The Distributional Effects of Adopting a Carbon Tax

Stephie Fried*, Kevin Novan†, William B. Peterman‡

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Abstract

This paper examines the non-environmental welfare effects of introducing a revenue-neutral carbon tax policy. Using a life cycle model, we find that the welfare effects of the policy differ substantially for agents who are alive when the policy is enacted compared to those who are born into the new steady state with the carbon tax in place. Consistent with previous studies, we demonstrate that, for those born in the new steady state, the welfare costs are always lower when the carbon tax revenue is used to offset an existing distortionary tax as opposed to being returned in the form of lump-sum payments. In contrast, during the transition, we find that rebating the revenue with a lump sum transfer is less costly than using the revenue to reduce the distortionary labor tax. Additionally, we find that the tax policy is substantially more regressive over the transition than in the steady state, regardless of what is done with the revenue. Overall, our results demonstrate that estimates of the non-environmental welfare costs of carbon tax policies that are based solely on the long-run, steady state outcomes may ultimately paint too rosy of a picture. Thus, when designing climate policies policymakers must pay careful attention to not only the long-run outcomes, but also the transitional welfare costs and regressivity of the policy.

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*Carleton College. Email: sfried@carleton.edu

†University of California, Davis. Email: knovan@ucdavis.edu

‡Federal Reserve Board of Governors. Email: william.b.peterman@frb.gov. Views expressed in this paper are those of the authors' and do not reflect the views of the Federal Reserve System or its staff.

1 Introduction

Establishing a price on carbon, using either a carbon tax or a cap-and-trade program, is well understood to be the most efficient approach for reducing greenhouse gas emissions (Pigou (1920), Dales (1968), Montgomery (1972), Baumol and Oates (1988)). These policies clearly have the potential to provide large welfare gains through environmental channels – e.g., reducing the risks posed by climate change and improving air quality. However, they can also significantly affect welfare through non-environmental channels. Specifically, by increasing the relative price of energy derived from fossil fuels, a carbon tax can alter individuals' decisions to consume, work, and save – potentially causing large general equilibrium impacts across the entire economy.

Previous studies highlight that the way in which revenue from a carbon tax is used can dramatically alter the non-environmental welfare consequences of a tax policy. In particular, using carbon tax revenue to offset pre-existing distortionary taxes (e.g., taxes on labor or capital income) has been shown to be far more efficient than recycling the revenue in the form of lump-sum rebates – a result referred to in the literature as the 'weak double-dividend hypothesis' (Goulder (1995), de Mooij and Bovenberg (1998), Bovenberg (1999)). Previous studies also highlight that the revenue recycling method can substantially alter the distribution of the welfare changes across income groups (Fullerton and Heutal (2007), Dinan and Rogers (2002), Metcalf (2007), Parry (2004), Parry and Williams (2010)).

While these previous studies provide a solid understanding of the long-run welfare and distributional impacts of revenue-neutral carbon tax policies, they may provide little insight into how the current, living population will be impacted. Specifically, the existing work tends to examine the welfare effects by comparing steady state outcomes in an economy with and without a carbon tax. This comparison ignores how these welfare effects may differ during the transition between the two steady states. In particular, in the steady state, agents experience the policy for their entire life cycle. In contrast, the current population only experiences the policy for a portion of their lifetime. Thus, if the policy is less costly during a specific portion of an agent's lifetime – for example, during an agents working lifetime –

then the welfare costs to current retired agents will be relatively larger. As a result, the average welfare costs among the current, living population may be much higher than the expected lifetime cost for an agent living in the steady state.

In this paper, we directly examine whether the welfare impacts of revenue-neutral carbon tax policies differ in the long-run steady state versus during the transition to the new steady state. To do so, we construct a quantitative, overlapping generations model (OLG) which incorporates idiosyncratic productivity shocks, mortality risk, retirement, and Social Security. Using the model, we explore the welfare consequences of imposing a $35 per ton tax on CO_2. The revenue from this tax is used to either (1) offset revenue generated by a tax on labor income, (2) offset revenue from a tax on capital income, or (3) is returned in the form of lump-sum payments. Exploring the impacts of these carbon tax policies in a life cycle model turns out to be particularly important because, as our results demonstrate, the welfare effects differ substantially by age. Therefore, the impact a policy has on the welfare of an agent alive at the time the policy is adopted depends crucially on whether the agent has already lived past the age when the tax policy is relatively more or less helpful.

Using our life cycle model, we first solve for the impact each carbon tax policy will have on the expected lifetime welfare of an agent born in the new, long-run steady state. We then compare the steady state welfare changes to the impacts each policy will have on the expected welfare of agents alive at the time the policy is introduced. Focusing first on the steady state effects, our results echo the findings from the existing literature. In the steady state, the expected non-environmental welfare costs are minimized when the carbon tax revenue is used to reduce either existing distortionary tax. In fact, our results suggest that using the carbon tax revenue to offset revenue generated by the capital or labor tax actually reduces the distortions caused by the tax system – leading to increases in the expected non-environmental welfare equivalent to 0.43 percent of expected lifetime consumption when offsetting the capital tax or 0.14 percent of expected lifetime consumption when offsetting the labor tax. In contrast, recycling the revenue in the form of lump-sum payments results in a a decrease in non-environmental welfare equivalent to 0.32 percent of an agent's expected lifetime consumption. The distributional impacts in the steady state also reiterate the findings from the earlier literature. If carbon tax revenues are recycled through lump-sum payments, low income households are the relative winners. Alternatively, if the revenues are used to reduce a pre-existing distortionary tax, without altering the progressivity or regressivity of that tax, then the higher income households are the relative winners.

While understanding how the alternative policies can impact agents' welfare in the long run is important, our results reveal that the steady state impacts serve as poor predictions of how the current, living population will be affected. In particular, we find that using carbon tax revenue to reduce the labor or capital tax will be much more costly during the transition. Focusing specifically on the cohorts alive at the time a carbon tax is implemented, on average, the non-environmental welfare of a living agent falls by the equivalent of 0.19 of expected future lifetime consumption if capital tax revenue is offset and non-environmental welfare falls by the equivalent of 1.98 percent of expected future lifetime consumption if labor tax revenue is offset. In contrast, recall that in the steady state, using carbon tax revenue to reduce the capital or labor tax caused agents' expected non-environmental welfare to increase.

The larger welfare costs during the transition are driven by the fact that the older generations suffer substantially more than younger generations under the policies that use carbon tax revenues to offset the labor or capital tax revenues. While reducing labor or capital taxes leads to an increase in the after-tax wage or risk-free rate, the benefits the old receive from these factor price changes are much smaller than the direct costs imposed by the carbon tax. For one, retirees have no remaining labor income. In addition, due to social security, which we include in our model, older retirees only fund a small fraction of their consumption from capital income – and therefore gain little from the increased returns to capital. Ultimately, the relatively high welfare costs for the older cohorts reduces the average welfare among the living generations. In contrast, under the lump-sum rebate policy, the welfare effects are much more uniform across the age groups, causing the aggregate welfare impact to be similar in the steady state and the transition. On average, we find that a living agent's non-environmental welfare falls by an amount equivalent to 0.39 percent of expected future lifetime consumption if revenues are recycled as lump-sum payments.

In addition to the labor and capital tax rebate mechanisms causing different aggregate welfare impacts over the transition and the steady state, our results reveal that the distributional consequences also differ in the short verus long-run. In particular, the regressivity of the capital tax rebate policy is dramatically larger during the transition. In the steady state, offsetting the capital tax leads to non-environmental welfare increases equivalent to 0.19 percent of expected lifetime consumption in the lowest income quintile and increases equivalent to 0.66 percent of expected lifetime consumption in the highest income quintile. However, among the agents alive at the time the policy is implemented, the lowest income quintile experiences a reduction in non-environmental welfare equivalent to 1.34 percent of the expected future lifetime consumption while the top income quintile experiences an average increase equivalent to 1.42 percent of expected future lifetime consumption.

Our results provide an important new insight to the literature. Consistent with the previous studies, we demonstrate that, in the steady state, the weak double dividend hypothesis holds. Specifically, the non-environmental welfare costs are always lower when the carbon tax revenue is used to offset an existing distortionary tax as opposed to being returned in the form of lump-sum payments. However, during the transition, the non-environmental welfare costs are not necessarily larger when the carbon revenues are recycled as lump-sum payments - i.e. the weak double dividend hypothesis breaks down. In particular, while our results reveal that the non-environmental welfare costs are still minimized by reducing the capital tax, we find that agents alive at the time the policy begins are better off receiving lump-sum payments as opposed to offsetting revenue from the distortionary labor tax.

More generally, our results demonstrate that estimates of the non-environmental welfare costs of carbon tax policies that are based solely on the long-run, steady state outcomes may ultimately paint too rosy of a picture. Previous studies in the macroeconomic and public finance literatures highlight that, across a variety of settings, the steady state and transition welfare effects of tax policies can differ substantially (e.g., see Domeij and Heathcote (2004), Fehr and Kindermann (2015), Dyrda et al. (2015)). Similarly, the findings from our analysis suggest that, as we transition to a new steady state, a revenue-neutral carbon tax policy has the potential to impose sizable costs that fall disproportionately on specific segments of the current population – in many cases, the old and the low income. This suggests that, when designing climate policies, policymakers must pay careful attention to not only the long-run outcomes, but also the transitional welfare costs and regressivity of the policy.

Our work is most closely related to Carbone et al. (2013). Similar to our analysis, Carbone et al. examine the welfare impacts of alternative revenue-neutral carbon tax policies using a life cycle model. While Carbone et al. examine a model with a single, representative agent for each age cohort, our life cycle model incorporates within age cohort heterogeneity through individual-specific productivity fixed effects as well as through idiosyncratic productivity shocks.[1] The inclusion of within cohort heterogeneity provides two important advantages. First, we are able to directly examine the general equilibrium welfare impacts not only across age groups, but also across income groups.[2] Second, by including uncertainty in an agent's lifetime income, our model is able to incorporate an additional channel through which a carbon tax policy may cause general equilibrium distortions within the economy. Specifically, when it comes to saving, individuals are motivated by two main factors – agents save for retirement and they accrue precautionary savings in response to income uncertainty. By studying the impact of a carbon tax in a life cycle model with income uncertainty, our paper is the first to incorporate both motives for saving when analyzing the welfare effects of a carbon tax.

The remainder of the paper proceeds as follows. Section 2 introduces the OLG model. Section 3 discusses the functional forms in the model and the calibration of the key pa-

[1]Chiroleu-Assouline and Fodha (2014) also include within-cohort heterogeneity in a life cycle model through the use of ability fixed effects. However, the authors focus solely on the welfare effects of a carbon tax in the steady state – not over the transition for an agent already in the model when the tax is adopted. In addition, the authors focus solely on recycling carbon revenues through a labor tax rebate.

[2]To predict the distributional impacts, Williams et al. (2015) instead use the estimates from Carbone et al. as inputs in a partial equilibrium, microsimulation model that translates the predicted income changes into estimates of the welfare impacts across income groups during the initial year the policy is in place – not over the agents' lifetimes.

rameters. Section 4 reports the steady state and transition results under the alternative, revenue-neutral carbon tax policies. Section 5 concludes.

2 Model

The following section describes the OLG model we use to examine the welfare and distributional impacts of various revenue-neutral carbon tax policies.

2.1 Demographics

Agents enter the model when they start working, which we approximate with a real world age of 20, and can live to a maximum age of J. Thus, there are $J-19$ overlapping generations. A continuum of new agents is born each period and the population of newborn agents grows at a constant rate, n. Lifetime length is uncertain and mortality risk varies over the lifetime. Parameter Ψ_j denotes the probability an agent lives to age $j+1$ conditional on being alive at age j. All agents who live to age J die with probability one the following period, i.e. $\Psi_J = 0$. Since agents are not certain how long they will live, they may die with positive asset holdings. In this case, we treat the assets as accidental bequests and redistribute them lump-sum across all living individuals in the form of transfers T_a. All agents are forced to retire at the exogenously determined age j_r. Upon retirement, agents receive social security payments S.

2.2 Households

An individual is endowed with one unit of productive time per period that can be divided between labor and leisure. At age j, agent i earns labor income $y^h_{i,j} \equiv w\mu_{i,j}h_{i,j}$, where w is the market wage-rate, $h_{i,j}$ denotes hours worked, and $\mu_{i,j}$ is the agent's idiosyncratic productivity. The log of an agent's idiosyncratic productivity consists of four additively separable components,

$$\log \mu_{i,j} = \epsilon_j + \xi_i + \nu_t + \theta_t. \tag{1}$$

This specification is based on the estimates in Kaplan (2012) from the Panel Study of Income Dynamics (PSID). Component ϵ_j governs age-specific human capital and evolves over the life cycle in a predetermined manner. Component $\xi_i \sim NID(0, \sigma^2_\xi)$ is an individual-specific fixed effect (or ability) that is observed when an agent enters the model and is constant for an agent over the life cycle. Component $\theta_t \sim NID(0, \sigma^2_\theta)$ is an idiosyncratic transitory shock to productivity received every period, and ν_t is an idiosyncratic persistent shock to productivity, which follows a first-order autoregressive process:

$$\nu_t = \rho\nu_{t-1} + \psi_t \text{ with } \psi_t \sim NID(0, \sigma^2_\nu) \text{ and } \nu_{20} = 0. \tag{2}$$

Thus, agents across cohorts are differentiated along one dimension which affects their labor productivity: their age-specific human capital, ϵ_j. Agents within an age cohort are differentiated along three dimensions which affect their labor productivity: their ability, ξ_i, their current transitory shock, θ_t, and their current persistent shock, ν_t. Different permanent ability types and the initial realization of the i.i.d. shock, θ_t, generate an initial productivity distribution within the cohort of 20 year old entrants to the model. Different realizations of the persistent shock ν_t over the lifetime cause the within cohort variation to grow with age.

We assume that agents cannot insure against idiosyncratic productivity shocks by trading explicit insurance contracts. Moreover, we assume that there are no annuity markets to insure against mortality risk. However, agents are able to partially self insure against labor-income risk by purchasing risk-free assets, $a_{i,j}$, that have a pre-tax rate of return, r_t.

Agents split their income between saving with the risk-free assets and consumption. When considering how a carbon tax would affect individuals consumption, it is important to note that carbon emitting energy sources are not only used in the production of final consumer goods, but carbon-based energy sources are also consumed directly by individuals as a final good (e.g., electricity, gasoline, heating oil, etc.). Therefore, in our model, agents can consume a generic consumption good, $c_{i,j}$, as well as a carbon emitting energy good, $e^c_{i,j}$.

As previous studies highlight (e.g., Metcalf (2007), Hassett et al. (2009)), the direct impact of a carbon tax – prior to any revenue recycling – is likely to be quite regressive. This is driven by the fact that lower income households devote a larger share of their expenditures to energy. To ensure that our model captures this negative relationship between income and energy expenditure shares, we assume that all agents must consume a minimum amount of energy, $\bar{e}$, and that agents derive no utility from the energy consumed up to this subsistence level.

In each period agents choose labor, savings, generic consumption, and energy consumption to maximize their expected stream of future discounted lifetime utility such that an agent at age j solves

$$\max_{c_{i,j}, e^c_{i,j}, h_{i,j}} u(c_{i,j}, h_{i,j}) + \mathbb{E}\left\{\sum_{k=j+1}^{J-j-1} \beta^{k-j} \prod_{q=j}^{k-1} (\Psi_q) u(c_{i,k}, e^c_{i,k} - \bar{e}, h_{i,k})\right\}. \tag{3}$$

We take the expectation in equation (3) with respect to the stochastic processes governing the idiosyncratic productivity shocks. Agents incorporate mortality risk by discounting the next period's utility by the Ψ_j. In addition they discount future utility by β, the discount factor. Agent's utility increases with consumption of either energy or the generic consumption good and decreases with more hours worked. We do not account for the environmental impact from reductions in total energy use in the utility function, instead focusing on the non-environmental effects of the carbon tax policy.

2.3 Production

Perfectly competitive firms produce a generic final good, Y, from capital, K, labor (measured in efficiency units), N, and carbon-emitting energy, E^p. The final good is the numeraire and can be used for both consumption and investment. The production technology features a constant elasticity of substitution, ϕ, between a capital-labor composite, $K^\zeta N^{1-\zeta}$, and energy,

$$Y = A\left[\left(K^\zeta N^{1-\zeta}\right)^{\frac{\phi-1}{\phi}} + (E^p)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}. \tag{4}$$

The country behaves as a small open economy with respect to energy. Energy is imported at price p_e in exchange for the final good with zero trade balance in every period. The small open economy assumption abstracts from the potential general equilibrium effects of climate policy on energy prices. However, global energy supplies and prices are not within any single country's control. Moreover, most countries have very limited market power with respect to energy prices, suggesting that the general equilibrium effects from a unilateral climate policy are likely to be small.

2.4 Government Policy

The government performs three activities: (1) it spends resources in an unproductive sector, G, (2) it runs a pay-as-you-go social security system, and (3) it taxes capital income, labor income, and energy (i.e., a carbon tax) to finance G.

The government pays social security benefits, S, to all agents that are retired. The benefits are independent of each specific agent's lifetime earnings. Instead, retired agents receive an exogenous fraction, b, of the average income of all working individuals.[3] The government finances the social security system with a flat tax on labor income, τ_s. Half of the payroll taxes are withheld from labor income by the employer and the other half are paid directly by the employee. The payroll tax rate is set such that the social security system has a balanced budget in every period.

The government taxes capital income, y^k, according to a constant marginal tax rate, τ_k. An agent's capital income is the return on his assets plus the return on any assets he receives as accidental bequests, $y^k \equiv r(a + T_a)$. The government taxes labor income according to a potentially progressive tax schedule, $T^h(\tilde{y}^h)$, where $\tilde{y}^h$ denotes the agent's taxable labor income. An agent's taxable labor income is his labor income, y^h, net of his employer's contribution to social security which is not taxable under U.S. tax law. Thus, $\tilde{y}^h \equiv y^h(1 - 0.5\tau_s)$, where $0.5\tau_s y^h$ is the employer's social security contribution.

Finally, the government can tax carbon energy. This tax not only raises government

[3] Also independent of individuals' decisions, if the change to the tax policy causes a change in the total labor earnings, then the size of the social security payment will also change.

revenue, but it can also lead to lower carbon emissions. The carbon tax, τ_c, places a price on the externality, carbon. Thus, the government applies the tax per unit of energy consumed, raising the price of energy from p_e to $p_e + \tau_c$.[4] In one of the tax policies, the government rebates this carbon-tax revenue through lump-sum transfers to the households, T_c.

Recall, the objective of our analysis is to examine the non-environmental welfare impacts of revenue-neutral tax policy changes that include a carbon tax. The preceding model incorporates three essential features needed to quantify the resulting welfare impacts. First, we include idiosyncratic risk which causes agents to save for precautionary reasons. Second, we model social security and retirement, which causes agents to save for life cycle reasons. Matching the strength of the overall saving motives with the observed data is important for our quantitative results because the distortions from a capital, labor, and energy tax can operate through general equilibrium channels and can be sensitive to the relative strength of agents' motives to save and work.[5] Third, we include energy as in input in both consumption and production. Household energy consumption varies substantially across income groups. Thus, modeling energy consumption directly is necessary for the model to capture the distributional effects of the tax.

2.5 Definition of a Stationary Competitive Equilibrium

In this section we define a stationary competitive equilibrium. The individual state variables, x, are asset holdings, a, idiosyncratic labor productivity, μ, and age j.

Given a social security replacement rate, b, government expenditures, G, demographic parameters, $\{n, \Psi_j\}$, a sequence of age-specific human capital, $\{\epsilon_j\}_{j=20}^{j_r-1}$, a labor-tax function, $T^h : \mathbb{R}_+ \to \mathbb{R}_+$, a capital-tax rate, τ_k, a social security tax rate, τ_s, a carbon-tax rate, τ_c, transfers from the climate policy, T_c, an energy price, p_e, a utility function $U : \mathbb{R}_+ \times \mathbb{R}_+ \times \mathbb{R}_+ \to \mathbb{R}_+$, social security benefits, S, and factor prices, $\{w, r, p_e\}$, a stationary

[4] Given that fossil fuel combustion accounts for over 80 percent of GHG emissions, a carbon tax behaves much like a tax on energy. This of course abstracts from substitution between fossil fuel energy sources with varying carbon intensities that could occur with a carbon tax.

[5] or example, a household with stronger incentives to save is less responsive to a change in the return to saving, reducing the distortionary cost of changes in the capital tax.

competitive equilibrium consists of agents' decisions rules, $\{c, h, e^c, a'\}$, firms' production plans, $\{E^p, K, N\}$, transfers from accidental bequests T_a, and the distribution of individuals, $\Phi(x)$, such that the following holds:

1. Given prices, policies, transfers, benefits, and ν that follows equation (2) the agent maximizes equation (3) subject to:

$$c + (p_e + \tau_c)e^c + a' = \\ \mu h w(1-\tau_s) + (1 + r(1-\tau_k))(a+T) - T^h\big(\mu h w(1-.5\tau_s)\big) + T_c \text{ for } j < j_r \quad (5)$$

$$c + (p_e + \tau_c)e^c + a' = S + (1 + r(1-\tau_k))(a+T) + T_c \text{ for } j \geq j_r$$

$$c \geq 0,\ e^c \geq 0,\ 0 \leq h \leq 1,\ a \geq 0,\ a_{20} = 0$$

2. Firms' demands for E^p, K, and N satisfy:

$$r = \zeta A \left[\left(K^\zeta N^{1-\zeta}\right)^{\frac{\phi-1}{\phi}} + (E^p)^{\frac{\phi-1}{\phi}}\right]^{\frac{1}{\phi-1}} \left(K^\zeta N^{1-\zeta}\right)^{-\frac{1}{\phi}} \left(\frac{N}{K}\right)^{1-\zeta} - \delta \quad (6)$$

$$w = (1-\zeta) A \left[\left(K^\zeta N^{1-\zeta}\right)^{\frac{\phi-1}{\phi}} + (E^p)^{\frac{\phi-1}{\phi}}\right]^{\frac{1}{\phi-1}} \left(K^\zeta N^{1-\zeta}\right)^{-\frac{1}{\phi}} \left(\frac{K}{N}\right)^{\zeta} \quad (7)$$

$$p_e + \tau_c = A \left[\left(K^\zeta N^{1-\zeta}\right)^{\frac{\phi-1}{\phi}} + (E^p)^{\frac{\phi-1}{\phi}}\right]^{\frac{1}{\phi-1}} (E^p)^{-\frac{1}{\phi}} \quad (8)$$

3. The social security policy satisfies:

$$S = b\left(\frac{wN}{\sum_{j<j_r} \Phi(x)}\right) \quad (9)$$

$$\tau_s = \frac{S \sum_{j \geq j_r} \Phi(x)}{wN} \tag{10}$$

4. Transfers from accidental bequests satisfy:

$$T_a = \sum (1 - \Psi) a' \Phi(x) \tag{11}$$

5. The government budget balances:

$$G = \sum \left[\tau_k r(a + T_a) + T^h \big(\mu h w (1 - .5\tau_s) \big) + \tau_c e^c \right] \Phi(x) + \tau_c E^p - T_c \tag{12}$$

6. Markets clear:

$$K = \sum a \Phi(x), \quad N = \sum \mu h \Phi(x) \tag{13}$$

$$\sum (c + p_e e^c + a') \Phi(x) + G + p_e E^p = Y + (1 - \delta) K \tag{14}$$

7. The distribution of $\Phi(x)$ is stationary, that is, the law of motion for the distribution of individuals over the state space satisfies $\Phi(x) = Q_\Phi \Phi(x)$ where Q_Φ is the one-period recursive operator on the distribution.

3 Calibration and Functional Forms

We calibrate the model in two steps. In the first step, we choose parameter values for which there are direct estimates in the data. In the second step, we calibrate the remaining parameters so that certain targets in the model match the values observed in the U.S. economy. Table 1 reports the parameter values.

Table 1: Calibration Parameters (Baseline)

Parameter	Value	Target
Demographics		
Retire Age: j_r	66	By Assumption
Max Age: J	100	By Assumption
Surv. Prob: Ψ_j	Bell and Miller (2002)	Data
Pop. Growth: n	1.1%	Data
Firm Parameters		
Capital Share: ζ	0.36	Data
Substitution Elasticity: ϕ	0.5	Van der Werf (2008)
Depreciation: δ	8.33%	$\frac{I}{Y} = 25.5\%$
Productivity: A	1	Normalization
Energy price: p_e	0.0025	$\frac{P_e E}{Y} = 0.05$
Productivity Parameters		
Persistence Shock: σ_ν^2	0.017	Kaplan (2012)
Persistence: ρ	0.958	Kaplan (2012)
Permanent Shock: σ_ξ^2	0.065	Kaplan (2012)
Transitory Shock: σ_θ^2	0.081	Kaplan (2012)
Preference Parameters		
Conditional Discount: β	0.998	$\frac{K}{Y} = 2.7$
Risk Aversion: θ_1	2	Conesa et al. (2009)
Frisch Elasticity: θ_2	0.5	Kaplan (2012)
Disutility of Labor: χ	55.8	Avg. $h_{i,j} = 0.333$
Subsistence Energy: $\bar{e}$	5.6	$\Delta\Omega = -12.8$
Consumption Energy Share: $1 - \gamma$	0.069	Avg. $\Omega = 10.2\%$
Government Parameters		
Labor Tax Function: Υ_0	0.258	Gouveia and Strauss (1994)
Labor Tax Function: Υ_1	0.768	Gouveia and Strauss (1994)
Labor Tax Function: Υ_2	1.92	Clears market
Capital Tax Rate: τ_k	0.36	Trabandt and Uhlig (2011)
Government Spending: G	0.124	$\frac{G}{Y} = 0.155$
Replacement Rate: b	0.5	Conesa et al. (2009)

3.1 Demographics

Agents enter the model at an age of 20. Agents are exogenously forced to retire at age $j_r = 66$. If an individual survives until age 100, he dies the next period. We choose the conditional survival probabilities based on the estimates in Bell and Miller (2002). We adjust the size of each cohort's share of the population to account for a population growth rate of 1.1 percent.

3.2 Preferences

Agents have time-separable preferences over a consumption-energy composite, $\tilde{c}$, and hours, h. The utility function is given by

$$U(\tilde{c}, h) = \frac{\tilde{c}^{1-\theta_1}}{1-\theta_1} - \chi \frac{h^{1+\frac{1}{\theta_2}}}{1+\frac{1}{\theta_2}} \tag{15}$$

where $\tilde{c} = c^{\gamma}(e - \bar{e})^{1-\gamma}$. This functional form is separable and homothetic in the consumption-energy composite and labor, implying a constant Frisch elasticity of labor supply over the life cycle.

We determine β to match the US capital-output ratio of 2.7. We choose χ such that agents spend an average of one third of their time endowment working. Following Conesa et al. (2009), we set the coefficient of relative risk aversion (θ_1) equal to 2 and consistent with Kaplan (2012), we set the Frisch elasticity (θ_2) equal to 0.5.[6]

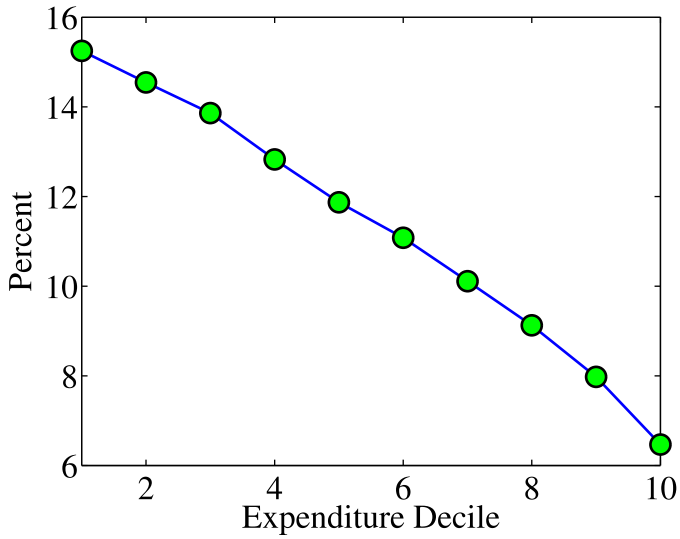
Recall, previous studies demonstrate that the carbon tax by itself will be regressive because lower income individuals devote a larger share of their total consumption expenditures to energy. Figure 1 plots the average energy budget share for each expenditure decile using data from the Consumer Expenditures Survey (CEX) from 1981-2003.[7] Consistent with

[6]Peterman (2016) demonstrates that setting the Frisch elasticity at 0.5 is consistent with including only fluctuations on the intensive margin.

[7]Energy expenditures include household expenditures on electricity, natural gas, gasoline, and coal and oil used in the home. To determine the average energy budget share for each decile, we first we first calculate the average energy budget share for each decile in each one year age bin. Weighting by the share of the population in each age bin, we then estimate the average energy budget share in each decile.

these previous findings, the average energy budget share falls considerably as average expenditures rise. At the extremes, energy expenditures are over 15 percent of total expenditures for the lowest decile but just over six percent for the highest decile.

Figure 1: Energy Budget Share: CEX



Together, parameters $\bar{e}$ and γ determine a household's energy share of total consumption, and how this share varies with the household's total consumption expenditures. In particular, the energy share of total consumption expenditures, Ω, is

$$\Omega = (1-\gamma) + \frac{\gamma p_e \bar{e}}{(1-\gamma)(c + p_e e^c)}. \tag{16}$$

If $\bar{e} = 0$, energy share equals $1-\gamma$ regardless of the level of an agent's total expenditures. However, if $\bar{e} > 0$, energy share will decrease with expenditures. Moreover, higher $\bar{e}$ increases the responsiveness of energy share to changes in total expenditures. We set $\bar{e}$ and γ such that our model matches the data with respect to the average energy share in the population and the percent difference in the energy share of the top and bottom halves of the expenditure distribution ($\Delta\Omega = \frac{\Omega_{top} - \Omega_{bottom}}{\Omega_{bottom}} \times 100$). The average energy share in the population is 10.2 percent. Moreover, we target $\Delta\Omega = -12.8$ percent.[8]

[8]In the CEX data, $\Delta\Omega = -33$ percent. However, the percent difference in expenditures between the top

Table 2 reports the value of the moments we target in the model and their corresponding value in the data.[9] Overall, the model fits these consumption data quite closely. For example, the first line of Table 2 reports that energy share in the data is 0.102 and energy share in the model is 0.100.

Table 2: Model Fit

Moment	Data	Model
Energy share: Ω	0.102	0.100
Energy share difference: $\Delta\Omega$	-0.128	-0.127
Hours: H	0.333	0.333
Govt spending to output: $\frac{G}{Y}$	0.155	0.155
Capital to output: $\frac{K}{Y}$	2.7	2.70

3.3 Idiosyncratic and Age-Specific Productivity

We calibrate the idiosyncratic labor productivity shocks based on the estimates from the PSID data in Kaplan (2012).[10] These parameters governing the permanent, persistent, and transitory idiosyncratic shocks to individuals' productivity are set such that the shocks are distributed log normally with a mean of one. We set the remaining shock parameters in accordance with the estimates in Kaplan (2012): $\rho = 0.958$, $\sigma_\xi^2 = 0.065$, $\sigma_\nu^2 = 0.017$ and $\sigma_\theta^2 = 0.081$.[11] We discretize all three of the shocks in order to solve the model, using two states to represent the transitory and permanent shocks and five states for the persistent shock. We set $\{\epsilon_j\}_{j=20}^{j_r-1}$ to match the average hourly earnings estimated in Kaplan (2012).

and bottom halves of the distribution is 142 percent in the CEX, but only 54 percent in our model. The variance in expenditures is smaller in our model than in the data because we assume that the idiosyncratic labor productivity shocks are log normal. This assumption, while standard in the literature, causes our model to miss the tails of the income distribution. Therefore, we adjust for the smaller expenditure variance in our model and target $\Delta\Omega = -12.8$ percent. In particular, we adjust $\Delta\Omega$ so that $\frac{54}{142} = \frac{-12.8}{-33}$.

[9] Note that in the data column, we report the percent difference in energy share ($\Delta\Omega$) adjusted for the smaller expenditure variance, since this is the value we target.

[10] For details on estimation of this process, see Appendix E in Kaplan (2012).

[11] These are the parameter values on the log of the productivity processes.

3.4 Production

We use 0.5 for the elasticity of substitution between the capital-labor composite and energy, ϕ. This parameter choice is within the range of estimates reported in Van der Werf (2008). We use $\zeta = 0.36$ for capital's share in the capital-labor composite. We calibrate the price of energy, p_e, so that energy's share of production is five percent.

3.5 Government Policies and Tax Functions

We begin our policy experiments in a baseline equilibrium that mimics the U.S. tax code. We follow the quantitative public finance literature (e.g., Castaneda et al. (2003), Conesa and Krueger (2006), Conesa et al. (2009), Peterman (2013)) and use estimates of the U.S. tax code from Gouveia and Strauss (1994). Gouveia and Strauss (1994) match the U.S. income tax code to the data using a three parameter functional form,

$$T^h(y_h; \Upsilon_0, \Upsilon_1, \Upsilon_2) = \Upsilon_0 \left(y_h - \left(y_h^{-\Upsilon_1} + \Upsilon_2 \right)^{\frac{-1}{\Upsilon_1}} \right) \tag{17}$$

Parameter Υ_0 governs the average tax rate and parameter Υ_1 controls the progressivity of the tax policy. To ensure that taxes satisfy the budget constraint, we leave parameter Υ_2 free in the baseline. Gouveia and Strauss (1994) estimate that $\Upsilon_0 = 0.258$ and $\Upsilon_1 = 0.768$.

We determine government spending, G so that it equals 15.5 percent of output, its average empirical value in the U.S data.[12] We set the tax rate on capital income, τ_k, to 36 percent based on estimates in Kaplan (2012), Nakajima (2010) and Trabandt and Uhlig (2011). Following Conesa et al. (2009), the replacement rate for the social security system, b, is 50 percent. We choose the payroll tax, τ_s, to ensure that the social security system has a balanced budget in every period.

Finally, in the computational experiment, we analyze a carbon tax set at \$35 dollars per ton of CO_2. This value is in line with the central estimate of the social cost of carbon

[12]To calculate the empirical value of $\frac{G}{Y}$, we use total government expenditures net of social security payments because social security is financed by a separate payroll tax in our model. Additionally, since we assume a small open economy with respect to energy, the model value of GDP (the denominator of $\frac{G}{Y}$) equals the value of total production minus the value of energy imports.

used in cost-benefit analyses performed by the U.S. Government.[13] To calibrate the size of the tax in the model, we calculate the empirical value of the tax as a fraction of price of a fossil energy composite of coal, oil, and natural gas in 2011. We calculate the price of this energy composite averaging of the price of each type of energy in 2011, and weighting by the relative consumption. Similarly, we calculate the carbon emitted from the energy composite by averaging over the carbon intensity of each type of energy in 2011, and weighting by the relative consumption. This process implies that a $35 per ton carbon tax equals 32 percent of our composite fossil energy price.

4 Results

4.1 Computational Experiment

To examine the welfare consequences of a carbon tax, we simulate a baseline economy with no carbon tax and conduct a series of counterfactual simulations in which we impose a constant carbon tax set at $35 per ton of CO_2. We simulate three different carbon tax policies which vary in how the revenue generated from the carbon tax is used: (1) the revenue is rebated through equal, lump-sum transfers to the household, (2) the revenue is rebated through a reduction in the capital-tax rate, and (3) the revenue is rebated through a reduction in the labor-tax rate. In order to isolate the effect of the carbon tax by itself, we also analyze the case in which the government does not rebate the carbon tax revenue and instead it is used in a non-productive sector (i.e. "throws it into the ocean"). We refer to this case as the no-rebate policy.

Under the different carbon tax policies, the size of the economy changes. Thus in addition to rebating the revenue from the carbon tax, in order to ensure that the government's budget constraint clears we need to alter either the capital or labor tax. This is because the carbon tax leads to changes in aggregate labor and capital supplies, which affect aggregate tax-revenue from the non-energy tax sources. In these cases, we choose to clear the budget

[13]In particular, the IAWG (2013) reports a central carbon cost estimate of $38/ton of CO_2 in 2015 dollars.

constraint – after rebating the revenue from the carbon tax – by changing the labor tax. In particular, we choose to alter the labor tax policy by changing the average tax rate but holding the general progressivity of the labor tax policy consistent with the policy in the baseline model.[14] Tables 3 and 4 report the tax parameters and the revenue raised from each of the tax instruments in the baseline and in each of the four simulations. Note that in the no-rebate simulation, total tax revenue exceeds the level of government spending, G. Since the government throws the carbon-tax revenue into the ocean, it does not contribute to financing G in this case.

Table 3: Tax Parameters

		Carbon Tax			
	Baseline	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Labor tax: Υ_0	0.26	0.25	0.27	0.26	0.19
Labor tax: Υ_1	0.77	0.77	0.77	0.77	0.77
Labor tax: Υ_2	1.92	1.92	1.92	1.92	1.92
Capital tax: τ_k	0.36	0.36	0.36	0.13	0.36
Carbon tax: $\frac{\tau_c}{p_e}$	0.00	0.33	0.33	0.33	0.33

Table 4: Percent of Government Revenue

		Carbon Tax			
	Baseline	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Labor Tax	68.26	68.42	69.25	69.91	49.80
Capital Tax	31.79	31.59	30.76	9.91	30.26
Carbon Tax	0.00	19.81	19.45	20.18	19.96
Lump-Sum Rebate	-	-	-19.45	-	-

We compare the welfare consequences of the policies for agents born in the new long-run steady state and for agents who are alive when the policy is introduced. Agents born in the new steady state live their whole lives in the steady state. In contrast, agents who are alive

[14] In particular, to clear the government budget constraint, after rebating the revenue from the carbon tax, we alter Υ_0 and hold τ_k, Υ_1 and Υ_2 fixed. This approach minimizes changes in the progressivity of the labor-tax function.

when the policy is introduced experience the transition to the new steady state for at least part of their life cycle. We refer to these agents as the living population.[15]

The appendix reports the effects of the policies on the aggregate variables and their life cycle profiles in both the steady state and during the transition. In the text, we focus on understanding the welfare consequences of the different policy options. Consistent with much of the double-dividend literature, we specifically examine the non-environmental welfare consequences of the carbon tax policies. The reduction in energy use, and as a result, the reduction in emissions, is similar across all simulations – ranging from -14.6 to -16.3 percent (see Table 9). Given that the energy reductions are quite stable across the policies considered, the welfare changes caused by improvements in environmental quality are likely to be similar across the different rebate options as well – particularly in the short-run when the changes to environmental quality resulting from a change in the stock of CO_2 may be quite small.

4.2 Aggregate Welfare Effects

We calculate the average welfare consequences of the different policy options. To measure the welfare impacts in steady state, we calculate the consumption equivalent variation (CEV) of the tax in each of the four counterfactual economies.[16] The CEV measures the uniform percentage change in an agent's consumption that is required to make the agent indifferent, prior to observing their ability and the idiosyncratic productivity and mortality shocks, between the old baseline steady state and the steady state under the new carbon tax policy.

When focusing on the welfare effects for the living agents, we calculate the CEV in terms of the cohort's expected future consumption over the portion of their lifecycle following the governments introduction of the policy. For example, to calculate the welfare effects of the policy for a cohort who is 25 when the tax is introduced, we compute the uniform percent change in consumption across all agents in the cohort that would be necessary in every remaining period of their lifetime, so that the cohort's average expected utility is the same

[15]The welfare implications for agents who are born during the transition are reported in the Appendix.

[16]We define the CEV as the expected percent increase in consumption an agent would need in every period of his life in the baseline to make him indifferent between the baseline and the policy.

as if they were to live the rest of their life in the pre-tax change, baseline steady state. The aggregate CEV over the transition is the weighted average of the CEVs for the different age cohorts, where the weights are determined by the relative population shares.

4.2.1 Steady State

The aggregate steady state CEVs, reported in the first row of Table 5, support the predictions from the weak double dividend hypothesis. The welfare costs of the policy are minimized when the carbon tax revenue is used to reduce the capital or labor tax. The aggregate CEVs under the capital and labor-tax rebates are 0.43 percent and 0.14 percent, respectively. In contrast, the aggregate CEV is -0.25 percent under the lump-sum rebate. Unlike the capital and labor tax rebates, the lump-sum rebates do not reduce the pre-existing distortions in the tax system.

The positive CEVs under the capital and labor-tax rebates suggest that the carbon tax leads to a slight improvement in welfare. Thus, we find evidence of a strong double dividend in which the carbon tax policy reduces the overall welfare cost of the tax system in addition to improving environmental quality. The strong double dividend arises because the carbon tax is less distortionary than either the capital or the labor taxes in our framework.

Table 5: Aggregate Welfare Effects (CEV, percent)

	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Steady State	-5.89	-0.32	0.43	0.14
Transition	-4.71	-0.39	-0.19	-1.98

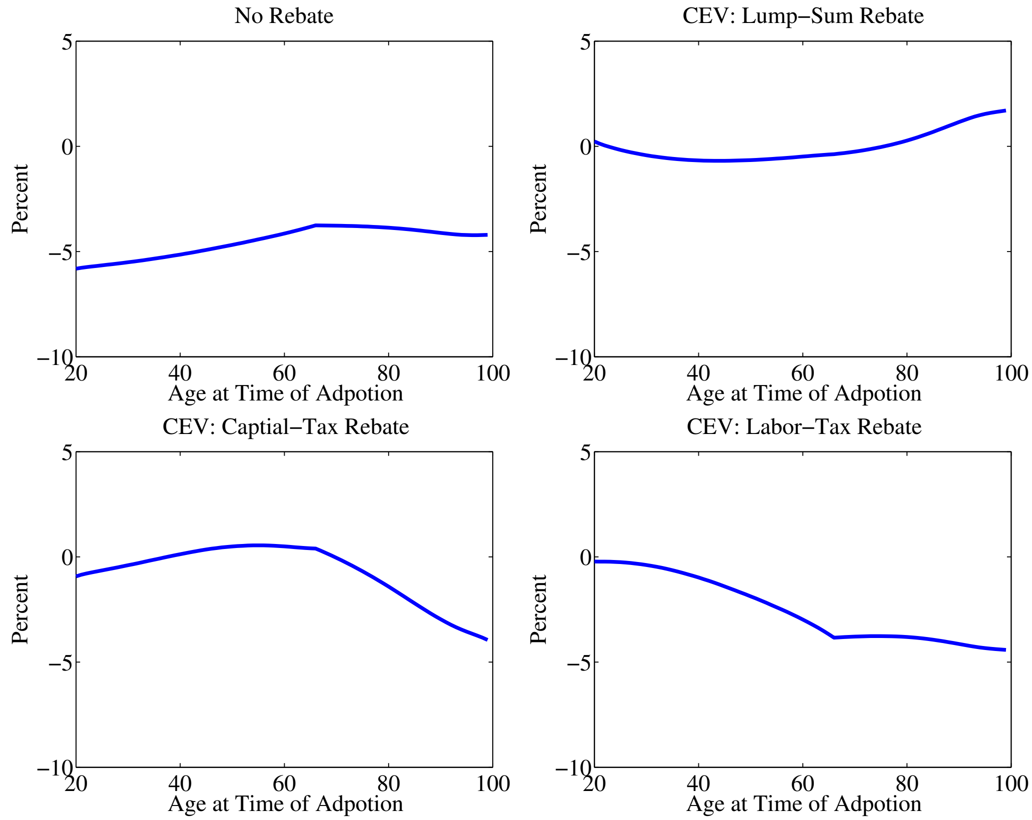
4.2.2 Transition

The second row of Table 5 reports the aggregate welfare effects of the carbon tax policies on the agents alive at the time the policies are implemented. Comparing the first and second rows of Table 5, we see that all of the policies are more costly for agents in the current living population as opposed to agents living in the new steady state. However, the increase in the short-run welfare costs is most pronounced under the carbon tax policies that include a capital-tax rebate or a labor-tax rebate.

The results reported in Table 5 also reveal that, in the short-run, the weak-double dividend does not hold. Specifically, among the agents alive at the time a carbon tax policy is introduced, rebating the carbon revenue in the form of lump-sum payments is no longer the most costly option. Instead, the welfare costs of providing labor-tax rebates turns out to be larger in the short-run.

To understand why the weak double dividend breaks down over the transition, and more generally, why the policies are more costly in the transition, it is useful to examine the average welfare effects for each age cohort. Figure 2 plots the average welfare effects agents alive at the time the carbon tax is implemented. The plots display the average welfare effects conditional on the agents age at the time the policy begins. These plots demonstrate that, depending on the carbon tax policy, the welfare effects can vary substantially across cohorts depending on the cohort's age when the tax is introduced.

Figure 2: CEV: Agents Alive At Time of Shock



If the welfare costs of the policy increase with age – i.e. the line in Figure 2 is downward sloping – then the welfare costs will generally be higher over the transition than in the steady state.[17] Over the transition, if the costs of the tax policy are relatively higher for agents when they are older and relatively lower for agents when they are younger, then the average welfare costs among the agents alive when the policy begins will be larger. The larger welfare costs among the living stems from the fact that agents who are old when the policy is adopted already lived beyond the ages when the tax policy is relatively less costly. In contrast, in the steady state, all agents experience the policy for their whole lifetime. Thus, higher welfare costs later in life and lower welfare costs earlier in life will have offsetting effects on average total lifetime utility.

From Figure 2, it is clear that the labor and capital-tax rebate policies impose relatively

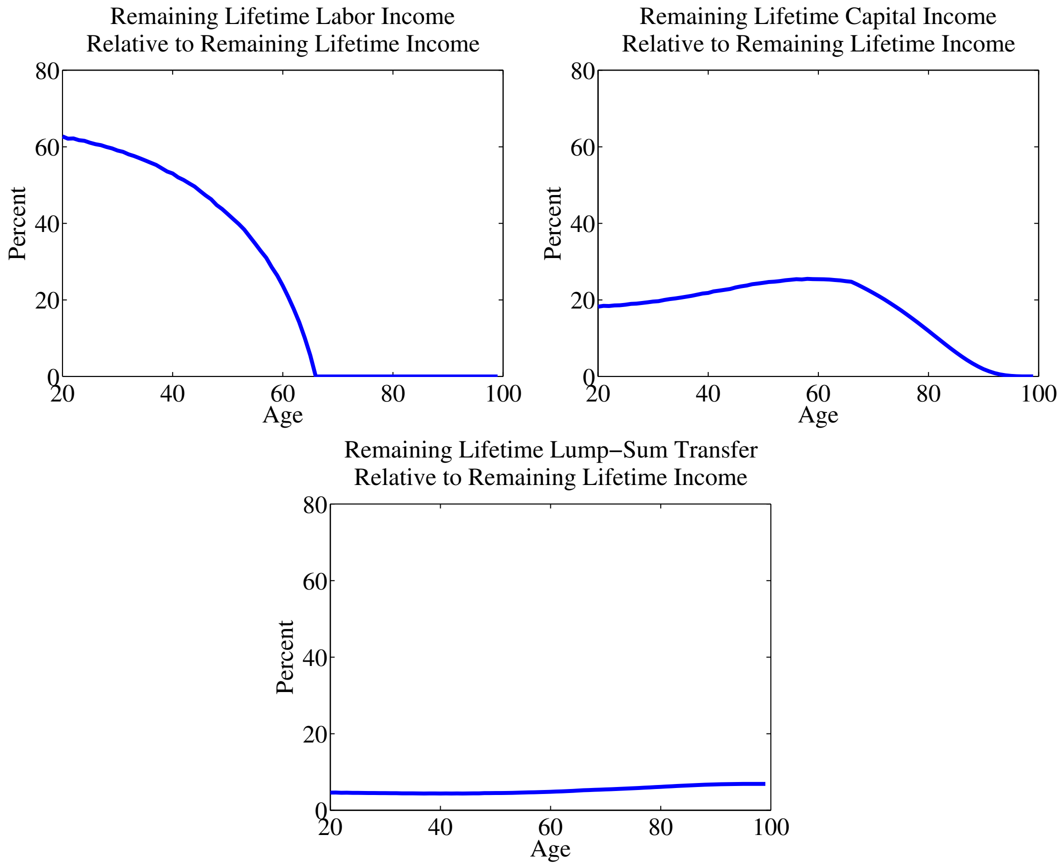
[17]In addition, as we find, the welfare effects for the cohort that is 20 years old when the policy is introduced needs to be similar or worse than the welfare effects in the steady state.

higher welfare costs on the older cohorts. In particular, the CEV by age is downward sloping for all ages under the labor tax rebate (bottom right panel of Figure 2 and downward sloping for all agents over age 66 in under the capital tax rebate (bottom left panel of Figure 2). Thus, theses two tax policies are more costly (or less beneficial) over the transition than in steady state. In contrast, under the lump-sum rebate policy, the CEV by age is relatively flat for all ages (top right panel of Figure 2). This is consistent with the previous results presented in Table 5 demonstrating that the welfare costs of the lump-sum rebate policy are very similar in the steady state and among the current living population.

The relatively flatter cohort-welfare profile for the lump-sum rebate compared to the labor rebate (see top right and bottom right profiles in Figure 2) is why the weak double dividend breaks down over the transition. The effects of the steep downward sloping CEV under the labor-tax rebate dominate the efficiency gains relative to the lump-sum rebate, making it the most costly of the revenue-neutral policy options over the transition.

With the three tax policies that rebate the carbon tax revenue, the variation in the welfare effects across age cohorts, which is again displayed in Figure 2, is primarily determined by the size of the rebate relative to the household's remaining lifetime income. For example, the relative impact of the capital tax rebate policy on a specific age cohort's average welfare depends on the share of remaining lifetime income the households in that age cohort receive from capital income. The top two panels of Figure 3 plot remaining lifetime labor and capital income relative to the total remaining lifetime income for each age cohort. The bottom panel plots remaining lifetime lump-sum transfer payments relative to remaining lifetime income for each age cohort.

Figure 3: Remaining Labor and Capital Income Relative to Remaining Income



Focusing first on the lump-sum rebate, the retirees receive the largest benefits from the lump-sum rebate because lump-sum transfers comprise the biggest fraction of remaining lifetime income for this age group.[18] This occurs because the retirees are depleting their savings and, thus, have low expected lifetime incomes relative to their younger counterparts. Similarly, the young agents receive the largest welfare benefits out of all the age cohorts from the labor tax rebate because expected future labor income comprises the biggest fraction of total remaining lifetime income for this age group (top left panel of Figure 3). Finally, middle-aged agents receive the largest welfare benefits from the capital tax rebate because

[18]Note that the very young also experience welfare benefits from the lump-sum rebate. As shown in Figure 3, the percent of the remaining lifetime income that comes from the lump sum transfers is downward sloping over ages for 20-40 year olds because of the relatively low income from both labor and capital at the beginning of the lifetime. Thus, the welfare benefits from the transfer fall between ages 20 and 40.

expected future capital income comprises the biggest fraction of total remaining lifetime income for the this age-group (top right panel of Figure 3).

Under the no-rebate case, the welfare costs of the policy decrease with the age of agents at the time of the implementation until agents are retired, after which they increase with age slightly. This pattern is driven by the fact that consumption rises throughout working life, causing energy's share of consumption to fall, and, thus reducing the welfare costs of the policy. After retirement, consumption decreases with age, causing energy's share of consumption to rise, and thus, increasing the welfare costs of the policy.

4.3 Distribution of Welfare Effects

While the policies may increase or decrease welfare in the aggregate, the effects are not uniform across the different subsets of the population. Some households benefit from a given policy while others are worse off. The first row of Table 6 reports the probability that the specific carbon tax policy increases an agent's lifetime welfare relative to the baseline. While both the capital and labor-tax rebates increase aggregate welfare in the steady state, these welfare gains are only experienced by 86 percent and 64 percent of the population, respectively. Likewise, even though the lump-sum rebate reduces aggregate welfare in the steady state, 32 percent of the population actually experiences welfare gains.

Table 6: Probability of a Welfare Gain (percent)

	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Steady State	0.00	31.90	86.03	63.57
Transition	0.00	27.98	49.47	13.81

Much of the heterogeneity in the welfare effects stems from differences in how the policies impact individuals across the income distribution. To analyze the distributional impacts, we calculate the CEV conditional on agents being in a specific income quintile. We determine the income quintiles from agents' realized lifetime expenditures in the baseline case, prior to imposing a carbon tax.

We categorize the policy as regressive if it has higher welfare costs (or smaller welfare benefits) for the lower income quintiles than for the higher income quintiles, and progressive otherwise. To quantify the progressivity or regressivity of a policy, we calculate the percent change in the Gini coefficient for lifetime welfare between the baseline and each policy simulation. We define the Gini coefficient, $\mathcal{G}$, as

$$\mathcal{G} = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} |x_i - x_j|}{2N^2 \bar{x}},$$

where x_i represents lifetime welfare of agent i, $\bar{x}$ is the mean of lifetime welfare, and N is the total number of agents in the economy. The Gini coefficient ranges between zero and one with zero implying perfect equality and one implying perfect inequality. Thus a positive percent change in the Gini coefficient implies that the policy increases inequality, and, hence is regressive, while a negative percent change implies that the policy decreases inequality and, hence, is progressive.[19]

4.3.1 Steady State

Table 7 shows the CEV by income quintile for each tax policy. The distributional consequences of the carbon tax differ substantially across the policies. If the carbon tax revenues are recycled through lump-sum payments, low income households are the relative winners. Alternatively, if the revenues are used to reduce one of the pre-existing distortionary taxes, the higher income households are the relative winners.

Referring to Table 7, the no rebate case demonstrates that the carbon-tax policy by itself is considerably more costly for lower income households, resulting in an increase in the Gini Coefficient of 0.96 percent.[20] In large part, the carbon tax by itself is regressive because

[19]Over the transition, the population value of the Gini coefficient is a weighted average of the Gini coefficient for each cohort where the weights are determined by the relative population shares. We calculate the Gini coefficient for a given age cohort from each household's remaining lifetime welfare. For example, for households who are 25 when the government introduces the policy, we calculate the Gini coefficient in the baseline and the transition from expected remaining lifetime welfare starting at age 25.

[20]The value of the Gini coefficient in the baseline is 0.13.This is much lower than the Gini coefficient for income in the US data, implying that we have less inequality in our model then the data. As numerous studies have noted (e.g., Guvenen et al. (2015)) a substantial portion of the income inequality in the US

lower income households devote larger fractions of their budgets to energy consumption. Therefore, a larger portion of lower income households' income is absorbed by the carbon tax, making them substantially worse off.

Table 7: Steady State Welfare Effects: Distribution

	No Rebate	Lump-sum Rebate	Capital Tax Rebate	Labor Tax Rebate
CEV By Quintile (percent)				
Quintile 1	-6.12	1.26	0.19	-0.76
Quintile 2	-5.93	0.07	0.35	-0.12
Quintile 3	-5.81	-0.69	0.52	0.29
Quintile 4	-5.73	-1.40	0.64	0.75
Quintile 5	-5.71	-2.14	0.66	1.37
% $\Delta\mathcal{G}$ From Baseline Value of 0.13				
	0.96	-4.19	0.82	2.30

The way in which carbon tax revenues are rebated to households can either exacerbate or mitigate the regressivity of the carbon tax policy. Under the lump-sum rebate, the policy is progressive, causing the Gini coefficient to fall by 4.26 percent. Since the rebate is the same size for all agents, agents with lower lifetime incomes receive a larger percentage increase in their post-rebate income. Figure 4 plots lifetime lump-sum transfer payments relative to lifetime income for the five income quintiles. For the first income quintile, the transfers are approximately six percent of lifetime income. For the fifth income quintile, they are only three percent. Thus, by rebating the revenue through equal, lump-sum transfers, the government is able to fully reverse the inherent regressiveness of the carbon tax, making the revenue-neutral carbon tax policy progressive.

Under the capital-tax rebate, the overall policy is regressive, causing the Gini coefficient to rise by 0.82 percent. However, the magnitude of this regressivity is slightly smaller than in the no-rebate case, suggesting that the capital-tax rebate actually offsets a small amount of the regressivity inherent in the carbon tax itself. The small distributional consequences

comes from the top one percent, which the log-normal distribution for labor-productivity does not capture.

from the capital-tax rebate result from two opposing mechanisms. First, agents who have a larger percentage of capital income (relative to total income) receive a larger rebate in percentage terms. The left panel of Figure 5 plots capital income as a fraction of total income in each of the quintiles. Higher income quintiles have relatively more capital income and, thus, receive a larger rebate than the lower income quintiles, suggesting the rebate would be regressive. However, the capital-tax rebate leads to an increase in the size of the economy which has a positive wealth effect across all of the income quintiles. The concavity of the utility function implies that the welfare gains from this wealth effect are larger for the lower income quintiles, suggesting that the rebate should be progressive. This second mechanism dominates and causes the carbon tax, coupled with a capital tax rebate, to ultimately be less regressive than in the no-rebate simulation.

Figure 4: Lifetime Lump-Sum Transfers Relative to Lifetime Income

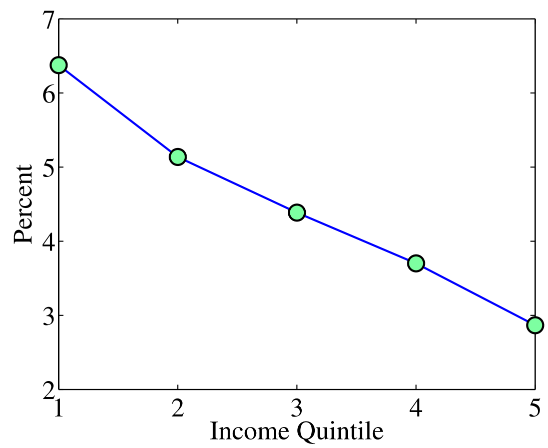
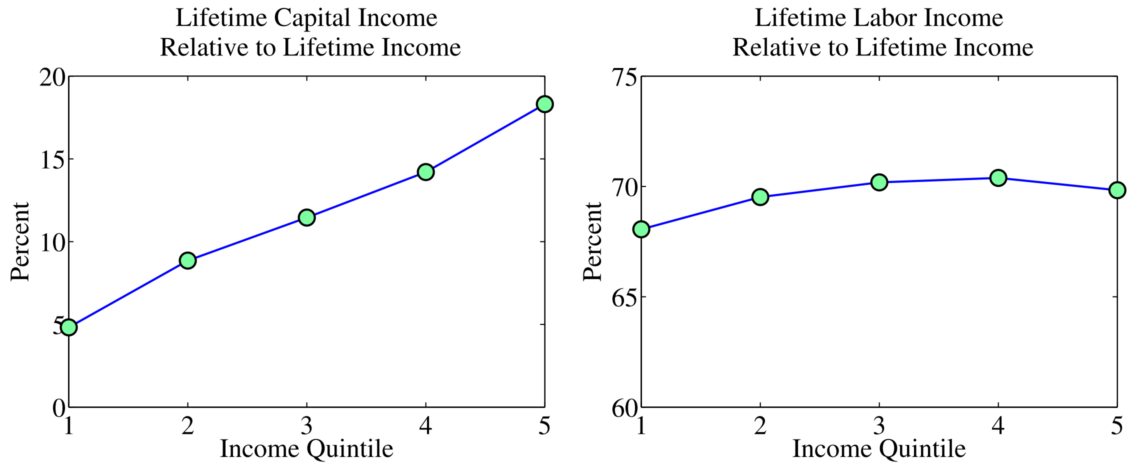


Figure 5: Capital and Labor Income as a Fraction of Total Lifetime Income



The regressive effects under the labor-tax rebate are close to three times as large as those under the capital-tax rebate; the Gini coefficient increases by 2.3 percent under the labor-tax rebate and only by 0.82 percent under the capital-tax rebate. Unlike the capital-tax rebate case, however, the fraction of total income that comes from labor is relatively constant across the income quintiles, suggesting that this is not the primary cause of the regressive effects from the labor-tax rebate (see right panel of Figure 5). Instead, reducing the labor-tax rate increases the variance in after-tax labor income. This increase in the variance improves welfare for the high income quintiles who mostly experience positive shocks, but reduces welfare for the low income quintiles who mostly experience negative shocks. The larger regressive effects under the labor-tax rebate suggest that the relative welfare gains to the higher income agents from the higher variance in labor income dominate the gains from a lower capital tax rate.

4.3.2 Transition

We now focus on the distributional impacts of the policy among the agents alive at the time the carbon tax policy is implemented. The top panel of Table 8 reports the CEV by income quintile for each tax policy. The bottom row reports the percent change in the Gini coefficient compared to the baseline value in which no carbon tax is adopted.[21] As in the steady state, during the transition, the lump-sum policy is progressive and the other capital and labor-tax rebate policies are regressive. However, when we compare the degree of the regressivity as measured by the percent changes in the Gini coefficients (bottom row of Table 7 compared to the bottom row of Table 8) we see that all of the policies are more regressive (or less progressive in the case of the lump sum rebate) over the transition than in the steady state.

Table 8: Transition: Welfare Effects For the Living Population: Distribution

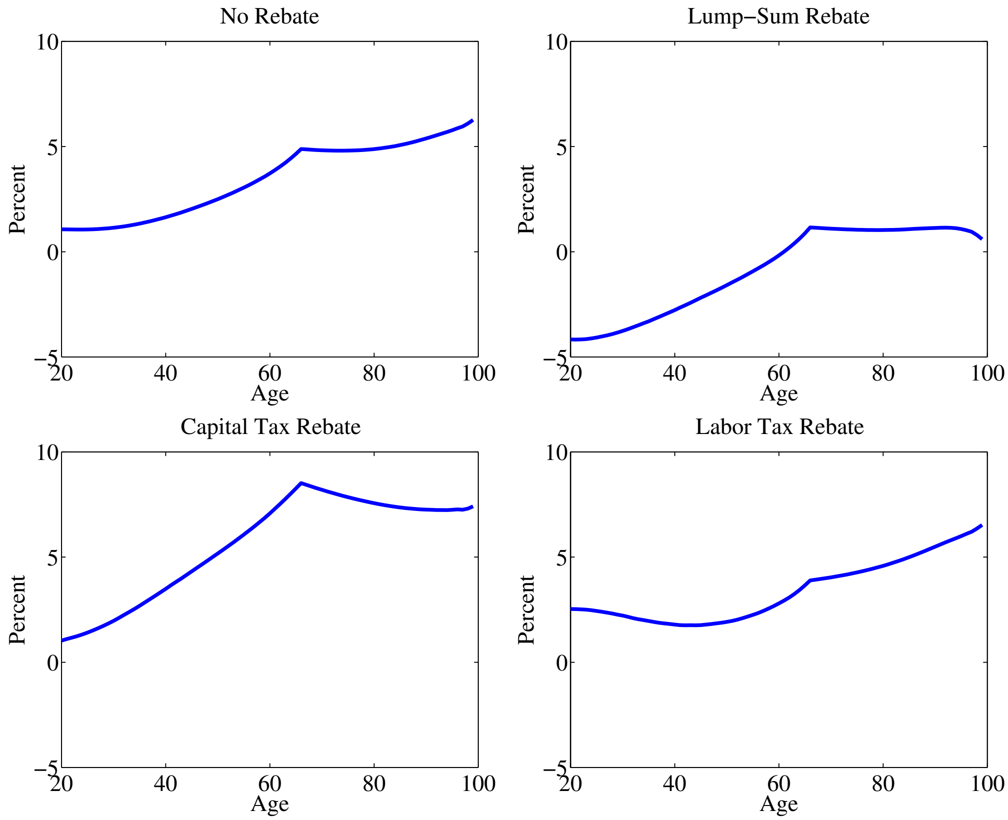
	No Rebate	Lump-sum Rebate	Capital Tax Rebate	Labor Tax Rebate
CEV (percent)				
Quintile 1	-5.04	0.93	-1.34	-2.38
Quintile 2	-4.78	-0.13	-0.49	-2.05
Quintile 3	-4.62	-0.72	0.09	-1.88
Quintile 4	-4.47	-1.30	0.68	-1.71
Quintile 5	-4.29	-1.98	1.42	-1.50
% $\Delta\mathcal{G}$ From Baseline Value of 0.15				
	2.77	-1.44	4.99	2.71

To understand why the distributional impacts tend to be more regressive (or less progressive) in the transition relative to the steady state, Figure 6 plots the percent change in the Gini coefficient for the different age groups.[22] If the percent change in the Gini increases with age – i.e. the line in Figure 6 is upward sloping – then the specific policy will generally be more regressive (or less progressive) over the transition than in steady state. The policy will be more regressive over the transition because the older cohorts alive when the policy begins will not experience the relative less regressive distributional affects during the earlier years of an agent's life cycle.

[21]Note that the baseline value of the Gini coefficient over the transition varies slightly from the steady state baseline value (0.13 compared to 0.15) because it is a weighed average of the Gini coefficient for the remainder of the living population's life cycles in the baseline. In contrast, we calculate the steady state baseline value of the Gini coefficient from the expected lifetime welfare of each individual, beginning at birth.

[22]For reference, Figure 11 in the Appendix plots the level Gini coefficient for each age cohort in the baseline.

Figure 6: Percent Change in the Gini Coefficient Between Baseline and Transition



Focusing first on the upper-left panel of Figure 6, the percent change in the Gini coefficient across the age cohorts is upward sloping. The carbon tax by itself causes greater increases in inequality among the older cohorts. The inequality consequences increase throughout working life because the variance in savings, and hence, agents' ability to respond to the tax, increases throughout the working lifetime. Among older retired agents, the inequality consequences continue to grow with the cohort's age because the lower bound on energy consumption starts to bind for the lower income agents as they deplete their savings. With energy consumption approaching $\bar{e}$, the lower income agents are less able to substitute consumption for energy, causing them to incur higher welfare costs than their wealthier counterparts.

Moving to the tax policies in which the carbon tax revenue is recycled, although the rebates have an effect on how regressive (or progressive) the policy is by age all the graphs in Figure 6 are still upward sloping over a majority of the lifetime. Hence regardless of how the carbon tax revenue is rebated the tax policy will be relatively more regressive (or less progressive) over the transition compared to in the steady state.

Under the lump-sum rebate policy, the percentage change in the Gini coefficient in the short-run relative to the long-run steady state does not increase as sharply with age indicating that some of the effect on inequality of the carbon tax by itself is offset by the rebate mechanism. The lump-sum rebate insures agents against negative income shocks, since agents receive the same transfer regardless of the shock. Lower-income retired agents value this insurance more due to the fact that their energy consumption is closer to $\bar{e}$ and they are less able to respond to a negative income shock. This effect is particularly strong for older retired agents for whom the lump sum rebate makes up a larger share of their total income.

Under the capital-tax rebate, the increase in inequality over the working lifetime is steeper than in the no-rebate case. However, for the retirees, the inequality effects of the tax actually decrease with the age cohort. These effects are driven by changes in the variance (across income groups) in the size of the rebate over the lifecycle. In particular, the variance in capital income grows with capital income throughout working life, implying that the variance in the rebate size also grows throughout working life, increasing the inequality consequences of the policy. However, once agents retire, the variance in capital income decreases with age as capital income decreases, causing the inequality consequences of the policy to fall with age for the retirees.

Finally, under the labor-tax rebate, the increase in inequality over the working lifetime is flatter than in the no-rebate case. The labor-tax rebate increases the variance in labor income. Younger working agents see a larger increase in variance over their lifetimes than older working agents because they experience the policy for more years. Thus, the inequality consequences from the labor tax rebate (not the carbon tax) decrease with age because the variance in labor income falls with age. This decrease offsets the increase in inequality from the tax, resulting in flatter inequality effects over the working life.

5 Conclusion

Imposing a carbon tax could potentially affect welfare not only through environmental channels (e.g., improving air quality), but also through non-environmental channels by causing large, general equilibrium impacts throughout the economy. Previous work in the environmental and public economics literatures highlight that the way in which the revenue from a carbon tax is used can dramatically alter the resulting non-environmental welfare costs. In particular, previous studies demonstrate that, in the long-run, it is far more efficient to use carbon tax revenues to reduce pre-existing distortionary taxes as opposed to returning the revenue to households in the form of lump-sum payments. While the existing research illustrates the impact revenue-neutral carbon tax policies can have on agents born in the future long-run steady state, there is little understanding of how agents living during the transition to the new steady state will be affected.

In this paper, we examine the welfare and distributional impacts various revenue-neutral carbon tax policies would have not only in the long-run steady state, but also during the transition to the new steady state. To do so, we construct a quantitative, overlapping generations model which incorporates within age cohort income heterogeneity. Using the model, we explore the welfare consequences of imposing a $35 per ton tax on CO_2. The revenue from this tax is used to either (1) offset revenue generated by a tax on labor income, (2) offset revenue from a tax on capital income, or (3) is returned in the form of lump-sum payments. By studying the impacts of carbon tax policies in a life cycle model which includes within cohort heterogeneity, we are able to examine how the welfare effects differ not only with age, but also with income.

Our results reveal that the welfare effects of revenue-neutral carbon tax policies can differ substantially for agents who are alive when the policy is enacted compared to those who are born into the new, long-run steady state. Consistent with previous studies, we demonstrate that, for those born in the new steady state, the expected non-environmental welfare costs are minimized when the carbon tax revenue is used to reduce a pre-existing distortionary tax as opposed to being returned in the form of lump-sum payments – a result often referred to as the 'weak double dividend hypothesis'. However, we find that, during the transition, the welfare costs incurred by recycling carbon tax revenues to reduce labor or capital taxes are substantially larger. In fact, our results suggest that, during the transition, the non-environmental welfare costs are not necessarily larger when the carbon revenues are recycled as lump-sum payments - i.e. the weak double dividend hypothesis breaks down. In addition, our results reveal that revenue-neutral carbon tax policies are much more regressive during the transition than in the steady state, regardless of the revenue recycling method.

The results presented in this paper demonstrate that estimates of the non-environmental welfare costs of carbon tax policies that are based solely on the long-run, steady state outcomes may paint too rosy of a picture. As we transition to a new steady state, a revenue-neutral carbon tax policy has the potential to impose sizable costs that fall disproportionately on specific segments of the current population – in many cases, the old and the low income. This suggests that, when designing climate policies, policymakers must pay careful attention to not only the long-run outcomes, but also the transitional welfare costs and regressivity of the policy.

Appendix: Additional Results

Steady state

We compare the baseline and counterfactual economies in the steady state. Column 2 of Table 9 reports the baseline values of the aggregate variables and columns 3-6 report the percent change in the aggregate variables from their baseline values in each of the three simulations.[23]

Regardless of the how the government uses the revenue, the carbon tax alters both the firms' and the households' decisions. On the firm side, the carbon tax reduces the firm energy use, which lowers the marginal products of both capital and labor. On the household side, the carbon tax raises the relative price of the consumption-energy composite, $\tilde{c}$. This price change

[23] We define the average net (after-tax) wage as $(1-\tau_l)w$ where τ_l is the average labor-tax rate.

increases the cost of retirement, which raises agents' incentivizes to save. Additionally, the price change distorts the household's intratemporal allocation between $\tilde{c}$ and leisure, generating both income and substitution effects. The income effect causes households to increase their hours, because the higher cost of $\tilde{c}$ makes them relatively poorer. However, the substitution effect causes households to reduce their hours and substitute leisure for consumption, since the cost of $\tilde{c}$ relative to leisure is higher.

The general equilibrium interactions among these different distortions lead to changes in factor prices. For example, all else constant, the decline in the marginal product of capital reduces the risk-free rate. Like the carbon tax, these factor price changes impact household decisions through both income and substitution effects. What the government does with the tax revenue determines which channels dominate and the corresponding implications for the steady-state aggregates.

Table 9: Steady State Aggregates

		Percent Change From Baseline: Carbon Tax			
	Baseline	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Macro Aggregates					
Output: Y	0.81	0.12	-2.70	2.76	0.59
Efficiency Hours: N	0.52	1.91	-0.95	-0.12	0.75
Capital: K	2.09	-0.80	-3.62	10.51	2.57
Consumption: C	0.41	-2.16	-0.17	3.14	2.86
Energy					
Prod. Energy: E^p	16.30	-13.08	-15.53	-10.78	-12.66
Con. Energy: $E^c - \bar{E}$	12.30	-23.25	-24.71	-22.22	-22.43
Tot. Energy: $E^p + E^c$	34.20	-14.60	-16.29	-13.13	-14.10
Prices and Transfers					
Avg. Net Wage: $(1-\tau_l)w$	0.76	-2.85	-3.85	1.95	5.96
Net Risk-Free Rate: $(1-\tau_k)r$	0.03	0.32	0.39	8.08	-7.22
Transfers: $T_a + T_p$	0.03	-0.51	79.43	12.09	3.51

Figure 7 shows the percent change in the life-cycle profiles induced by the policies.[24] For example, the dashed red line in the top left panel plots the average percent difference in total

[24]For reference, Figure 8 plots the lifecycle profiles in levels in the baseline and under each of the policies.

savings between the baseline and the capital-tax rebate for each age. Savings are lower in every period of the life cycle under the lump-sum rebate (relative to the baseline) because the lump-sum rebate reduces agents' need to save to finance retirement. In contrast, savings are higher in every period of the life cycle under the capital-tax rebate because the rise in the after-tax risk-free rate increases the return to savings.

Additionally, the higher after-tax risk-free rate under the capital-tax rebate encourages agents to delay consumption until later in life since an additional unit of consumption for a young agent costs more in terms of forgone future consumption (bottom left panel of Figure 7). Agents also shift hours to earlier in life because the increase in the after-tax risk-free rate raises the the return to working more for younger agents than for older agents (top right panel of Figure 7). Analogous reasoning reveals that the fall in the risk-free rate under the labor-tax rebate causes agents to shift consumption to earlier in life and hours to later in life.

Finally, in all four simulations, energy use is lower in every period of the lifecycle because the carbon tax raises the relative price of energy (bottom right panel of Figure 7). This change in energy consumption is generally largest for the middle-aged agents.[25] The level of energy consumption is highest for this age group, implying that their energy demand is the most elastic.

[25]Note that unlike the other policies, the change in energy consumption is similar for the young and middle-age agents under the capital-tax rebate. This is because the size of the capital-tax rebate is largest for the middle-aged agents. This positive income effect in middle age partially offsets their more elastic demand, and leads to similar energy responses from both the young and the middle-aged.

Figure 7: Lifecycle Profiles: Percent Change From Baseline

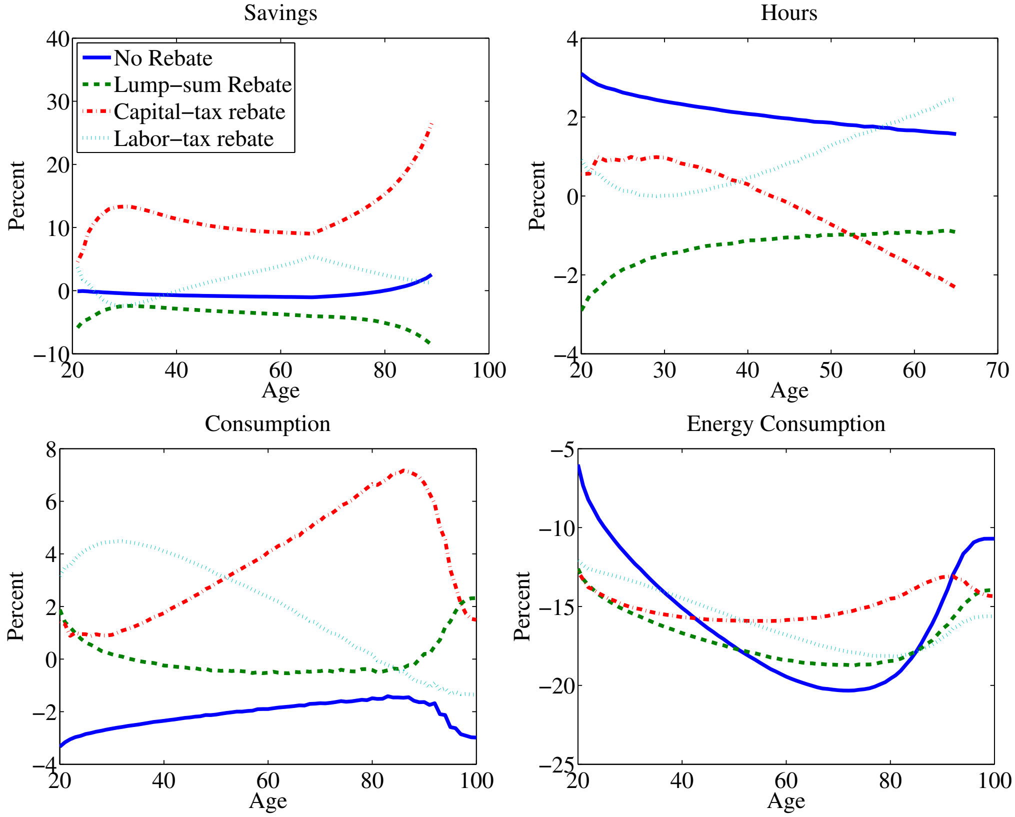
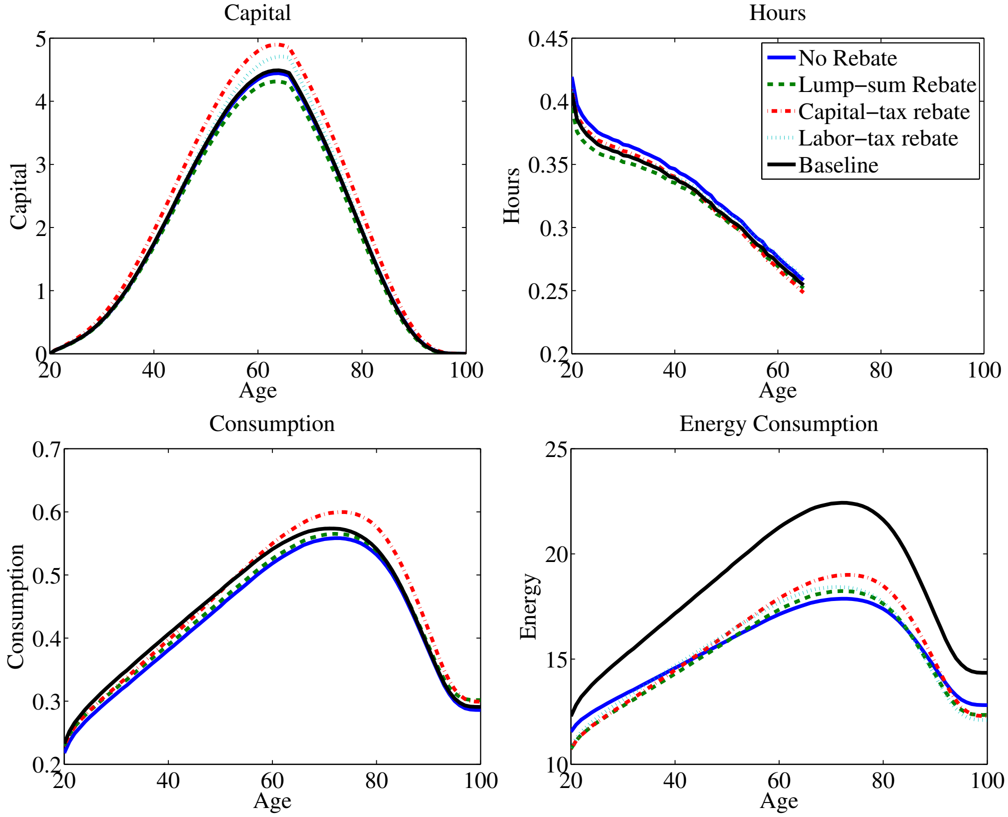


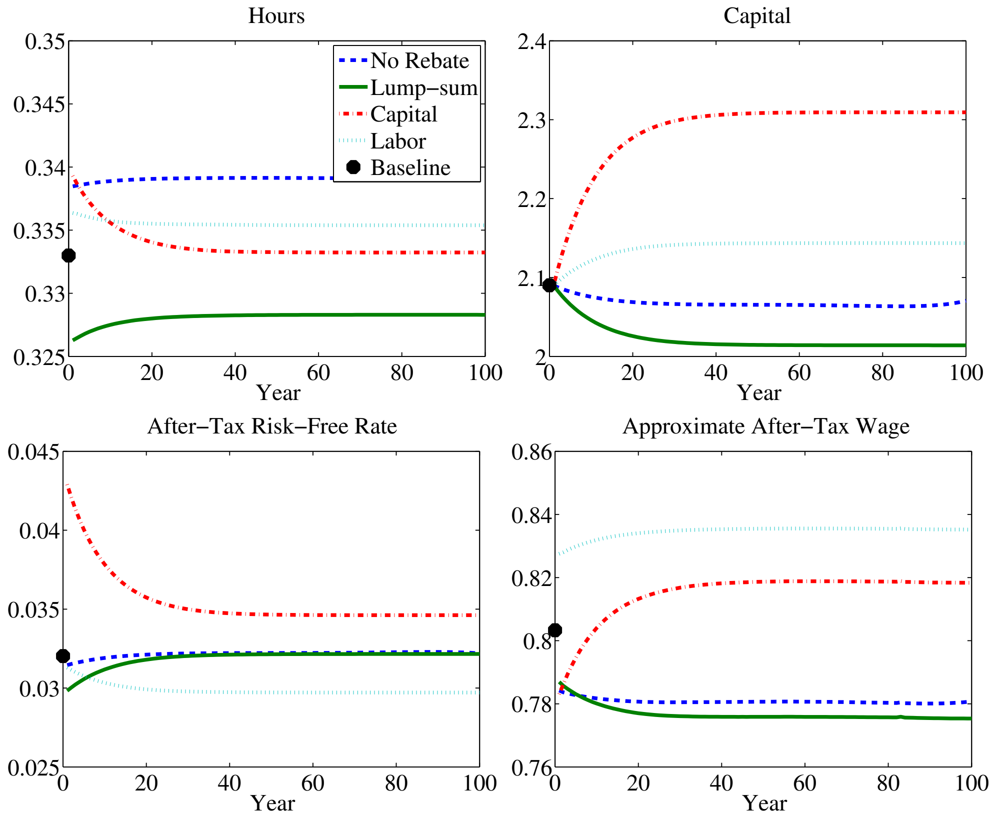
Figure 8: Lifecycle Profiles: Levels



Transition

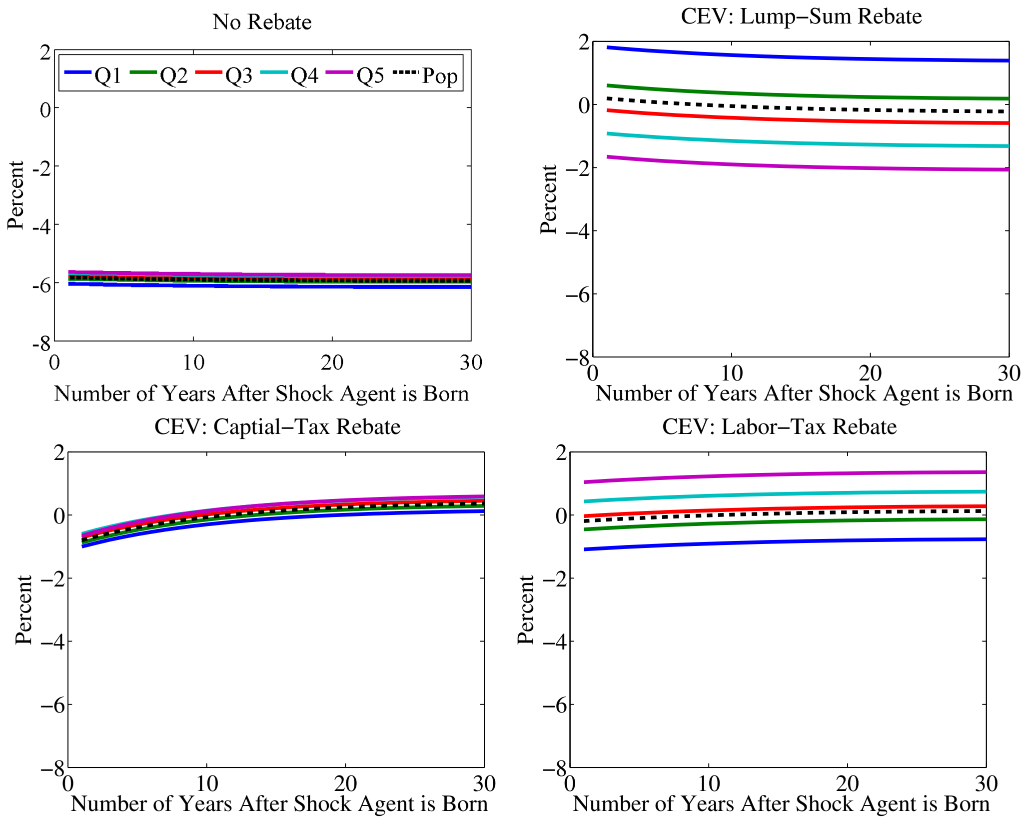
We report the results along the transition path to the new steady state with the policy in place. Figure 9 shows the evolution of capital, labor, the after-tax risk-free rate, and the average after-tax wage. The capital stock adjusts gradually to its new steady state under the policy. The other three variables jump in response to the policy change and then converge to their steady state levels in conjunction with the capital stock. The speed of the transition to the new steady state is primarily determined by the evolution of the capital stock. The capital-tax rebate results in a larger change in the capital stock, leading to a longer transition than in the other three policy simulations.

Figure 9: Transition Dynamics: Aggregates



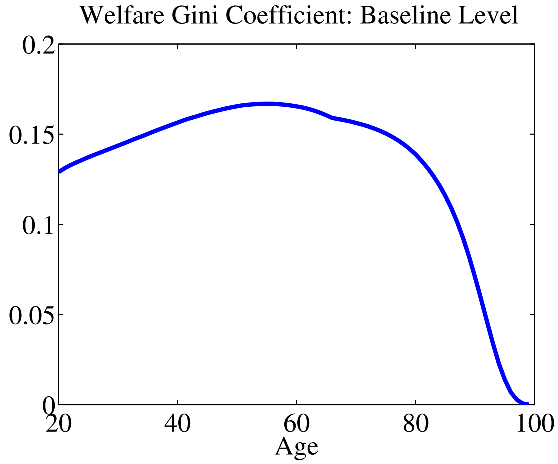
The discussion in the text focused on the welfare effects in the different simulations for agents who are alive when the carbon tax is introduced. We now turn to the welfare effects of agents who are born after the shock is introduced, but before the economy has fully transitioned to its new steady state. Figure 10 reports the CEV for these agents. In all cases, the welfare effects converge to the steady state results as the number of years after the shock that the agent is born increases. Under the no rebate, lump-sum, and labor-tax rebates, welfare changes relatively little as the economy approaches its new steady state. However, under the capital-tax rebate, welfare increases gradually as the economy transitions. The capital-tax rebate leads to a comparatively large accumulation of capital, increasing the wage rate and, thus, welfare over the transition.

Figure 10: Transitional Welfare for Newborn Agents



The discussion in the text measured the magnitude of the distributional effects for each age cohort by the percent change in the Gini coefficient from its value in the baseline. For reference, Figure 11, plots the Gini coefficient for each age cohort in the baseline. The Gini coefficient is humped shaped over the lifecycle, rising until agents near retirement and then falling. All agents experience the same productivity shock at birth, but they receive different and persistent realizations of these shocks over the course of their working life, causing inequality to rise with the cohort's age until retirement. For age cohorts that are retired, the progressive social security system reduces this inequality.

Figure 11: Gini Coefficient for Each Age-Cohort: Baseline



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