Should Robin Hood Wear Green? Understanding the Distributional and Efficiency Impacts of a Carbon Tax

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Abstract

How do the welfare effects of a carbon tax vary across income and age groups? Moreover, how does recycling the carbon-tax revenue through lump-sum transfers, or though reductions in the capital- or labor-tax rates impact these welfare effects? This paper develops an overlapping generations model to analyze these questions in both the steady state and over the transition to the steady state. Our life-cycle analysis of the distribution of welfare effects incorporates three key channels: (1) household energy consumption, (2) general equilibrium changes in factor prices, (3) income uncertainty. Our results reveal that the method of revenue recycling dramatically changes the welfare effects of the carbon tax policy for different age and income groups.

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1 Introduction

Policies that place a price on carbon emissions (e.g. a carbon tax or a cap-and-trade system) are generally viewed as the most efficient mechanisms to reduce emissions (Palmer and Burtraw (2005); Fischer and Newell (2008)). If implemented, these policies would have large effects on welfare through environmental channels (i.e. reduced carbon emissions) and through non-environmental channels (i.e. their impacts on energy prices and the broader economy). Furthermore, a carbon tax has the potential to generate substantial amounts of government revenue.[1] Previous studies in both the public and environmental economics literatures highlight that the way in which these tax revenues are recycled (i.e., lump sum rebates vs. reductions in pre-existing distortionary taxes) can dramatically impact the non-environmental welfare consequences (e.g., Goulder (1995); de Mooij and Bovenberg (1998); Bovenberg (1999)). Additionally, the revenue recycling method can substantially alter the distribution of the welfare changes across income groups (e.g., Fullerton and Heutal (2007), Bento et al. (2009); Dinan and Rogers (2002); Metcalf (2007); Parry (2004)). However, this earlier work has almost exclusively focused on static or infinitely lived models. Yet, the macroeconomic literature examining distortionary taxation in a variety of other settings reveals that it is crucial to examine the impacts of tax policies in a life-cycle setting because the welfare effects from changes in distortionary taxes vary considerably across age groups (Conesa et al. (2009); Peterman (2013)).

Following the insights from the macroeconomic literature, we develop a quantitative, overlapping generations model to reexamine the welfare effects of a revenue-neutral carbon tax policy. By including income heterogeneity within each generation, we are able to explore how the non-environmental welfare changes differ not only across different age cohorts, but also within the same age cohort. Importantly, we are able to simultaneously consider the impact a carbon tax will have on welfare through three key channels: (1) changes in household energy consumption, (2) general equilibrium changes in factor prices, and (3) the rebate

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[1] For example, in 2011, the CBO estimated that a cap-and-trade program that would have set a price of 20 dollars in 2012 to emit a ton of CO_2 (and increased that price by 5.6 percent each year thereafter) would raise a total of 1.2 trillion dollars during its first decade.

mechanism for the carbon tax revenue. Previous studies have looked at these channels (e.g., Carbone et al. (2013); Williams et al. (2015)), but no study has simultaneously examined all three channels in a model with both age and income heterogeneity. Additionally, we are able analyze the welfare effects in both the steady state under the policy and during the transition to this new steady state. The welfare effects over the transition are particularly important because they measure the effect of the policy on the living population, as opposed to on future generations that are not responsible for initially implementing the policy.

Focusing first on the steady-state welfare effects, our distributional results confirm the predictions from the environmental-tax literature. If carbon tax revenues are recycled through lump-sum payments, low income households are the relative winners. If the revenues are used to reduce an existing distortionary tax, without altering the progressivity or regressivity of that tax, then the higher income households are the relative winners. Our aggregate steady-state results also reiterate the findings from the earlier literature; the welfare costs are minimized when the government uses the carbon-tax revenue to reduce distortionary taxes, particularly the capital-tax.

In contrast, our results reveal that during the transition between steady states, the aggregate welfare costs are actually minimized by recycling the revenue through lump sum transfers instead of reducing pre-existing distortionary taxes. This novel finding results from both the age and income heterogenity. The age heterogeneity is important because the welfare costs of the policy are particularly large for the older generations under the capital and labor tax rebates. These rebates raise either the after-tax wage or risk-free rate, but the old do not experience large benefits from these factor price changes because their remaining income from capital and labor is relatively small. The resulting high welfare costs for the old reduce aggregate welfare over the transition. Under the lump-sum rebate, the size of the transfer is independent of the agent's income and, thus, the welfare effects are more equal across the age groups.

The inclusion of income heterogeneity within cohorts also contributes to the finding that, in the transition period, lump-sum transfers are superior to reductions in distortionary taxes.

This is due to the fact that the lump-sum rebates serve to insure agents against negative income shocks. Agents receive the same transfer regardless of whether they experience a good or bad shock. However, the transfer results in a larger percentage increase in income, and hence in consumption, when the agent has a bad shock because he has lower income in this state. This insurance increases expected welfare, assuming that agents are risk averse. The capital and labor-tax rebates do not have this insurance property because the size of the rebate increases with the agent's income in both of these cases.

The paper proceeds as follows: Section 2 presents the computational model and Section 3 discusses the functional forms and the calibration. Section 4 reports the results from different revenue-neutral implementations of a carbon tax. Finally, Section 5 concludes.

2 Model

2.1 Demographics

Time is discrete and there are J overlapping generations. A continuum of new agents is born each period. 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, $\Psi_J = 0$. Since agents are not certain how long they will live, they could 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 (exogenous) 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 he divides between labor and leisure. An agent i, age j, 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, $\mu_{i,j}$ 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). Variable ϵ_j governs age-specific human capital. Variable $\xi_i \sim NID(0, \sigma_\xi^2)$ is an individual-specific fixed effect (or ability) that is observed at birth and is constant for an agent over the life cycle. Variable $\theta_t \sim NID(0, \sigma_\theta^2)$ 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:

$$\nu_t = \rho \nu_{t-1} + \psi_t \text{ with } \psi_t \sim NID(0, \sigma_\nu^2) \text{ and } \nu_1 = 0. \tag{2}$$

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, the realization of the transitory shock, θ_t, and the realization of the persistent shock, ν_t. Different permanent ability types generate an initial productivity distribution within a cohort. As the cohort ages, different realizations of ν_t across individuals over time increase the variance of this distribution.

Agents cannot insure against idiosyncratic productivity shocks by trading explicit insurance contracts, and 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 a one-period, risk-free asset, $a_{i,j}$, and consumption. Agents can consume both a generic consumption good, $c_{i,j}$, and a carbon emitting energy good, $e^c_{i,j}$. Energy consumption includes expenditures on electricity, gasoline, heating oil, etc. All agents must consume a minimum amount of energy, $\bar{e}$. Variable $\bar{e}$ represents subsistence energy required for light, transportation, heat, etc. Agents choose labor, savings, generic consumption, and energy consumption to maximize their lifetime utility

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

We take the expectation in equation (3) with respect to the stochastic processes governing the idiosyncratic productivity shocks. Agents discount the next period's utility by the product of Ψ_j and β. Parameter β is the discount factor conditional on surviving. The product, $\beta\Psi_j$, is the unconditional discount rate. Agents do not derive utility from energy consumption required for subsistence, $\bar{e}$.

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 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 and labor income, and energy (i.e., a carbon tax) to finance G.[2]

The government pays social security benefits, S, to all agents that are retired. The benefits are independent of the agent's lifetime earnings. Instead, retired agents receive an exogenous fraction, b, of the average income of all working individuals. The government finances the social security system with a flat tax on labor income, τ_s. It sets the tax rate to ensure that the social security system has a balanced budget in every period.

The government taxes capital income according to a constant marginal tax rate, τ_k. An agent's period t 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 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 to both reduce carbon emissions and to finance its spending. A 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 $p_e + \tau_c$. In one of the policy experiments we analyze, the government rebates the carbon-tax revenue through lump-sum transfers to the households, T_c.

2.5 Definition of a Stationary Competitive Equilibrium

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

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[2] Given that fossil fuel combustion accounts for over 80 percent of GHG emissions, a carbon tax effectively functions as a tax on energy use.

parameters, $\{n, \Psi_j\}$, a sequence of age-specific human capital, $\{\epsilon_j\}_{j=1}^{j_r-1}$, 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 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:

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

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

$$c \geq 0,\ e^c \geq 0,\ 0 \leq h \leq 1,\ a \geq 0,\ a_1 = 0$$

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:

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

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

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.

3.1 Demographics

In the model, agents are born at the real-world age of 20 that corresponds to a model age of 1. Agents are exogenously forced to retire at real-world age of 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 use two for the coefficient of relative risk aversion, $\theta_1 = 2$, and following Kaplan (2012), we use 0.5 for the Frisch elasticity, $\theta_2 = 0.5$.

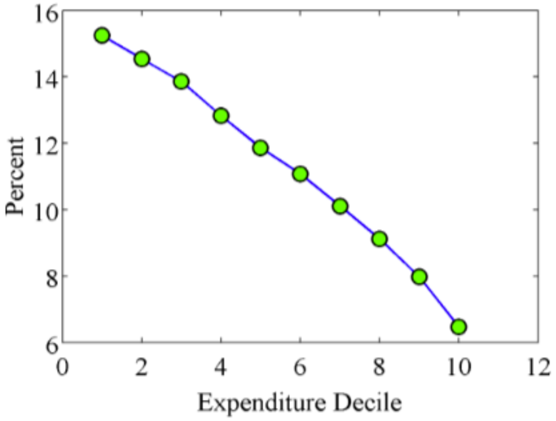
One reason a carbon tax could be regressive is because lower income individuals devote

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	1.004	$\frac{K}{Y} = 2.7$
Risk Aversion: θ_1	2	Conesa et al. (2009)
Frisch Elasticity: θ_2	0.5	Kaplan (2012)
Disutility of Labor: χ	62.5	Avg. $h_{i,j} = 0.333$
Subsistence Energy: $\bar{e}$	9.6	$\Delta\Omega = -12.8$
Consumption Energy Share: $1-\gamma$	0.055	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	2.12	Clears market
Capital Tax Rate: τ_k	0.36	Gravelle (2004)
Government Spending: G	0.124	$\frac{G}{Y} = 0.155$
Replacement Rate: b	0.5	Conesa et al. (2009)

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. 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. Energy share of total consumption expenditures, Ω, is

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

For $\bar{e} = 0$, energy share equals $1-\gamma$ for all expenditure levels. For $\bar{e} > 0$, energy share decreases with expenditures. Higher $\bar{e}$ increases the responsiveness of energy share to changes in total expenditures. We pin down $\bar{e}$ and γ to match 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, $\Delta\Omega = \frac{\Omega_{top} - \Omega_{bottom}}{\Omega_{bottom}} \times 100$, based on the CEX data. The average energy share in the population is 10.2 percent.

In the CEX data, $\Delta\Omega = -33\%$. However, the percent difference in expenditures between the top and bottom halves of the distribution is 142 percent in the CEX, but only 54 percent in our model. Therefore, we adjust for the smaller expenditure variance in our model and target $\Delta\Omega = -12.8\%$.

3.3 Idiosyncratic Productivity

We calibrate the idiosyncratic labor productivity shocks based on the estimates from the PSID data in Kaplan (2012).[3] These permanent, persistent, and transitory idiosyncratic shocks to individuals' productivity are normally distributed with a mean of zero. 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 $\sigma_\theta^2 = 0.081$. 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.

3.4 Age-Specific Human Capital

We set $\{\epsilon_j\}_{j=0}^{j_r-1}$ to match the values estimated in Kaplan (2012). These values are based off the average hourly earnings by age in the Panel Survey of Income Dynamics.

3.5 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.

3.6 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.

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

tax code from Gouveia and Strauss (1994). Gouveia and Strauss (1994) match the U.S. 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 progressively 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.[4] 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.

4 Results

We simulate a baseline economy with no carbon tax and we conduct a series of counterfactual simulations in which we introduce a constant carbon tax set at 35 dollars per ton CO_2. We consider four different rebate options for the carbon tax revenue: (1) the government does not rebate the revenue and instead "throws it into the ocean," (2) rebates through equal, lump-sum transfers to the household, (3) rebates through a reduction in the capital-tax rate, and (4) rebates through a reduction in the labor-tax rate.

To implement changes in the labor-tax, we fix Υ_2 at its value in the baseline and reduce the labor-tax rate by lowering parameter Υ_0. This approach minimizes changes in the progressivity of the labor-tax function. It is necessary to adjust the labor-tax rate not

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[4] 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.

only in the labor-tax rebate case but also in the other three counterfactual simulations to ensure that government spending under the carbon tax equals its baseline value. This is because the carbon tax leads to changes in aggregate labor and capital supplies, which affect aggregate tax-revenue. Table 2 reports the tax parameters in the baseline and in each of the four simulations.

Table 2: Tax Parameters

		Carbon Tax			
	No Carbon Tax	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Labor tax: Υ_0	0.26	0.26	0.26	0.28	0.19
Labor tax: Υ_1	0.77	0.77	0.77	0.77	0.77
Labor tax: Υ_2	2.12	2.12	2.12	2.12	2.12
Capital tax: τ_k	0.36	0.36	0.36	0.09	0.36
Carbon tax: $\frac{\tau_c}{p_e}$	0.00	0.33	0.33	0.33	0.33

Table 3 reports the fraction of government revenue from the labor, capital, and carbon taxes in the baseline and in each of the four counterfactual 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. Section 4.1 compares the steady states in each of the counterfactual economies with the baseline and Section 4.2 reports the results over the transition. In both sections, we analyze the results for different income quintiles. We form the income quintiles from agents' realized lifetime expenditures.

Table 3: Percent of Government Revenue

		Carbon Tax			
	No carbon Tax	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Labor Tax	71.04	71.03	71.94	72.99	51.71
Capital Tax	29.01	28.97	28.06	5.85	27.36
Carbon Tax	0.00	20.63	20.47	21.18	20.95
Lump-Sum Rebate	-	-	-20.47	-	-

4.1 Steady State

We compare the baseline and counterfactual economies in the steady state. Column 2 of Table 4 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.[5]

Regardless of the rebate mechanism, 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 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. The government's rebate mechanism determines which channels dominate and the corresponding implications for the steady-state aggregates.

In the no-rebate case, the government increases its total tax levy, reducing each agent's disposable income and his corresponding ability to save. This negative income shock dominates the agent's need to increase savings to finance the more expensive retirement under the carbon tax, and the aggregate capital stock falls by 0.96 percent. All else constant, the lower capital stock and energy use reduce the marginal product of labor and the market wage falls by 2.84 percent. Moreover, hours rise because the income effects from the increased tax

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

levy and from the carbon tax dominate the substitution effect from the carbon tax.

In the lump-sum rebate case, each agent receives a uniform transfer over his entire life cycle. This transfer reduces the agent's need to save, since it increases government transfer payments during retirement. This effect dominants the agent's need to increase savings to finance the more expensive retirement, and the aggregate capital stock falls by 3.64 percent. The lower capital stock and energy use reduce the marginal product of labor and the market wage falls by 3.86 percent. Moreover, both hours and consumption fall because the substitution effects from the lower wage rate and from the carbon tax dominate the corresponding income effects and agents substitute leisure for consumption.

In the capital-tax rebate case, each agent receives a rebate proportional to his capital income. All else constant, the lower capital-tax rate increases the after-tax risk-free rate, raising the agent's incentives to save. This effect complements the agent's need to increase retirement savings and the aggregate capital stock rises by 11.04 percent. The higher capital stock dominates the decline energy use, causing the marginal product of labor and the accompanying market wage to rise. Moreover, both hours and consumption rise because the substitution effect from the higher wage dominates and agents substitute consumption for leisure.

In the labor-tax rebate case, each agent receives a rebate proportional to his labor income. All else constant, the lower labor-tax rate raises the after-tax wage, increasing each agent's disposable income and his corresponding ability to save. This positive income shock complements the agent's need to increase retirement savings and the aggregate capital stock rises by 3.00 percent. The higher capital stock and lower labor-tax rate dominate the decline energy use, causing after-tax market wage to rise. Moreover, both hours and consumption rise because the substitution effect from the higher after-tax wage dominates and agents substitute consumption for leisure.

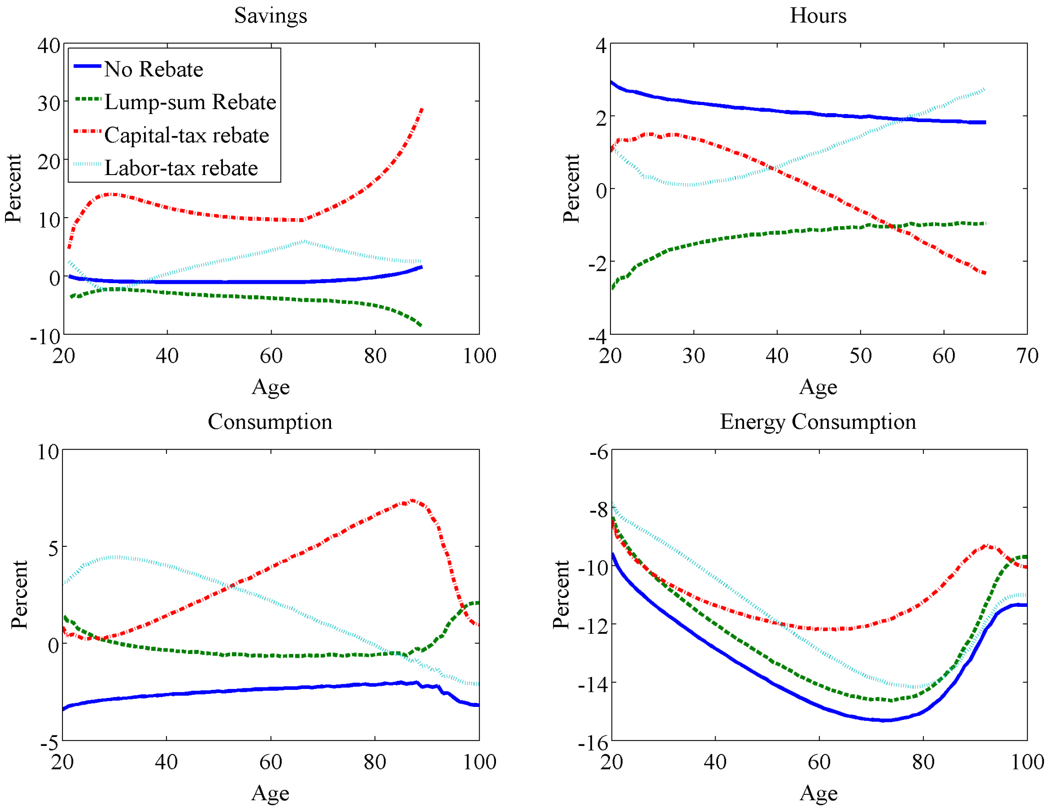
Table 4: Steady State Aggregates

		Percent Change From Baseline: Carbon Tax			
	No carbon Tax	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Macro Aggregates					
Output: Y	0.84	0.12	-2.74	3.06	0.82
Efficiency Hours: N	0.52	2.01	-1.00	0.08	0.87
Capital: K	2.27	-0.96	-3.64	11.04	3.00
Consumption: C	0.41	-2.53	-0.32	2.90	2.71
Energy					
Prod. Energy: E^p	16.79	-13.10	-15.58	-10.52	-12.48
Con. Energy: $E^c - \bar{E}$	9.65	-26.50	-24.83	-22.41	-22.55
Tot. Energy: $E^p + E^c$	36.03	-13.20	-13.91	-10.90	-11.85
Prices and Transfers					
Avg. Net Wage: $(1-\tau_l)w$	0.77	-2.84	-3.86	2.04	6.43
Net Risk-Free Rate: $(1-\tau_k)r$	0.03	0.83	0.37	9.91	-8.47
Transfers: $T_a + T_p$	0.03	-0.58	81.25	12.92	4.15

Figure 2 shows the percent change in the life-cycle profiles induced by the policies. For example, the dashed red line in the top left panel plots the average percent difference in total 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 2). 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 2). 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, energy use is lower in every period of the life cycle for all the rebate options because the carbon tax raises the relative price of energy (bottom right panel of Figure 2). The change in energy consumption is largest for the middle-aged agents. The level of energy consumption is highest for this age group, implying that their energy demand is the most elastic.

Figure 2: Lifecycle Profiles: Percent Change From Baseline



4.1.1 Welfare: Population

Table 5 reports the consumption equivalent variation (CEV) of the tax in each of the four counterfactual economies. 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. Table 5 reports the population CEV and the CEV within each of the five income quintiles. The population CEV measures the change in the ex ante (i.e., before ability is realized), expected (with respect to the idiosyncratic shocks) welfare of a newborn individual in the long-run equilibrium. The CEV in a given income quintile measures the ex-ante change in expected welfare conditional on being born in that particular income quintile.

The population CEV is negative when the government does not rebate the carbon-tax revenue. In this case, the government raises additional revenue which reduces each agent's disposable income and does not contribute to his utility, making him considerably worse off. However, when the government does return the revenue to the household, it can undo the negative welfare effects from the carbon tax. The population CEV is close to zero under the labor-tax and lump-sum rebates and it is positive under the capital-tax rebate.

The near-zero welfare cost occurs under the labor tax and lump-sum rebate because the welfare benefits from these rebates almost exactly offset the welfare costs from the carbon tax. The welfare benefits from the labor-tax rebate are the reduced distortions from the labor tax. However, unlike the labor-tax rebate, the lump-sum does not directly reduce any pre-existing distortionary taxes. The welfare benefits arise in this case because the lump-sum rebate partially insures agents against negative income shocks. Agents receive the same transfer regardless of whether they have a good or bad shock. However, the transfer results in a larger percentage increase in income, and hence in consumption, when the agent has a bad shock because he has lower income in this state. All else constant, this insurance raises expected welfare because agents are risk adverse, offsetting the welfare cost of the carbon tax.

The CEV is positive under the capital-tax rebate because the carbon tax is less distortionary then the capital tax in our framework. Regardless of the size of the carbon tax, the household must consume the subsistence level of energy, $\bar{e}$. This required energy consumption reduces the household's ability to respond to tax, making energy demand relatively inelastic. Thus, the carbon tax shifts the tax system towards less elastic factors, reducing its overall burden. This result provides evidence of a small double dividend where the carbon tax reduces the overall welfare cost of the tax system in addition to improving environmental quality.[6]

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[6] We find no evidence of a double dividend under the capital tax rebate in specifications in which $\bar{e} = 0$. We are currently exploring the sensitivity of the relative rankings of the tax policies to changes in $\bar{e}$.

4.1.2 Welfare: Distribution Across Income Quintiles

Table 5: Steady State CEV (percent)

	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Quintile 1	-6.73	1.53	-0.11	-1.07
Quintile 2	-6.36	0.33	0.27	-0.27
Quintile 3	-6.15	-0.38	0.51	0.24
Quintile 4	-5.94	-1.12	0.77	0.78
Quintile 5	-5.82	-1.83	0.87	1.50
Population	**-6.28**	**-0.04**	**0.38**	**0.03**

The carbon-tax policy is considerably more costly for lower income households when the government does not rebate the tax revenue. This regressivity arises because lower income households devote larger fractions of their budgets to energy consumption. Therefore, the carbon tax taxes a larger portion of lower income households' total expenditures than it does for higher income households, making them substantially worse off.

The government can reverse the regressiveness of the tax policy by rebating the revenue in a progressive manner. For example, when the government rebates the revenue through equal, lump-sum transfers, the carbon tax policy increases welfare for the lower income quintiles and decreases it for the higher income quintiles. This rebate mechanism redistributes income from the high to low income households because the wealthier agents fund a larger portion of the transfer since they consume more energy (in absolute terms).

Unlike in the lump-sum rebate case, the government exacerbates the regressiveness of the carbon tax policy when it rebates the revenues through ether the capital-tax or labor-tax rates. The left panel of Figure 3 plots capital income as a fraction of total income in each of the quintiles. The policy is regressive under the capital-tax rebate because capital income represents a larger fraction of total lifetime income for higher income individuals. Thus, a reduction in the capital-tax rate leads to a larger percentage increase in income for wealthier households.

Figure 3: Labor and Capital Income as a Fraction of Total Lifetime Income

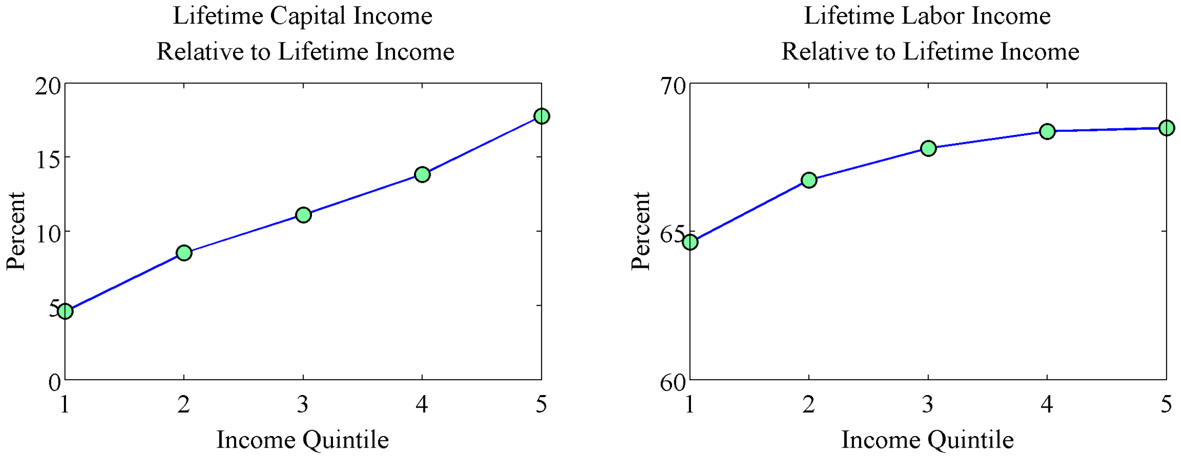
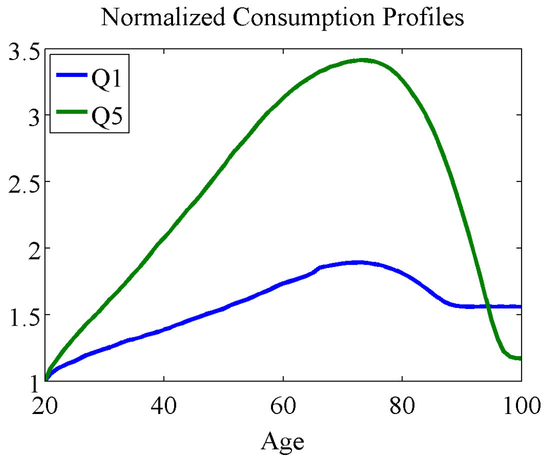


Figure 4: Consumption Profiles For First and Fifth Income Quintiles



The right panel of Figure 3 plots the labor income as a fraction of total income in each of the income quintiles. Unlike in the capital-tax case, the fraction of total income that comes from labor income is relatively constant across the income quintiles. However, when the government reduces the labor income tax, agents move consumption from later in life towards earlier in life (see bottom left panel of Figure 2). This shift smooths the consumption profile over the life cycle. Figure 4 plots the average consumption profiles for agents in the first and fifth income quintiles. The consumption profile is much steeper for the wealthier agents, implying that these agents benefit more from the consumption smoothing, making the labor-tax rebate regressive.

4.2 Transition

We report the results along the transition path to the new long-run equilibrium with the policy in place. Figure 5 shows the evolution of capital, labor, the after-tax risk-free rate, and the average after-tax wage. As a measure of welfare, we calculate the CEV in terms of an agent's expected future consumption over the remainder of his life cycle. For example, to calculate the welfare effect of the policy for an agent who is 25 when the tax is introduced, we compute the expected, uniform percent change in consumption the agent would need in every remaining period of his life to make him indifferent between living the rest of his life in the baseline versus under the policy. We begin by discussing the welfare effects for the living population.[7] We next examine how the welfare implications vary across income quintiles. Then we analyze the welfare effects for agents who are different ages when the government introduces the carbon tax policy. Finally, we study the interaction between the age and income welfare effects.

4.2.1 Welfare: Population

The bottom row of Table 6 reports the CEV for the living population under each rebate mechanism. The welfare costs of the capital and labor-tax rebates over the transition are much larger than their costs in the steady-state. These higher costs arise for two reasons. First, life-cycle factors are particularly important over the transition because, unlike an agent living in the steady state, an agent living through the transition does not experience the effects of the policy for his entire life time. Under the labor-tax rebate, these life-cycle factors imply that agents who are retired when the government introduces the policy do not receive any rebate, and, thus, are considerably worse off. Second, the capital stock adjusts slowly to its new long-run level causing factor prices to evolve throughout the transition.

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[7] We use the term living population to refer to the population who is alive when the government introduces the carbon tax.

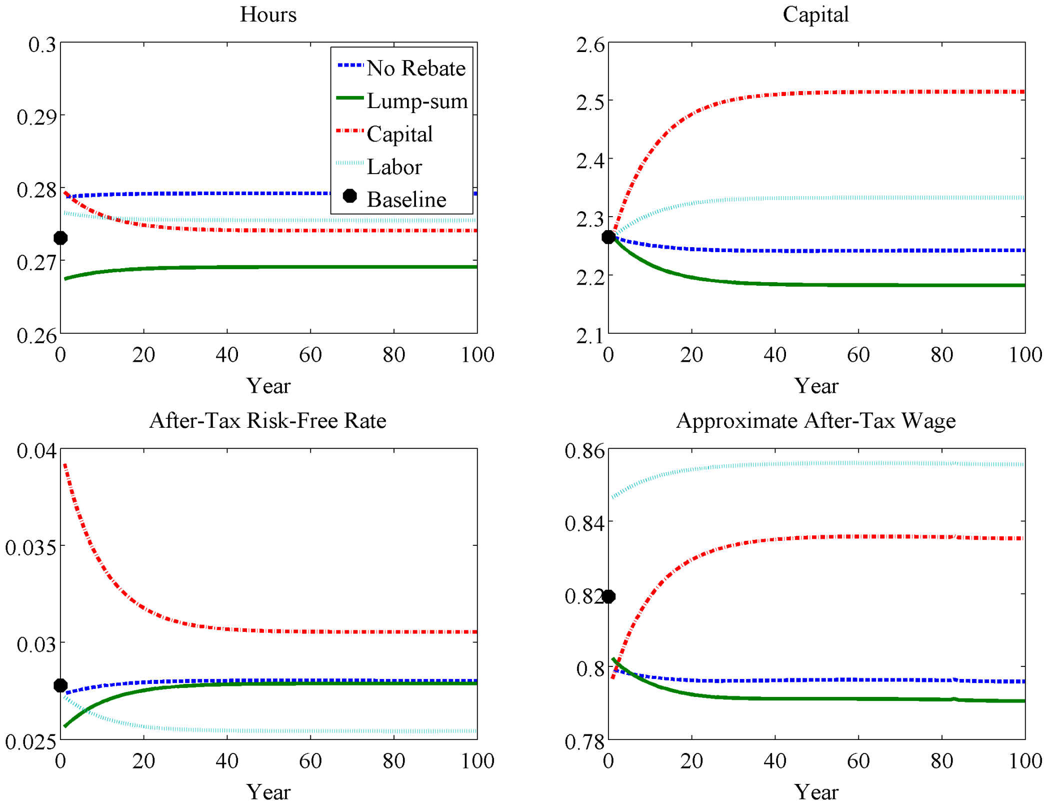
This gradual adjustment of the capital stock increases the transitional welfare cost of the capital-tax rebate because one benefit from the rebate is a higher equilibrium capital stock, but reaching this new equilibrium takes time.

Unlike in the steady state, over the transition, the revenue-neutral policy with the smallest welfare cost is the lump-sum rebate. As discussed in Section 4.1, the lump-sum rebate incentivizes agents to reduce their savings relative to the baseline. Thus, when the government introduces the carbon tax policy, the living population has saved more than they would have, had they known that the government was going to introduce the policy. All else constant, these "extra savings" increase the expected welfare over the remainder of living population's life cycle, making the lump-sum rebate the least costly rebate option over the transition.

Table 6: Transition CEV (percent)

	No Rebate	Lump-sum Rebate	Capital Rebate	Labor Rebate
Quintile 1	-5.43	1.23	-1.53	-2.70
Quintile 2	-4.98	0.19	-0.45	-2.22
Quintile 3	-4.72	-0.40	0.26	-1.96
Quintile 4	-4.47	-0.96	0.98	-1.72
Quintile 5	-4.19	-1.62	1.86	-1.40
Population	**-4.87**	**-0.07**	**-0.10**	**-2.12**

Figure 5: Transition Dynamics: Aggregates



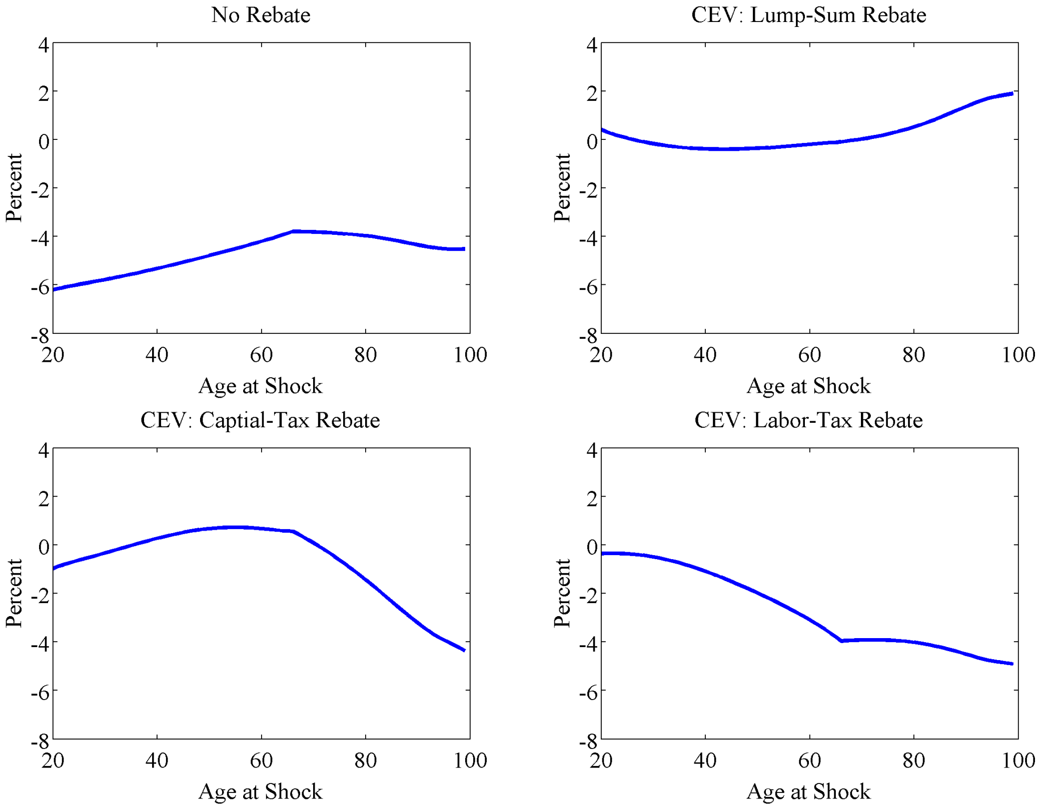
4.2.2 Welfare: Distribution Across Income Quintiles

The welfare effects across quintiles are qualitatively the same over the transition as in the steady state. The carbon tax policy is regressive then the government does not rebate the tax revenue and also when it rebates the revenue through reductions in either the capital- or labor-tax rates. The policy is progressive then the government rebates the revenue through lump-sum transfers. The intuition is the same as in Section 4.1.

4.2.3 Welfare: Distribution Across Age Cohorts

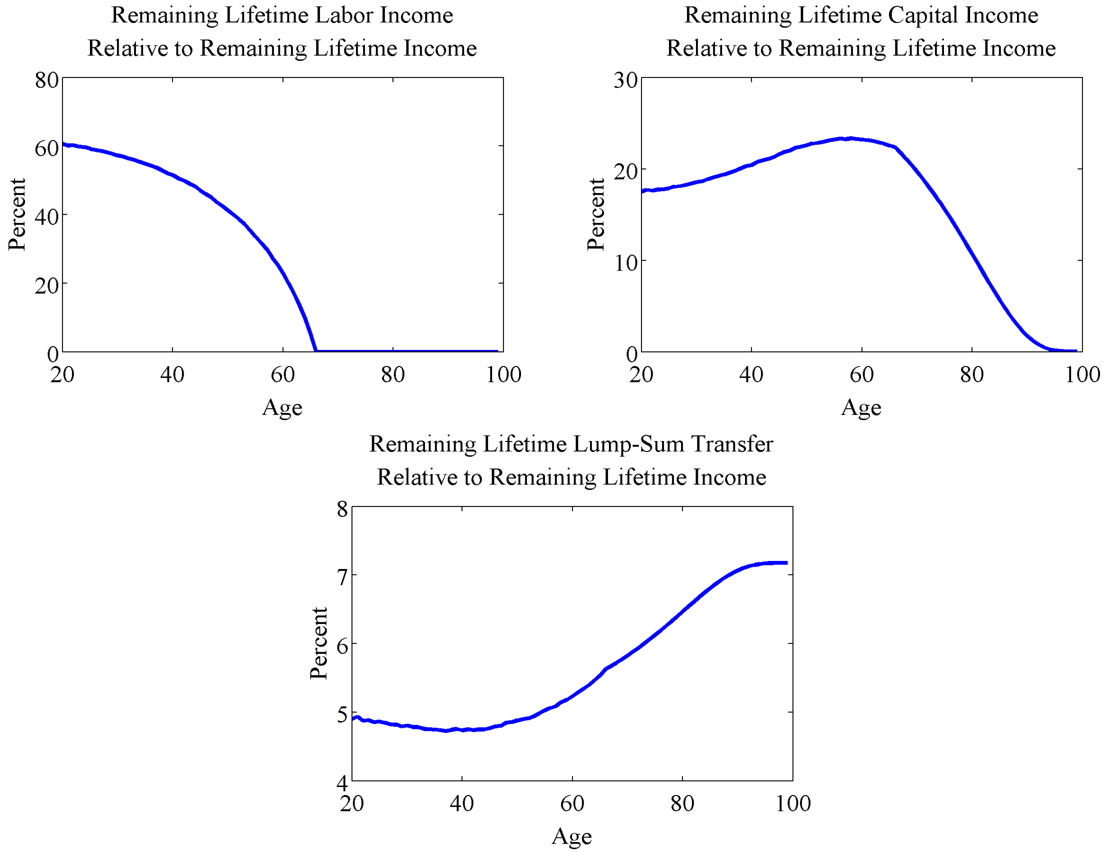
Regardless of the rebate option, the carbon tax decreases the average expected welfare for the living population. However, the government's rebate choice can make the carbon tax policy welfare improving for some age cohorts over the transition. Figure 6 plots the CEV for each age cohort for the four rebate options. The lump-sum rebate is the most welfare improving for the older retirees, the capital-tax rebate is the most welfare improving for the middle-aged agents, and the labor-tax rebate is most welfare improving for the very young agents.

Figure 6: CEV: Agents Alive At Time of Shock



The welfare effects across age cohorts are primarily determined by the size of the rebate relative to the household's remaining lifetime income. The relative size of the capital and labor-tax rebates depends on the household's remaining lifetime capital and labor income, respectively. The top two panels of Figure 7 plot remaining lifetime labor and capital income relative to remaining lifetime income for each age cohort. The bottom panel plots remaining lifetime lump-sum transfer relative to remaining lifetime income for each age cohort.

Figure 7: Remaining Labor and Capital Income Relative to Remaining Income



All else constant, changes in the wage rate have larger welfare consequences for younger agents because expected future labor income comprises the largest fraction of total remaining lifetime income for this age group. The rise in the after-tax wage is the dominant effect under the labor-tax rebate, and, thus, the young benefit most from this rebate option out of all the age cohorts.

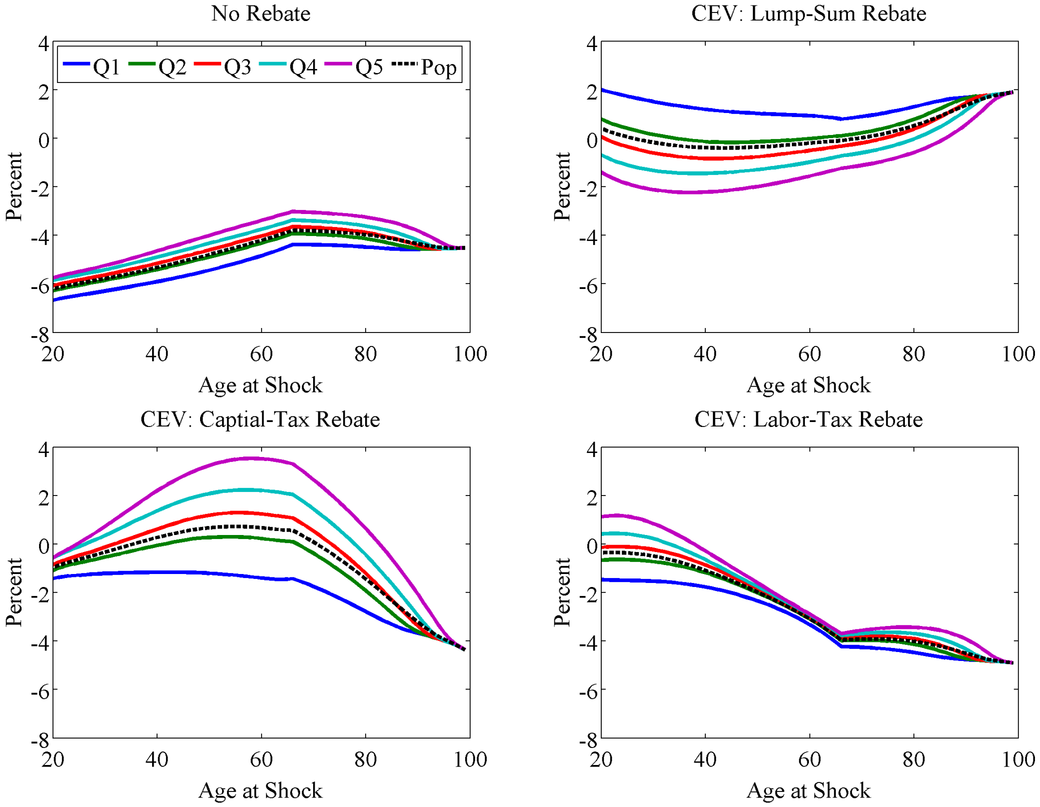
Changes in the risk-free rate have the largest consequences for middle-aged agents because expected future capital income comprises the largest fraction of total remaining lifetime income for this age group. The dominant effect under the capital-tax rebate is the fall in the after-tax risk-free rate and, thus, the middle aged agents benefit most from this rebate option out of all the age cohorts.

Retirees receive the smallest benefits out of all the age cohorts from the capital and labor-tax rebates because the fraction of their remaining lifetime income that is from labor or capital is smallest for the retirees. However, lump-sum transfers relative to remaining lifetime income are largest for the retirees because they are depleting their savings and, thus, have low expected lifetime incomes relative to their younger counterparts. Thus, under the lump-sum rebate the retirees have the best welfare outcome of all the age cohorts.

The no-rebate case differs from the three rebate options because the government increases its total tax levy, reducing each agent's disposable income. This negative wealth effect reduces welfare for all agents. The rebate is particularly costly for the younger agents because it leads to a drop in the market wage. Additionally, the policy is more costly for the retirees relative to the older working agents because the retirees are less able to adjust to the shock.

4.2.4 Welfare: Distribution Across Age and Income Groups

Figure 8: CEV: Agents Alive At Time of Shock



Finally, we analyze the interaction between age and income over the transition. Figure 8 plots the CEV by age and income quintile for each of the four rebate options. We find that the tax policy generally does not have uniform effects for all agents in a given income quintile or age cohort.

The lump-sum rebate is welfare improving older agents and for low-income agents on average. These results continue to hold when we interact age and income. However, the variance in the CEV across the income quintiles is substantially larger for the younger agents because the variance in lifetime income is greatest for this group.

The capital-tax rebate case is welfare improving for middle-aged agents and for high-income agents on average. However, the effects are not uniform across either of these demographic groups. In particular, the capital tax is only welfare improving for households who are both high-income and middle-aged. The CEV is negative for young and old high-income households, and also for middle-aged low-income households. The variance in the CEV across the income quintiles is substantially larger for the middle-aged agents because the variance in capital income as a fraction of remaining lifetime income is greatest for this group.

The labor-tax rebate case does not improve welfare for any income quintile or age group on average. Moreover, the distributional effects of the labor-tax rebate averaged over the age cohorts are regressive (see Table 6). However, the bottom right panel of Figure 8 shows that the rebate is considerably less regressive for the middle-agents. This change occurs because the labor tax leads to a fall in the risk-free rate which is most costly for the middle-aged, wealthy households, undoing most of the regressiveness of the policy for this age group.

5 Conclusion

We develop an overlapping generations model to quantify the distributional implications of a carbon tax across both income and age groups for different revenue-recycling schemes. We find that the welfare effects vary considerably between the steady state and the transition. In particular, in the steady state, the welfare cost from the revenue-neutral carbon-tax policy is smallest under the capital-tax rebate and largest under the lump-sum rebate, but over the transition, the welfare cost is largest under the labor-tax rebate and smallest under the lump-sum rebate.

Additionally, we find that the rebate mechanism has substantial implications for the distribution of welfare effects across income and age groups over the transition. In particular, the lump-sum rebate *improves* welfare for low income households and also for older households at all income levels, the capital-tax rebate *reduces* welfare for all households except those who are middle-aged and wealthy, and the labor-tax rebate *reduces* welfare for all households except those who are very young and wealthy.

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