominal bequest, but the impacts are largest on the richest lifetime income group. In the long run, this policy is highly progressive because the equal per-household rebates provide a disproportionately large benefit to lower-income groups while the relatively large decline in interest rates disproportionately hurts the wealthy.

REFERENCES

Auerbach, Alan J., and Itai Grinberg (convening authors), and Thomas Barthold, Nicholas Bull, W. Gavin Elkins, Pamela Moomau, Rachel Moore, Benjamin Page, Brandon Pecoraro, and Kyle Pomerleau (discussing authors). 2017. "Macroeconomic Modeling of Tax Policy: A Comparison of Current Methodologies." *National Tax Journal* 70, no. 4: 819–836.

Auerbach, Alan J., and Laurence J. Kotlikoff. 1987. *Dynamic Fiscal Policy*. Cambridge: Harvard University Press.

Baker, James A. III, Martin Feldstein, Ted Halstead, N. Gregory Mankiw, Henry M. Paulson Jr., George P. Shultz, Thomas Stephenson, and Rob Walton. 2017. "The Conservative Case for Carbon Dividends." Climate Leadership Council. Washington, DC. https://www.clccouncil.org/media/TheConservativeCaseforCarbonDividends.

Ballard, Charles F. 2002. "International Aspects of Fundamental Tax Reform." In *United States Tax Reform in the 21st Century*, edited by George R. Zodrow and Peter Mieszkowski, 109–139. Cambridge, UK: Cambridge University Press.

Brill, Alex M. 2017. Carbon Tax Policies: *A Conservative Dialogue on Pro-Growth Opportunities*. Alliance for Market Solutions, Washington, DC.

Bull, Nicholas, Kevin A. Hassett, and Gilbert E. Metcalf. 1994. "Who Pays Broad-Based Energy Taxes? Computing Lifetime and Regional Incidence." *Energy Journal* 15, no. 3: 145–164.

Caron, Justin, Jefferson Cole, Richard Goettle, Chikara Onda, James McFarland, and Jared Woollacott. 2018. "Distributional Implications of a National CO_2 Tax in the U.S. Across Income Classes and Regions: A Multi-Model Overview." *Climate Change* 9, no. 1: 1840004-1-32.

Congressional Budget Office. 2011. "Trends in the Distribution of Household Income between 1979 and 2007." Washington, DC.

Cronin, Julie Anne, Don Fullerton, and Steven E. Sexton. 2017. "Vertical and Horizontal Redistributions from a Carbon Tax and Rebate." Working Paper 23250. Cambridge: National Bureau of Economic Research.

Cutler, David M., and Lawrence F. Katz. 1992. "Rising Inequality? Changes in the Distribution of Income and Consumption in the 1980s." *American Economic Review* 82, no. 2: 546–551.

Diamond, John W., and Alan D. Viard. 2008. "Welfare and Macroeconomic Effects of Deficit-Financed Tax Cuts: Lessons from CGE Models." *In Tax Policy Lessons from the 2000s*, edited by Alan D. Viard, 145–193. Washington, DC: The AEI Press.

Diamond, John W., and George R. Zodrow. 2007. "Economic Effects of a Personal Capital Income Tax Add-On to a Consumption Tax." *Finanzarchiv* 63, no. 3: 374–395.

———. 2008. "Consumption Tax Reform: Changes in Business Equity and Housing Prices." *In Fundamental Tax Reform: Issues, Choices and Implications*, edited by John W. Diamond and George R. Zodrow, 227–260. Cambridge: MIT Press.

———. 2013. "Promoting Growth, Maintaining Progressivity, and Dealing with the Fiscal Crisis: CGE Simulations of a Temporary VAT Used for Debt Reduction." *Public Finance Review* 41, no. 6: 852–884.

———. 2014. "Dynamic Macroeconomic Estimates of the Effects of Chairman Camp's 2014 Tax Reform Discussion Draft." Tax Policy Advisers LLC. Houston, TX.

———. 2015. "Modeling U.S. and Foreign Multinationals in a Dynamic OLG-CGE Model." Working paper. Rice University, Houston, TX.

Diamond, John W., George R. Zodrow, Thomas S. Neubig, and Robert J. Carroll. 2014. "The Dynamic Economic Effects of a US Corporate Income Tax Rate Reduction." *In Pathways to Fiscal Reform in the United States*, edited by John W. Diamond and George R. Zodrow, 343–386. Cambridge: MIT Press.

Energy Information Administration. 2009. *State Energy Data System*. Energy Information Administration, Washington, DC.

Fullerton, Don, and Diane L. Rogers. 1993. *Who Bears the Lifetime Tax Burden?* Washington, DC: Brookings Institution Press.

Gleckman, Howard. 2017. "Did the GOP Just Open the Door to a Carbon Tax in 2025?" Urban-Brookings Tax Policy Center, http://www.taxpolicycenter.org/taxvox/did-gop-just-open-door-carbon-tax-2025.

Goulder, Lawrence H. 1989. "Tax Policy, Housing Prices, and Housing Investment." *Regional Science and Urban Economics* 19, no. 2: 281–304.

Goulder, Lawrence H., and Lawrence H. Summers. 1989. "Tax Policy, Asset Prices, and Growth." *Journal of Public Economics* 38, no. 3: 265–296.

Grainger, Corbett A., and Charles D. Kolstad. 2010. "Who Pays a Price on Carbon?" *Environmental Resource Economics* 46: 359–376.

Gravelle, Jane G. 2002. "Behavioral Responses to a Consumption Tax." *In United States Tax Reform in the 21st Century*, edited by George R. Zodrow and Peter Mieszkowski, 25–54. Cambridge, UK: Cambridge University Press.

Gunning, Timothy G., John W. Diamond, and George R. Zodrow. 2008. "Selecting Parameter Values for General Equilibrium Model Simulations." *Proceedings of the One Hundredth Annual Conference on Taxation*, 43–49. National Tax Association, Washington, DC.

Hassett, Kevin A., Aparna Mathur, and Gilbert Metcalf. 2009. "The Incidence of a U.S. Carbon Tax: A Lifetime and Regional Analysis." *Energy Journal* 30, no. 2: 155–177.

Hendrickson, Chris T., Lester B. Lave, and H. Scott Matthews. 2006. Environmental Life Cycle Assessment of Goods and Services: *An Input-Output Approach*. Washington, DC: Resources for the Future Press.

Interagency Working Group on Social Cost of Greenhouse Gases. 2016. "Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866." US Government. https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

Joint Committee on Taxation. 2005. "Macroeconomic Analysis of Various Proposals to Provide $500 Billion in Tax Relief." JCX-4-15. Joint Committee on Taxation, Washington, DC.

———. 2017. "Macroeconomic Analysis of the 'Tax Cut and Jobs Act' as Ordered Reported by the Senate Committee on Finance on November 16, 2017." JCX-61-17. Joint Committee on Taxation, Washington, DC.

Jorgenson, Dale W., Richard J. Goettle, Mun S. Ho, and Peter J. Wilcoxen. 2013. *Double Dividend: Environmental Taxes and Fiscal Reform in the United States*. Cambridge: MIT Press.

———. 2015. "Carbon Taxes and Fiscal Reform in the United States." *National Tax Journal* 68, no. 1: 121–138.

———. 2018. "The Welfare Consequences of Taxing Carbon." *Climate Change* 9, no. 1: 1840013-1-39.

Keuschnigg, Christian. 1990. "Corporate Taxation and Growth, Dynamic General Equilibrium Simulation Study." In *Simulation Models in Tax and Transfer Policy*, edited by J. Brunner and H. Petersen, 245–277. Frankfurt: Campus Verlag.

Larsen, John, Shashank Mohan, Whitney Herndon and Peter Marsters. 2018. "Energy and Environmental Implications of a Carbon Tax in the United States." Prepared by Rhodium Group for Columbia SIPA Center on Global Energy Policy. http://energypolicy.columbia.edu/ourwork/topics/climate-change-environment/carbon-tax-research-initiative/carbon-taxinitiative-research

Marron, Donald, Eric Toder, and Lydia Austin. 2015. "Taxing Carbon: What, Why, and How." Tax Policy Center, Washington, DC.

Mathur, Aparna, and Adele Morris. 2014. "Distributional Effects of a Carbon Tax in Broader U.S. Fiscal Reform." *Energy Policy* 66: 326–334.

———. 2017a. "A U.S. Carbon Tax and the Earned Income Tax Credit: An Analysis of Potential Linkages." Climate and Energy Economics Discussion Paper, Brookings Institution, Washington, DC.

———. 2017b. "Fill the Gaps in the Tax Bill with a Carbon Tax and Expanded Benefits for Working Families." Brooking Institution. https://www.brookings.edu/blog/planetpolicy/2017/12/08/fill-the-gaps-in-the-tax-bill-with-a-carbon-tax-and-expanded-benefits-for-working-families/.

McKibbin, Warwick J., Adele C. Morris, Peter J. Wilcoxen, and Yiyong Cai. 2015. "Carbon Taxes and U.S. Fiscal Reform." *National Tax Journal* 68, no. 1: 139–156.

McLure, Charles E. Jr., Jack Mintz, and George R. Zodrow. 2015. "U.S. Supreme Court Unanimously Chooses Substance over Form in Foreign Tax Credit Case: Implications of the PPL Decision for the Creditability of Cash-Flow Taxes." *International Tax and Public Finance* 22, no. 5: 887–907.

Minnesota IMPLAN Group. 2008. State-Level U.S. Data for 2006. Minnesota IMPLAN Group, Stillwater, MN.

Poterba, James. 1989. "Lifetime Incidence and the Distributional Burden of Excise Taxes." *American Economic Review* 79, no. 2: 325–330.

President's Advisory Panel on Federal Tax Reform. 2005. *Simple, Fair, and Pro-Growth: Proposals to Fix America's Tax System*. Washington, DC: US Government Printing Office.

Rausch, Sebastian, Gilbert E. Metcalf, and John M. Reilly. 2011. "Distributional Impacts of Carbon Pricing: A General Equilibrium Approach with Micro-Data for Households." *Energy Economics* 33: S20–S33.

Rausch, Sebastian, and John Reilly. 2015. "Carbon Taxes, Deficits, and Energy Policy Interactions." *National Tax Journal* 68, no. 1: 157–177.

Rosenberg, Joseph, Eric Toder, and Chenxi Lu. 2018. "Distributional Effects of Taxing Carbon." Prepared by the Urban-Brookings Tax Policy Center for Columbia SIPA Center on Global Energy Policy. http://energypolicy.columbia.edu/ourwork/topics/climate-change-environment/carbon-tax-research-initiative/carbon-taxinitiative-research.

Tuladhar, Sugandha D., W. David Montgomery, and Noah Kaufman. 2015. "Environmental Policy for Fiscal Reform: Can a Carbon Tax Play a Role?" *National Tax Journal* 68, no. 1: 179–194.

US Environmental Protection Agency. 2009. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2007*. Washington, DC.

Williams, Roberton C. III, Hal Gordon, Dallas Burtraw, Jared C. Carbone, and Richard D. Morgenstern. 2015. "The Initial Incidence of a Carbon Tax Across Income Groups." *National Tax Journal* 68, no. 1: 195–214.

Wolff, Edward N., and Maury Gittleman. 2011. "Inheritances and the Distribution of Wealth or Whatever Happened to the Great Inheritance Boom? Working Paper 445. US Bureau of Labor Statistics, Washington, DC.

Zodrow, George R. 2002. "Transitional Issues in the Implementation of a Flat Tax or a Retail Sales Tax." In *United States Tax Reform in the 21st Century*, edited by George R. Zodrow and Peter Mieszkowski, 245–283. Cambridge, UK: Cambridge University Press.

Zodrow, George R., and John W. Diamond, 2013. "Dynamic Overlapping Generations Computable General Equilibrium Models and the Analysis of Tax Policy." *In Handbook of Computable General Equilibrium Modeling*, vol. 1, edited by Peter B. Dixon and Dale W. Jorgenson, 743–813. Amsterdam: Elsevier Publishing.

APPENDIX

Details of the Diamond-Zodrow Model

This appendix provides a brief description of the Diamond-Zodrow model used in this analysis; for a complete description, see Zodrow and Diamond (2013). To simplify our analysis of the effects of carbon taxes, we use the closed economy version of our model. This is not especially problematical because (1) international capital flows would be affected by changes in after-tax returns to capital, and the carbon tax reforms considered have relatively minor effects on the after-tax return to capital; and (2) all of the carbon tax proposals currently under consideration include border adjustments for the relatively small changes in relative consumer prices that occur so that the effects on trade of any carbon tax, including those analyzed in this report, should be relatively small.[28] For a description of how international capital flows and international trade, as well as income shifting by US and foreign multinational companies, have been added in the open-economy version of our model, see Diamond and Zodrow (2015).

The Diamond-Zodrow model is a dynamic, overlapping generations, computable general equilibrium (CGE) model of the US economy that focuses on the macroeconomic and distributional effects of tax reforms, including immediate impact, transitional, and long-run effects. The model combines various features from other broadly similar CGE models, including those constructed by Auerbach and Kotlikoff (1987), Goulder and Summers (1989), Goulder (1989), Keuschnigg (1990), and Fullerton and Rogers (1993). Key model parameter values used in our simulations are listed in table A1,[29] while table A2 provides information on the characteristics of the 12 income groups.[30] Versions of the model have been used in analyses of tax reforms by the US Department of the Treasury (President's Advisory Panel on Federal Tax Reform 2005), the Joint Committee on Taxation (2005, 2017), and in a number of recent tax policy studies (Diamond and Zodrow 2007, 2008, 2013, 2014, 2015; Diamond, Zodrow, Neubig, and Carroll 2014; and Diamond and Viard 2008).

As discussed above, the model includes four consumer/producer sectors—a corporate composite good sector (C), a noncorporate composite good sector (N), and owner-occupied (H) and rental housing (R) sectors. The corporate sector is subject to the corporate income tax, and the "noncorporate" sector—which includes S corporations as well as LLCs, LLPs, partnerships, and sole-proprietorships—is taxed on a pass-through basis at the individual level. Using Cobb-Douglas production functions, firms in each sector combine labor and capital to produce their outputs to minimize after-tax costs. The time paths of investment are determined by profit-maximizing firm managers who take into account all business taxes as well as the costs of adjusting their capital stocks, correctly anticipating the macroeconomic changes that will occur after the carbon tax reform is enacted. Firms finance their investments with a fixed mix of equity and debt and pay out a fixed fraction of their earnings as dividends.

On the consumption side, each household has an "economic life" of 55 years, with 45 working years and a fixed 10-year retirement. Households supply labor and saving for capital investment, and their demands for all housing and nonhousing goods are modeled using an overlapping generations structure in which representative households[31] in each of the 55 different generations alive in any given year (each period in the model lasts one year) make consumption choices to maximize lifetime welfare subject to a lifetime budget constraint that includes personal income and other taxes, and they make a fixed "target" bequest.[32,33] Each generation includes 12 lifetime income groups as described above, with each group characterized by its own lifetime earnings profile, government transfers profile, wealth holdings, housing consumption, saving/bequest behavior, and other income-specific characteristics.

The government purchases fixed amounts of the two composite goods and makes transfer payments, which it finances with a corporate income tax, a progressive labor income tax (modeled as different constant marginal tax rates applied to the labor income of each of the 12 lifetime income groups), and constant rate capital income tax rates applied to the three forms of individual capital income in the model—interest income, dividends, and capital gains.[34] The modeling of the corporate income tax includes explicit consideration of deductions for depreciation or immediate expensing for both new and old assets (which are treated separately), other production and investment incentives, and state and local income and property taxes. The model includes a simple representation of the Social Security system, including its progressive benefit structure and the earnings cap on payroll taxes. Social Security benefits reflect indexing for carbon-tax-induced price inflation in the short run, but this consumer price indexing is phased out over a 30-year period to reflect the fact that the calculation of Social Security benefits at the time of retirement reflects indexation to wages rather than to consumer prices. As stressed by Cronin, Fullerton, and Sexton (2017), among others, the indexation of government transfers—they note that roughly 90 percent of government transfers in the United States are indexed for inflation—disproportionately benefits low-income families by offsetting the carbon-tax-induced price increases they face; it thus significantly reduces the regressivity of carbon taxes.

All markets are assumed to be competitive and in equilibrium in all periods, and the economy must begin and end in a steady-state equilibrium, with all of the key macroeconomic variables growing at the exogenous growth rate, which equals the sum of the exogenous population and productivity growth rates. Note that carbon taxes can affect the levels of the macroeconomic variables in the model; for example, carbon taxes might change the levels of investment, the capital stock, and GDP, relative to the values that would have occurred in the absence of reform. However, once the economy reaches a new steady-state equilibrium after enactment of the reform, all variables again increase at the long-term growth rate in the economy, which is not affected by the carbon tax (or any other policy reform). The model does not include unemployment so that any labor supply response reflects changes in labor supply in the context of a full employment economy.

Table A1: Parameter Values Used in the DZ Model

Symbol	Description	Value
	Utility Function Parameters	
ρ	Rate of time preference	0.015
σ_U	Intertemporal elasticity of substitution (EOS)	0.40
σ_C	Intratemporal EOS	0.80
σ_H	EOS between composite good and housing	0.30
σ_N	EOS between corporate composite good and noncorporate composite good	2.00
σ_R	EOS between rental and owner-occupied housing	1.50
α_C	Utility weight on the composite consumption good	0.73
α_H	Utility weight on nonhousing consumption good	0.48
α_N	Utility weight on composite corporate good	0.62
α_R	Utility weight on owner-occupied housing	0.76
α_{LE}	Leisure share of time endowment	0.40
	Production Function Parameters	
ε_C	EOS for corporate good	1
ε_N	EOS for noncorporate good	1
ε_H, ε_R	EOS for owner and rental housing	1
γ_C	Capital share for corporate good	0.27
γ_N	Capital share for noncorporate good	0.30
γ_H, γ_R	Capital shares for owner and rental housing	0.98
$\beta_C, \beta_N; \beta_H, \beta_R$	Capital stock adjustment cost parameters	5; 15
ζ	Dividend payout ratio in corporate sector	0.40
$b_C, b_N; b_H, b_R$	Debt-asset ratios	0.35; 0.40
n	Exogenous growth rate (population plus productivity)	3

Table A2: Various Share Values for the 12 Lifetime Income Groups

Lifetime Income Group	Wage Income	After-Tax Income	Owner-Occupied Housing	Bequest
1	0.0024	0.0017	0.0006	0.0004
2	0.0157	0.0125	0.0092	0.0022
3	0.0376	0.0325	0.0197	0.0087
4	0.0497	0.0428	0.0337	0.0109
5	0.0608	0.0521	0.0520	0.0131
6	0.0706	0.0609	0.0578	0.0196
7	0.0793	0.0686	0.0924	0.0218
8	0.0901	0.0778	0.1012	0.0240
9	0.1073	0.0917	0.1156	0.0283
10	0.1800	0.1588	0.1776	0.0871
11	0.1964	0.1806	0.2065	0.1307
12	0.1103	0.2201	0.1336	0.6533

Mapping RHG Price Changes to the DZ Model

The RHG price changes must be converted to the analogous price increases for the four consumer/producer goods in our model—those produced by the corporate (C), noncorporate (N), owner-occupied housing (H), and rental housing (R) sectors described above. This mapping proceeds as follows.

We begin with IRS Statistics of Income (SOI) data on all businesses by NAICS industry and by type of organization (all active corporations, S corporations, partnerships, and nonfarm sole proprietorships).[35] All housing production is assumed to occur in the H and R sectors. We use data on total business receipts to approximate the C-sector (all C corporations) and N-sector (the noncorporate or pass-through sector) shares of production for each of the nonhousing NAICS industry classifications. The US Bureau of Economic Analysis PCE (personal consumption expenditures) bridge table[36] identifies the output shares of the various NAICS industries that comprise each PCE category. Using our data on the C-sector share of each industry, we calculate the production-weighted average of the C-share of each the 14 nonhousing consumer goods. If that share is greater (less) than 50 percent, we classify the good as being produced by the C (N) sector in our model.[37] The resulting allocation of the 15 RHG consumer goods across the four DZ production sectors is shown in the third column of table A3.

Finally, we use these data to calculate the carbon-tax-induced price changes for each of the four sectors in our model. First, we assume that the carbon-tax-induced price increase for the owner-occupied housing (H) sector and the rental housing (R) sector are the same and equal to the housing price increase calculated by RHG. Second, we calculate the carbon-tax-induced price increase in the corporate sector (C) and the noncorporate sector (N) as the consumption-weighted average of the price increases of the 14 RHG consumer goods that have been allocated to each of those two sectors. The weights used in calculating these price changes are shown in table A4. For the benchmark carbon tax, the resulting increases in consumer prices in the four sectors in the model are (1) 1.3–1.6 percent in the corporate (C) sector, (2) 1.5–1.7 percent in the noncorporate (N) sector, and (3) 1.7–2.7 percent in the owner-occupied housing (H) and rental housing (R) sectors. For the high carbon tax case, these price changes are (1) 2.0–2.2 percent in the corporate (C) sector, (2) 2.2–2.3 percent in the noncorporate (N) sector, and (3) 2.4–4.0 percent in the owner-occupied housing (H) and rental housing (R) sectors. For the low carbon tax case, these price changes are (1) 0.4–0.6 percent in the corporate (C) sector, (2) 0.4–0.7 percent in the noncorporate (N) sector, and (3) 0.5–1.1 percent in the owner-occupied housing (H) and rental housing (R) sectors.

Table A3: Parameter Values Used in the DZ Model

Consumer Good Notation	RHG Personal Consumption Expenditure (PCE) Category	DZ Sector
C1	Motor vehicles and parts	C
C2	Furnishings and durable household equipment	C
C3	Recreational goods and vehicles	C
C4	Other durable goods	C
C5	Food and beverages purchased for off-premises consumption	C
C6	Clothing and footwear	C
C7	Gasoline and other energy goods	C
C71	*Motor vehicle fuels, lubricants, and fluids*	C
C72	*Fuel oil and other fuels*	C
C8	Other nondurable goods	C
C9	Housing and utilities	R, H
C91	*Housing*	R, H
C92	*Water supply and sanitation*	R, H
C93	*Electricity*	R, H
C94	*Natural gas*	R, H
C10	Health care	N
C11	Transportation services	N
C12	Recreation services	N
C13	Food services and accommodations	N
C14	Financial services and insurance	C
C15	Other services	N

Table A4: Sectoral Weights for Carbon-Tax Induced Price Increases Calculated by RHG

Good	Personal Consumption Expenditure Category	Weights C-Sector	Weights N-Sector	Weights R-Sector	Weights H-Sector
P1	Motor vehicles and parts	0.0948			
P2	Furnishings and durable household equipment	0.0625			
P3	Recreational goods and vehicles	0.0748			
P4	Other durable goods	0.0424			
P5	Food, beverages for off-premises consumption	0.1805			
P6	Clothing and footwear	0.0774			
P7	Gasoline and other energy goods				
P71	*Motor vehicle fuels, lubricants, and fluids*	0.0570			
P72	*Fuel oil and other fuels*	0.0043			
P8	Other nondurable goods	0.2161			
P9	Housing and utilities			1.0000	1.0000
P10	Health care		0.4306		
P11	Transportation services		0.0782		
P12	Recreation services		0.0984		
P13	Food services and accommodations		0.1688		
P14	Financial services and insurance	0.1902			
P15	Other services		0.2240		
	Sum of weights	1.0000	1.0000	1.0000	1.0000

Review of Studies of the Distributional Effects of Carbon-Tax-Induced Price Changes

In this appendix, we review six recent studies that that are representative of a large literature in which researchers capture the price effects of various carbon tax policies by using highly disaggregated models with considerable detail on both the carbon intensity of different goods and services and differences in consumption patterns across income groups.

Hassett, Mathur, and Metcalf (2009)

We begin with an early study by Hassett, Mathur, and Metcalf (HMM) (2009) that carefully examines the major distributional question regarding carbon taxes: Is a carbon tax likely to be regressive because low-income households disproportionately consume carbon-intensive goods and services, especially gasoline and utilities? HMM examine the effects of a tax of $15 per metric ton of carbon dioxide under the assumptions of full forward shifting of the tax and no behavioral responses. They estimate the incidence of a carbon tax in three different years, but we will focus on the last year analyzed, which is 2003. HMM use Bureau of Economic Analysis (BEA) input-output tables to calculate the effects of a carbon tax on consumer prices and Bureau of Labor Statistics Consumer Expenditure Survey (CES) data to determine household consumption patterns over 42 consumer goods.

HMM begin by calculating the incidence of the carbon tax by annual income decile. They show that the carbon tax is quite regressive, as the top income group bears a burden equal to only 0.81 percent of annual income, while the lowest income group bears a burden 4.6 times as large, equal to 3.74 percent of annual income. They also show that much of this regressivity is due to the direct effects of the carbon tax on fuel and utility prices, although the indirect effects of the carbon tax on the prices of other consumer goods are also regressive (the burden ratio described above is 5.9 for the direct effects but 3.6 for the indirect effects).

HMM then show that the incidence of the carbon tax changes dramatically—in the direction of greatly reduced regressivity—when households are ranked according to lifetime income. They use two alternative approaches to estimating lifetime income. The first method, which follows Poterba (1989), among others, is to use annual consumption as a proxy for lifetime income, as the permanent income hypothesis implies that consumption should be proportional to lifetime income. They note, however, that Bull, Hassett, and Metcalf (1994) suggest that consumption tracks annual income over the life cycle more closely than permanent income, and energy consumption is a larger share of total consumption for the elderly, especially those with low income. Under these circumstances, using annual consumption as a proxy for lifetime income overstates the regressivity of a consumption-based tax such as a carbon tax. Accordingly, they use an "adjusted" lifetime income measure developed by Bull, Hassett, and Metcalf under which individuals are classified by education level on the grounds that income and consumption patterns differ systematically by education level. They estimate life cycle profiles by education level for energy consumption and total consumption and then define "incidence" as the ratio of the present value of lifetime energy consumption to the present value of total consumption.

Using annual consumption as a proxy for lifetime income, they find that a carbon tax is much less regressive than when households are ranked according to annual consumption rather than annual income. The top income group bears a burden equal to 0.89 percent of annual income, while the lowest income group bears a burden only 1.7 times as large, equal to 1.49 percent of annual income. The regressivity of a carbon tax is further diminished under their adjusted measure of lifetime income. In this case, the top income group bears a burden equal to 0.93 percent of annual income, while the lowest income group bears a burden only 1.2 times as large, equal to 1.16 percent of annual income.

HMM also examine the regional incidence of a carbon tax and find that regional variation is fairly modest. They show that much of this variation is due to the direct effects of the carbon tax and attributable to differences in the fuels used for electricity generation, driving patterns, and weather conditions.

Grainger and Kolstad (2010)

A similar study by Grainger and Kolstad (2010) generally confirms the results of HMM and also considers the effects of family size on the incidence of a carbon tax. Grainger and Kolstad (GK) (1) assume that a carbon tax would be fully shifted forward as higher prices to consumers; (2) ignore any behavioral responses on the part of both firms and consumers to the tax; (3) use annual household income as the measure of taxpaying capacity in their benchmark case—although they also examine the incidence of a carbon tax with respect to annual consumption (as a proxy for lifetime income) as well as the effects of adjusting their incidence estimates for household size; and (4) assume a constant tax of $15 per metric ton of CO_2 emissions.

GK use data from the 2003 CES on consumption of goods and services for households in each quintile of the income distribution and input-output (IO) data from the BEA coupled with emissions factors calculated by Hendrickson et al. (2006) to determine the carbon intensity of production by industrial sector. They then use BEA data to match the sectors of the IO model to personal consumption expenditure categories and CES extracts published by the National Bureau of Economic Research to match the latter to the expenditure categories in the CES.

GK first estimate the incidence of the carbon tax relative to annual household income and then with respect to annual consumption expenditures as a rough proxy for lifetime income under the assumption that annual consumption is proportional to lifetime income. They then adjust both of these measures for family size, using equivalence scales to take into account economies of scale in providing household services.[38]

The results of the GK analysis, which use annual income as the measure of taxpaying capacity, imply the carbon tax is quite regressive, as the tax burden borne by the poorest quintile relative to annual income is 3.2 times greater than that of the richest quintile. For the reasons noted above, and as shown by HMM, the regressivity of the carbon tax declines when incidence is measured relative to lifetime income (using annual consumption expenditures as a proxy), as the tax burden of the poorest quintile falls to roughly 1.4 times that of the richest quintile.

Adjusting these estimates for family size significantly increases the regressivity of the carbon tax because lower-income households tend to have fewer persons. For example, in the GK sample, households in the poorest income quintile have 1.8 persons on average, while households in the richest income quintile are comprised of 3.1 persons on average. As a result, relative to "annual equivalent income," the tax burden borne by the poorest quintile relative to annual income is 7.0 times greater than that of the richest quintile; relative to "lifetime equivalent income," this ratio is 3.5. GK also note that in all cases the regressivity of carbon taxes is driven largely by direct energy consumption. Finally, they show that the regressivity of the carbon tax could be reduced or eliminated by recycling some of the revenues into tax cuts or public expenditure increases targeted toward poorer households.[39]

Williams, Gordon, Burtraw, Carbone, and Morgenstern (2015)

Williams, Gordon, Burtraw, Carbone, and Morgenstern (2015) link a dynamic overlapping generations model with a microsimulation model to analyze the short-run incidence of a $30 per ton of CO_2 carbon tax, held constant in real terms, coupled with alternative methods of recycling carbon tax revenues; their analysis includes general equilibrium changes in factor prices due to both carbon-tax-induced price increases and revenue recycling that were ignored by Grainger and Kolstad (2010). Their general equilibrium analysis models the effects of changes in after-tax rates of return on life cycle saving and captures the interactions between carbon taxes and existing taxes that are emphasized in the "double dividend" literature.

The Williams et al. model includes 19 competitive industries, including 16 intermediate goods, comprised of 15 energy and energy-intensive industries and 1 composite of all other intermediate goods, 17 commodities, 3 primary production inputs (labor, capital and natural resources), and 8 income sources. The government initially imposes taxes on labor income, capital income, and consumption spending and then imposes the carbon tax. Revenues are used to finance public services and transfer payments to households, which grow at the growth rate of the economy; the cumulative net real present value of government services and transfer payments is held constant (but is not necessarily constant in each period). Consumption expenditures and household incomes are taken from CEX data, and household incomes are adjusted using an equivalence scale equal to the square root of the number of members of the household.

The central conclusion of the analysis is that the incidence of carbon taxes “depends much more on how carbon tax revenue is used” than on carbon-tax-induced price changes (Williams et al. 2015, 195). Specifically, the authors find that (1) recycling revenues to reduce capital income taxation proportionately across all income groups improves economic efficiency but increases regressivity, (2) providing all individuals with lump sum rebates reduces regressivity but is relatively economically inefficient, and (3) reducing labor income taxes proportionately across all income groups has effects that are intermediate to the first two options, as reducing labor income taxation is more progressive than reducing capital income taxes and more efficient than lump sum rebates.

Williams et al. find that none of the carbon tax policies results in a “double dividend” for the mean household—that is, the mean household suffers a welfare loss from the imposition of the carbon tax (unless the benefits from reduced carbon emissions are considered), and the welfare loss is (1) largest for the relatively inefficient lump sum rebate, (2) smallest for the reduction in capital income taxes (due to the benefits of increased saving and capital accumulation), and (3) falls between these two cases for the reduction in labor income taxes, which are more efficient than the lump sum rebate due to their effects on labor supply and less regressive than the reduction in capital income taxation since labor income is less concentrated in the higher-income quintiles.

The carbon tax with a lump sum rebate is the most progressive of the three policies, as the poorest quintile experiences a welfare gain of more than 3 percent of income, with the welfare changes falling uniformly until the richest quintile experiences a windfall loss of nearly 2 percent of income, although the first three quintiles all experience welfare gains. By comparison, the carbon tax with a reduction in capital income taxation is the most regressive policy, with the lowest income quintile losing nearly 1 percent of income and the welfare changes increasing uniformly but reflecting welfare losses except for the richest quintile, which experiences a modest welfare gain. Finally, the carbon tax with a cut in labor income taxes results in welfare losses for all five quintiles, but is associated with the smallest overall changes in welfare (all less than 0.5 percent of income); this policy is slightly regressive between the first and second quintiles but progressive thereafter, especially between the fourth and fifth quintiles.

Williams et al. characterize their results as indicating that (1) the lump sum rebate will be preferred by those who wish to reduce inequality (or wish to implement a policy that would benefit the majority of voters), (2) reductions in labor income taxation will be preferred by those who want to have a roughly equiproportionate effect on all income classes or want to minimize large losses for any group, and (3) reductions in capital income taxation will be preferred by those who wish to maximize total welfare (and are not concerned about increasing income inequality).

Rausch, Metcalf, and Reilly (2011)

Rausch, Metcalf, and Reilly (RMR) (2011) also analyze the distributional impacts of carbon pricing using a general equilibrium model coupled with microsimulation data. They analyze the near-term (5–10 years) effects of a $20 per ton tax on CO_2 emissions using the MIT US Regional Energy Policy (USREP) general equilibrium model and data on 15,588 households. Their analysis focuses on the distributional effects of carbon-tax-induced price changes and the associated changes in income, as well as differences in the regional impacts of carbon tax policies, due primarily to difference in the regional composition of energy sources, especially electricity. Like Williams et al. (2015), RMR stress that the use of carbon tax revenues is critical to understanding the effects of carbon tax policies. In addition, they find that variation of impacts within income groups may be greater than the variation across income groups that is the focus of studies that examine the progressivity of carbon tax policies. The benchmark RMR analysis uses annual income as a measure of taxpaying capacity, but they also show that using two alternative proxies for lifetime income has relatively little impact on the results. Finally, the authors also examine variation in the distributional impacts of carbon tax policies across racial and ethnic groups and across regions.

The USREP model used by RMR has considerable detail on energy markets. Energy demand reflects the demands of five industrial sectors and three final demand sectors, and the modeling of energy supply includes oil and natural gas, coal, hydroelectric power, and nuclear power. The model also divides the United States into six regions, with labor mobile only within regions and capital mobile within and across regions. The model includes international trade in goods but not in factors of production.

RMR also (1) use CEX data to obtain household consumption expenditures, income, and demographic characteristics; (2) utilize emissions data from the US Environmental Protection Agency (2009); and (3) use state-level data from Minnesota IMPLAN Group (2008) and the Energy Information Administration (2009) to allocate production and consumption in the United States across the six regions in their model. They consider a $20 per ton tax on carbon dioxide emissions, with the revenues used to finance (1) an equiproportionate reduction in marginal income tax rates, (2) a per capita lump sum rebate (with no adjustment for household size), or (3) a rebate that is proportional to initial household capital income (which acts as a rough proxy for a cap-and-trade system in which emission permits are given to businesses rather than auctioned). Noting that over 90 percent of transfer payments in the United States are explicitly indexed for inflation, RMR assume that government transfers are fixed in real terms—an assumption that mitigates the effects of carbon-tax-induced price increases on lower- and middle-income families.

The main results of the RMR study show that the carbon tax coupled with a reduction in income tax rates has the lowest overall welfare cost—0.18 percent of total household income. However, this policy is regressive with respect to annual income; they report that the average tax burden relative to annual income for the lowest income decile, ignoring the bottom 2 percent of the income distribution, is roughly three times the average burden borne by the highest income decile.

By comparison, the two policies that involve lump sum rebates are more progressive but also less efficient (as in the Williams et al. [2015] analysis), with welfare costs that are more than twice as large as the policy that involves a carbon tax with income tax rate reductions (a welfare cost of 0.38 percent of income for the rebate based on capital income and a welfare cost of 0.46 percent of income for the per capita rebate). The per capita rebate policy is uniformly progressive, with the average tax burden relative to annual income for the top decile roughly 60 percent higher than that borne by the bottom decile (again neglecting the bottom 2 percent). In contrast, the burden for the rebate based on capital income is modestly progressive over the first nine income deciles but then becomes sharply regressive between the ninth and tenth deciles, reflecting the concentration of capital income in the highest income group.

RMR also estimate the incidence of their carbon tax policies using two proxies for lifetime income. First, to reduce life cycle effects, they limit their sample to households where the head of household is between the ages of 40 and 60. Second, they classify households by the educational outcome of the head of household under the assumption that lifetime income is positively correlated with educational attainment. In both of these cases, the distributional impacts of the three carbon tax policies are broadly similar to those obtained when incidence is measured with respect to annual income. The authors do not, however, follow Williams et al. (2015) and others in estimating the incidence of their carbon tax proposals using annual consumption expenditures as a proxy for lifetime income.

RMR discuss several factors underlying their incidence results. First, they note that the carbon tax policies have negative effects on factor incomes, with wages on average falling less than returns to capital—an effect that tends to make the imposition of carbon taxes less regressive, especially relative to studies that assume full forward shifting of the tax. It should be noted, however, that these effects might be overstated, given that the RMR analysis ignores international capital mobility.

Second, they show that household welfare losses increase sharply (in absolute value) with the share of expenditures on electricity and natural gas, and these expenditure shares are disproportionately large for lower-income groups. For example, the expenditure shares for electricity (natural gas) are 5.8 percent (2.2 percent) for the poorest income decile but 1.8 percent (0.8 percent) for the highest income decile.

Third—and especially relevant for our analysis—RMR decompose the effects of carbon taxes taken in isolation (that is, ignoring the revenues raised) into carbon-tax-induced price effects, other price effects, and income effects. They show that the tax burden of carbon pricing, taken in isolation, is very close to proportional in their model, with a burden relative to annual income that varies across all income deciles in a very tight range of −0.61 percent to −0.67 percent. This suggests that the distributional impacts of carbon tax policies are almost entirely determined by the approach used to distribute carbon tax revenues—the focus of this report. RMR also show that (1) the burden of all the consumer price changes caused by the carbon tax is moderately regressive, ranging from 0.91 percent of income for the lowest income decile to 0.65 percent for the highest income decile; and (2) the income effects of the carbon tax are progressive and large enough to offset the regressive price effects described in the first point, primarily due to the declines in the rate of return to capital noted above. The effects of carbon pricing, considered in isolation, are thus roughly proportional in their model.[40]

Cronin, Fullerton, and Sexton (2017)

In a recent contribution to this literature, Cronin, Fullerton, and Sexton (CFS) (2017) use the Treasury Distribution Model, which has data on 322,000 households including 22,000 nonfilers, to analyze the incidence of a $25 per ton tax on all carbon emissions. CFS focus on variation in carbon tax burdens within groups, which they show is much larger than the variation across groups that is the focus of most studies of carbon tax incidence (including this analysis). In particular, they find that (1) the importance of carbon tax rebates differs considerably among poorer families so that tax burdens within lower-income groups differ significantly, (2) similar heterogeneity of burden occurs for higher-income deciles including the richest group, (3) redistributions within income groups are typically increased by the revenue recycling options they consider, and (4) policies that reduce tax burden differentials across income groups tend to increase such differentials within income groups. In addition, CFS also provide information on the distributional effects of carbon tax reforms across income groups, which are summarized below.[41]

For the reasons noted above, CFS argue that incidence should be measured relative to lifetime income, and, following Williams et al. (2015), use current consumption as a proxy for lifetime income. Like Rausch, Metcalf, and Reilly (2011), they assume that government transfers are indexed for inflation, including inflation attributable to carbon-tax-induced consumer price increases (although they also consider real increases in transfer programs targeted toward the poor), and also take into account inflation indexing of income brackets and other tax parameters. Note, however, that the CFS analysis assumes full forward shifting of carbon taxes, ignores changes in factor prices, and ignores behavioral responses on the part of consumers and firms.

The CFS model matches information from 300,000 individual tax returns and 22,000 information returns to data on the consumption patterns and income of similar families in CEX data to model consumer demands. Medical Expenditure Survey data and administrative data from the US Department of Health and Human Services are used to impute Medicare, Medicaid, and workers compensation benefits to households. Current Population Survey data are used to impute transfer benefits, while saving behavior is imputed using Survey of Consumer Finances data. The supply side of the model reflects an input-output model of production similar to those described above. Estimates of the carbon intensities of the various goods in the model are based on data from the US Energy Information Administration and the US Environmental Protection Agency. This model is then used to estimate carbon-tax-induced price changes and the associated changes in expenditures under the assumption that quantities demanded are held fixed.

Like Rausch, Metcalf, and Reilly (2011), CFS first estimate the incidence of the carbon tax in isolation—that is, ignoring the revenues raised. For purposes of comparison, they show that with families ranked by annual income (adjusted for family size and economies of scale in sharing resources) and no indexation of transfers or income tax brackets, a carbon tax is regressive, with an average burden equal to 1.2 percent of annual income for the bottom income decile and 0.52 percent for the highest income decile. They then show that with incidence measured relative to annual consumption and inflation indexation of transfer payments and income tax brackets, the carbon tax is progressive, with a tax burden equal to 0.45 percent of annual consumption for the lowest consumption decile and 0.80 percent for the highest consumption decile. CFS note, however, that the increase in total federal tax burden is still largest in absolute terms for those in the bottom consumption decile: the tax burden for these households nearly doubles, while the tax burden for those in the top consumption decile increases by only 1.57 percent.

CFS then consider a carbon tax coupled with a per capita lump sum rebate of all revenues (other than those used to finance the indexation of transfer payments and income tax brackets). They find that this policy is uniformly progressive across all consumption deciles, with households in the first seven consumption deciles experiencing tax reductions; the lowest consumption decile experiences a tax reduction equal to 2.59 percent of consumption, while the richest households experience an increase in their tax burdens equal to 0.58 percent of consumption.

CFS also consider a policy under which carbon tax revenues are returned in the form of an equiproportionate increase in the Earned Income Tax Credit and all other transfer benefits (in addition to the inflation indexation of transfers). They find that this policy is not as progressive as the per capita rebate because many transfers are not means tested so that the lowest consumption decile receives 5 percent of transfers while the top decile receives 13 percent. The first eight consumption deciles experience tax reductions, but these are generally smaller (in absolute value) than with the per capita rebate. For example, the first three consumption deciles experience reductions in tax burdens that range from 0.96–1.07 percent, while these tax reductions ranged from 1.29–2.59 percent with the per capita rebate. Consumption deciles seven through nine experience almost no change in tax burden, while the highest consumption decile has a 0.5 percent increase in tax burden.[42]

Finally, CFS consider a carbon tax reform in which equal shares of revenues are used to reduce payroll taxes to compensate workers and increase social security benefits to compensate retirees. They show that this reform is roughly proportional (although slightly progressive) with tax changes relative to annual consumption that fall with a narrow range, -0.38 to 0.32 percent of annual consumption, with nine of the ten deciles experiencing small tax reductions.

Rosenberg, Toder, and Lu (2018)

Finally, as part of this project, Rosenberg, Toder, and Lu (RTL) (2018) use the Tax Policy Center Microsimulation Model to provide a detailed static analysis of the same three carbon tax proposals discussed in this report. They use the same Rhodium Group (2018) data on carbon-tax-induced price increases and carbon tax revenues that we utilize and also calculate the distributional effects of carbon taxes for several alternative uses of the revenues raised. Because the RTL study is part of this research project, we only summarize its results very briefly.

RTL take the price changes calculated by Rhodium Group and allocate the associated burden of the three carbon taxes across income groups, taking into account the sources of income (the burden is allocated in proportion to labor compensation, the labor share of business income, wage-indexed transfer payments [only in the long run as such transfer payments are indexed to consumer prices in the short run], and above-normal returns to capital[43,44]) and the uses of income (following an approach similar to the studies discussed above). RTL consider four revenue recycling options, the first three of which are similar to those we analyze—reducing payroll taxes, providing households with a lump sum rebate, reducing the federal deficit, and reducing the statutory corporate income tax rate from its postreform value of 21 percent.

RTL find that the burdens of the three carbon taxes analyzed, taken in isolation (ignoring revenue recycling) and assuming that the tax imposes a burden on half of the normal return to capital, is somewhat regressive with respect to annual income—although they also note the advantages of measuring incidence with respect to a longer time period, including over the life cycle. For example, for the benchmark carbon tax, they estimate that after-tax income would initially decline by 2.1 percent for taxpayers in the bottom quintile, by 1.8 percent in the middle quintile, and by 1.5 percent for the top quintile. After 20 years, these figures are 2.0 percent, 1.4 percent, and 1.1 percent.

Revenue recycling significantly changes these results. In all cases, we report the RTL results for the benchmark carbon tax under the assumption that the tax imposes a burden on half of the normal return to capital.

The payroll tax offsets most of the burden of the carbon tax, and the net effect of the carbon tax/payroll tax reduction policy is only mildly regressive except at the top of the income distribution, where the carbon tax becomes progressive. Specifically, the after-tax income of the lowest quintile falls but by only 0.5 percent, while the middle quintile experiences a net effect of zero, the fourth quintile has a gain of 0.4 percent, the highest quintile suffers a loss of 0.1 percent, and the top 1 percent experience a loss of 1.1 percent.

The per capita household rebate is the most progressive of the various carbon tax policies and is uniformly progressive throughout the income distribution. The lowest quintile has an increase in after-tax income of 5.4 percent, while the middle quintile experiences a gain of 0.6 percent, and the top quintile has a loss of 0.8 percent.

Using carbon tax revenues to reduce the deficit is mildly and uniformly regressive. The lowest income quintile experiences a reduction in after-tax income of 2.1 percent, while the middle quintile has a loss of 1.8 percent, and the top quintile has a loss of 1.5 percent.

Finally, using carbon tax revenues to further reduce the corporate income tax rate from its post-2017-reform level of 21 percent is the most regressive of the carbon tax policies and is uniformly regressive throughout the income distribution. The lowest quintile has a decline in after-tax income of 1.7 percent, and the middle quintile experiences a loss of 1.0 percent, while the top quintile has an increase in after-tax income of 0.8 percent.

NOTES

1. Note, however, that in some cases additional policies may be required to achieve efficiency—for example, to the extent that some carbon emissions are not covered by the tax or some external social costs are not included in the calculation of the level of the tax.
2. Negative estimates for the SCC are unusual but can arise if the benefits of climate change, such as increased agricultural production due to greater concentrations of carbon dioxide, are sufficiently large.
3. Marron, Toder, and Austin note that it is difficult to measure the SCC because (among other reasons) (1) costs must be measured over many years since greenhouse gases remain in the atmosphere for many years; (2) costs depend on the highly uncertain stock of greenhouse gases at each point in time; (3) cost estimates depend on a wide variety of controversial assumptions, including the choice of the discount rate, the costs of adapting to climate change, and the valuation of low probability but extremely costly catastrophic events; and (4) estimates of the SCC in the United States vary significantly depending on whether international or solely domestic costs are considered, since the United States bears only 7–10 percent of global SCC.
4. Using NIPA classifications of personal consumption expenditures, with “Gasoline and Other Goods” and “Housing and Utilities” disaggregated into two and four subcategories, respectively, results in a total of 19 consumer goods.
5. This path is based on figures provided in Interagency Working Group on Social Cost of Greenhouse Gases, United States Government (2016).
6. For a recent comparison of various models used to simulate the effects of tax reforms, including macroeconomic forecasting models broadly similar to the macroeconomic module of the NEMS model underlying the Rhodium Group’s modeling effort and our dynamic, overlapping generations, computable general equilibrium model, see Auerbach and Grinberg (2017).
7. For example, for the case of the carbon tax coupled with the payroll tax reduction discussed below, 40 percent of the long-run increase in GDP is achieved within 10 years, nearly 60 percent is achieved within 20 years, and 93 percent occurs within 50 years, with the simulations continuing for at least 150 years until a true steady-state equilibrium (in which all of the macroeconomic variables increase precisely at the fixed growth rate) is reached.
8. Thus, for example, an individual with an “economic age” of one year has completed her education and has been in the labor force for one year.
9. See Cronin, Fullerton, and Sexton (2017) for a recent review of this literature.
10. We will define progressivity with respect to average tax burdens—that is, a progressive (proportional, regressive) tax is defined as one under which the average tax burden increases (remains constant, decreases) with increases in the measure of taxpaying capacity.

11. See Jorgenson et al. (2013) for a discussion of the literature on the possibility of double dividends with environmental taxes.

12. These general conclusions are confirmed in a recent study by Caron et al. (2018) that analyzes the distributional effects of various carbon tax policies within the context of five of the models that are used in the Stanford Energy Modeling Forum 32 project noted below. Specifically, they conclude that (1) the distributional impacts of carbon tax policies are primarily driven by the nature of revenue recycling; (2) capital income tax reductions are the most efficient but also the most regressive of the carbon tax policies, while lump sum redistributions are the most progressive but the least efficient; and (3) a mixed policy such as using half of revenues to reduce capital income taxes and half for lump sum rebates can eliminate regressivity or even make the carbon tax slightly progressive, while policies utilizing transfers to hold the lowest income quintile harmless can be achieved at a cost of roughly 10 percent of revenues.

13. Other possibilities, not addressed in our analysis, occur when environmental taxes are imposed (particularly in the presence of unemployment) on goods that are complementary to untaxed leisure and thus indirectly reduce labor supply distortions, when environmental quality is a substitute for leisure, when environmental quality affects production by increasing labor productivity, and when the incidence of environmental taxes is on economic rents.

14. See the March 2015 issue of the National Tax Journal for a forum on the effects of carbon taxes under alternative revenue recycling options and the February 2018 issue of Climate Change for the papers from the Stanford Energy Modeling Forum 32 study of various carbon tax scenarios in the United States. The latter issue includes a paper by JGHW (2018) in which they update their results for the revenue recycling options involving capital and labor income tax reductions and lump sum rebates. See also Mathur and Morris (2014).

15. Broadly similar results are obtained in another CGE analysis of the effects of carbon taxes by McKibbin, Morris, Wilcoxen, and Cai (2015), who also consider a variety of carbon tax revenue recycling options. They stress that while most revenue recycling policies result in small reductions in GDP, using carbon tax revenues to cut taxes on capital income increases investment, employment, and wages, and leads to significant increases in GDP (on the order of 1 percent of GDP for a tax on the carbon content of fossil fuels that starts at $15 per ton and increases at a real rate of 4 percent until 2050 and is then held constant in real terms). See also Rausch and Reilly (2015).

16. Rausch and Reilly (2015) examine the interaction between various regulatory policies, such as corporate average fuel economy (CAFE) standards for vehicles, renewable portfolio standards (RPSs) that require increased production of energy from renewable sources, and carbon taxes under various revenue recycling options. Assuming a carbon tax of $20 per ton increasing at a real rate of 4 percent, they find relatively small aggregate welfare losses under all of the policies they consider, except for a small gain when carbon tax revenues are used to cut personal income taxes in the presence of RPS.

17. Expensing is sufficient to result in a marginal effective tax rate of zero on new investment,

so that coupling expensing with interest deductibility results in negative effective rates; for a recent demonstration of these well-known results, see McLure, Mintz, and Zodrow (2015).

18. These revenues are similar but not identical to those estimated by Rhodium Group (2018), as we can duplicate their carbon tax rates exactly but can then only approximate their revenue levels within the context of our model specification.

19. This figure represents the total revenue raised by the carbon tax. Note that static estimates of the effects of carbon taxes, such as those prepared by Rosenberg, Toder, and Lu (RTL) (2018) as part of this project, include a "revenue offset" of roughly 25 percent, which reflects the estimated reduction in income and payroll tax revenues due to the decline in labor and capital income attributable to the imposition of the carbon tax. By comparison, such income and payroll tax revenue effects are calculated endogenously in our general equilibrium model so that no revenue offset is needed. A rough "partial equilibrium" or static calculation suggests that our model parameterization is consistent with a revenue offset of approximately the same magnitude as that estimated by RTL and others.

20. Medicare payroll taxes are not reduced, and the 0.9 percent tax on high-income taxpayers enacted under the Affordable Care Act is also unchanged.

21. See Zodrow (2002) for a discussion of such reform-induced losses.

22. Recall from the discussion above that these results include only the aggregate price effects of the carbon tax proposals and thus do not capture the effects by income group of differential consumption of consumer goods with varying energy intensity. However, recall also that the results of the distributional studies described in appendix C suggest that for the case relevant to our analysis—lifetime incidence analysis with inflation indexation of transfer payments—the distributional implications of these differential price changes are swamped by the distributional effects of the alternative methods of revenue recycling that are the focus of our analysis.

23. Interest rates decline slightly—by 13–20 basis points—after enactment of this carbon tax reform.

24. After-tax real wages increase for lifetime income groups 1–9 and decline for income groups 10–12.

25. The second-lowest lifetime income group experiences significantly larger welfare gains than the lowest group primarily because the price of rental housing increases more than the price of owner-occupied housing and the lowest lifetime income group consumes significantly more rental housing than the second group.

26. Given our assumption of a closed economy, we do not model foreign ownership of US debt.

27. Note that as in the case of equal per capita rebates, rental housing again increases over time while owner-occupied housing declines somewhat. In the case of revenue recycling in the form of debt reduction, this occurs because interest rates decline more significantly than in the other simulations, which has a disproportionately large impact on the wealthy, who must save more to finance their target bequest; this causes a relatively large reduction in the demand for owner-occupied housing.

28. For extensive discussion of border tax adjustments for carbon taxes, see the forum on this topic in the June 2017 issue of the National Tax Journal.

29. For a discussion of some of these choices, see Gunning, Diamond, and Zodrow (2008).

30. These are based on data from Congressional Budget Office (2011) and Wolff and Gittleman (2011).

31. Households are not differentiated according to family size.

32. This relatively simple approach to modeling bequests follows Fullerton and Rogers (1993). One advantage of the target bequest approach is that it addresses the concern that the responsiveness of the saving of far-sighted households to after-tax returns is unreasonably large in life cycle models (Ballard 2002; Gravelle 2002); with a target bequest, an increase in the after-tax rate of return reduces bequest saving since the target bequest is more easily attained and thus mutes savings responses in the model.

33. We assume that individuals hold their bequests fixed in nominal terms and thus do not adjust their bequests for carbon-tax-induced price increases. This assumption could be interpreted as implicitly reflecting consideration of the future environmental benefits that will accrue to heirs—that is, parents do not feel a need to increase their bequests to offset the price effects of the carbon tax since their children will receive the environmental benefits of emission reductions. Adjusting the size of the bequest for carbon-tax-induced price increases has relatively small effects on the macroeconomic results but substantially affects the distributional effects, effectively causing a redistribution primarily from the current high-income elderly to future generations of high-income households. The bequest is not included in the individual utility function (or can be treated as separable).

34. The tax rates used in the model reflect the changes enacted in the 2017 Tax Cuts and Jobs Act. The tax rate applied to capital gains is an effective annual accrual tax rate.

35. IRS Tax Statistics, Business Tax Statistics, https://www.irs.gov/statistics.

36. BEA, "PCE Bridge, 73 Commodities, 2015," https://www.bea.gov/industry/more.htm.

37. This approach assumes that the C-sector share for each industry can be determined accurately from the SOI data for that industry, which capture the C-sector share of the income value-added in that industry. However, this industry classification is tenuous in the sense that the intermediate inputs in an industry might be produced by industries from a different sector, which, if sufficiently important, might change the overall classification of the industry. To check this, we also calculated the C-sector share for each industry using BEA input-output data (BEA, Input-Output Tables, Supplemental Estimate Tables, Total Requirements, Industry by Commodity, 71 Industries, https://www.bea.gov/industry/io_annual_htm) to determine the share of each intermediate good used to produce the output of each industry and then used the associated intermediate good C-sector shares to calculate the overall C-sector share for the industry. Using these adjusted industry C-sector shares did not change the allocation of any of the 15 RHG consumer goods across the four DZ consumption/production sectors.

38. Following Cutler and Katz (1992), GK assume that "equivalent persons," E, can be defined as E=(A+0.4K)1/2, where A is the number of adults in the household and K is the number of children.

39. GK provide several additional results. First, they show that if all greenhouse gases are subject to the tax (i.e., taxing gases such as methane, nitrous oxide, and ozone rather than just CO_2), the tax policy is slightly more regressive. Second, they show that taxing only emissions from the consumption of energy goods (gasoline, electricity, natural gas, and fuel oil) is somewhat more regressive relative to annual and lifetime household income but somewhat less regressive than the carbon tax relative to annual income and lifetime income when these measures are adjusted for family size as described above.

40. RMR also conduct several analyses that go beyond the scope of the analysis in this paper but are nevertheless quite interesting. For example, they show that black households and, to a lesser extent, Hispanic households bear a larger share of the burden than white households, primarily because their expenditure shares of energy products are relatively high. In their regional analysis, RMR show that the North and South Central regions are disproportionately negatively affected by carbon taxes, primarily because they are heavily reliant on coal for electricity generation, while the Northeast and West regions bear relatively small burdens, primarily due to greater reliance on hydroelectric and nuclear power for electricity generation. The authors also show that variations in carbon tax burdens within income groups and across regions can be larger than those across income groups.

41. Like Rausch, Metcalf, and Reilly (2011), CFS show that the variation in tax burdens within groups is significant for the reforms they analyze. As above, because such variation is beyond the scope of this report, we discuss only their results across income groups.

42. In contrast, Mathur and Morris (2017a) examine a policy reform in which the revenues from a carbon tax, assessed at $32 per ton of carbon dioxide, are used solely to finance the expansion of the Earned Income Tax Credit (EITC) for childless workers and to make other adjustments such that low-income households are not harmed by any reductions in wages (and thus to the EITC) attributable to the tax. They show that such a policy creates net benefits for households in the lower-income deciles and also improves work incentives.

43. The normal returns to capital are either assumed to be (1) exempt from tax due to the consumption-based nature of the carbon tax or (2) partially taxed (50 percent) due to the taxation of investment goods that are subject to the income tax.

44. Note that because our model assumes competitive markets, it does not include economic rents.

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