

## THE INTERGENERATIONAL INCIDENCE OF GREEN TAX REFORM<sup>\*,†</sup>

SEBASTIAN RAUSCH<sup>\*,§,¶,||</sup> and HIDEMICHI YONEZAWA<sup>‡</sup>

<sup>\*</sup>*Center for Economic Research at ETH (CER-ETH)  
Department of Management, Technology and Economics  
ETH Zurich, Zurich, Switzerland*

<sup>§</sup>*Joint Program of the Science and Policy of Global Change  
Massachusetts Institute of Technology, Cambridge, USA*

<sup>¶</sup>*Department of Management, Technology and Economics  
ETH Zurich (Swiss Federal Institute of Technology Zurich)  
Zürichbergstrasse 18, 8032 Zurich, Switzerland  
[||srausch@ethz.ch](mailto:srausch@ethz.ch)*

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We examine the lifetime incidence and intergenerational distributional effects of an economy-wide carbon tax swap using a numerical dynamic general equilibrium model with overlapping generations of the U.S. economy. We highlight various fundamental choices in policy design including (1) the level of the initial carbon tax, (2) the growth rate of the carbon tax trajectory of over time, and (3) alternative ways for revenue recycling. Without revenue recycling, we find that generations born before the tax is introduced experience smaller welfare losses, or even gain, relative to future generations. For sufficiently low growth rates of the tax trajectory, the impacts for distant future generations decrease over time. For future generations born after the introduction of the tax, the negative welfare impacts are the smallest (largest) when revenues are recycled through lowering pre-existing capital income taxes (through per-capita lump-sum rebates). For generations born before the tax is introduced, we find that lump-sum rebates favor very old generations and labor (capital) income tax recycling favors very young generations (generations of intermediate age).

**Keywords:** Carbon tax; green tax reform; intergenerational incidence; distributional impacts; overlapping generations; climate policy.

**JEL Codes:** H23, Q52, D91, Q43, C68

<sup>\*</sup>This paper has been written for a special issue of Climate Change Economics as part of the Energy Modeling Forum (EMF) 32 study, which focuses on carbon pricing and revenue recycling in the context of future U.S. climate policies. The analysis presented in the paper therefore closely adheres to the policy scenarios that were pre-defined in the EMF32 study.

<sup>†</sup>This paper contains supplementary material available on the journal website. The supplementary material includes details on the nested CES structures for consumption and sectoral production activities.

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# 1. Introduction

The public acceptance for climate mitigation policies depends crucially on how the economic costs of achieving carbon dioxide (CO<sub>2</sub>) emissions reductions are distributed among heterogeneous socio-economic groups. A plethora of applied research in public and environmental economics has investigated the distributional impacts of market-based regulatory instruments such as carbon taxes or systems of tradable emissions permits focusing on the annual incidence of households (Hassett *et al.*, 2009; Bento *et al.*, 2009; Rausch *et al.*, 2010, 2011; Fullerton and Monti, 2013; Rausch and Schwarz, 2016). Assessments of the economic incidence of carbon pricing based on a comprehensive lifetime perspective of households are, however, scarce.<sup>1</sup> Moreover, the problem of controlling CO<sub>2</sub> emissions naturally involves important trade-offs between current and future generations of households: policies emphasizing more immediate and stringent action in the short run are likely to place higher burdens on current generations whereas delaying emissions reductions will shift the burden to future — but more wealthy — generations.

This paper examines the lifetime incidence and intergenerational distributional impacts of a carbon pricing policy using the example of the U.S. economy.<sup>2</sup> We closely follow the policy scenarios laid out in the Stanford Energy Modelling Forum (EMF) Study 32, thus focusing on a green tax reform, which involves a carbon tax and alternative ways for recycling the carbon revenues, including the option of lowering pre-existing (distortionary) income taxes. We are interested in understanding how the intergenerational incidence is affected by fundamental choices in policy design including (1) the initial level of the carbon tax rate, (2) the growth rate of the carbon tax trajectory of over time, and (3) alternative ways of recycling the revenue back to the economy (lump-sum rebates or cuts in either capital or labor income taxes).

To shed light on the efficiency and intergenerational distributional effects of a carbon tax swap, we build on Rausch (2013) employing a dynamic general-equilibrium overlapping generations (OLG) model for the U.S. economy that is uniquely well-suited for assessing the impacts of a carbon price on the macro-economy, its interactions with important fiscal tax distortions, and the public budget (including government spending and income from a range of different tax instruments). Our model setup is similar to Auerbach and Kotlikoff (1987) and Altig *et al.* (2001) where households with rational expectations live for a finite number of periods and maximize their lifetime utility by choosing optimal life-cycle consumption and savings behavior. A key difference is the disaggregated multi-sectoral production structure of the model including intermediate production, specific detail on the energy sector

<sup>1</sup>Rausch (2013), Williams *et al.* (2015), and Carbone *et al.* (2013) focus on the intergenerational implications of public debt consolidation financed through a carbon tax. Also in a setting with overlapping generations, Gonand and Jouvét (2015) examine the interrelation between the demographic structure of a country and the size of efficiency gains associated with using the revenue from environmental taxes to lower pre-existing tax distortions.

<sup>2</sup>Importantly, in our analysis we only consider the impacts in terms of economic cost. Considering the benefits from environmental protection, which are likely to vary by age and cohort, is beyond the scope of this paper.

both in terms of primary energy carriers and energy-intensive industries, and sector- and fuel-specific carbon inputs.<sup>3</sup> The model thus combines elements of a standard Auerbach and Kotlikoff (1987)-type OLG approach with those of energy-economy models typically employed to investigate climate policy issues (see e.g., Paltsev *et al.*, 2005; Caron *et al.*, 2012).

Our analysis shows that carbon pricing brings about large differences in the welfare impacts across generations and that these crucially depend on policy design. Focusing on the impact of the carbon tax itself, i.e., without considering revenue recycling, we find, firstly, that current generations born before the tax is introduced experience smaller welfare losses, or even gains, as compared to future generations born after the introduction of the tax. While current generations are exposed less to higher future prices of consumption, they also benefit from an increase in the value of their capital assets. Secondly, for sufficiently low increases in the tax rate over time, the pattern of impacts across generations is U-shaped with the highest welfare loss occurring for the generation born when the tax is introduced. Future generations born after the introduction of the tax are worse off compared to a situation without a carbon tax but the losses diminish as the marginal productivity of factors of production partly recovers along the transition to a new long-run equilibrium. For sufficiently high increases in the tax rate over time, the losses for successive future generations increase.

Layering on top of a carbon tax policy the distributional impacts from alternative ways for revenue recycling, we find that for future generations born after the introduction of the tax, the negative welfare impacts are the smallest (largest) when revenues are recycled through lowering pre-existing capital income taxes (through per-capita lump-sum rebates); the welfare impacts under labor tax recycling fall in between these two cases. For current generations born before the introduction of the tax, no clear ranking among the three revenue recycling options emerges but rather the pattern of intergenerational impacts depends on the recycling instrument. We find that lump-sum rebates favor very old generations, labor income tax recycling favors very young generations, and capital income tax recycling favors generations of intermediate age.

Despite the different distributional effects for current generations across different revenue recycling options, our main insight is that recycling the carbon revenue via reductions in capital income taxes is most beneficial for the vast majority of current and future generations. The reason is that the distortions associated with pre-existing capital income taxes are higher than for labor income. This also reflect that lowering the user of cost of capital provides additional incentives for investment, in turn yielding positive growth effects which compound over time.

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<sup>3</sup>Fried *et al.* (2017), also based on an OLG framework but without sectoral differentiation of carbon intensity across sectors, examine how the welfare impact of carbon tax and revenue recycling differs between agents born in the future steady state and agents alive at the time of implementing the policy. Similarly, Chioleu-Assouline and Fodha (2014) use a macroeconomic single-commodity OLG framework to examine environmental tax reforms involving a mix of pollution taxes and labor tax cuts.

The remainder of this paper is structured as follows. Section 2 describes the analytical framework and how we calibrate and solve the numerical model. Section 3 lays out the policy scenarios, provides some basic conceptual considerations about inter-generational incidence of a carbon tax, and presents and discusses our simulation results. Section 4 concludes.

## 2. The Model

### 2.1. Overlapping generations households

Time is discrete and the economy is populated by overlapping generations. A new generation of households  $g$  is born at the beginning of year  $t = g$  and exits at the end of year  $t = g + N$ .<sup>4</sup> The generation  $g$  is endowed with  $\omega_{g,t} = \omega(1 + \gamma)^g$  units of time in each period  $g \leq t \leq g + N$ .<sup>5</sup>  $\gamma$  denotes the exogenous steady-state growth rate of the economy.<sup>6</sup>

In each period households allocate their time between labor and leisure. We assume that households are forward-looking with perfect foresight over their finite lifetime. Full consumption,  $z_{g,t}$  consists of leisure time,  $l_{g,t}$ , and (material) consumption,  $c_{g,t}$  in a constant-elasticity-of substitution (CES) function. Lifetime utility of generation  $g$ ,  $u_g$ , is of the constant-intertemporal- elasticity-of substitution form (CIES) and thus additively separable over time. Each generation chooses optimal consumption and leisure paths over their lifecycle subject to lifetime budget and time endowment constraints. The lifetime utility maximization problem for generation  $g$  is given by

$$\begin{aligned}
 \max_{c_{g,t}, l_{g,t}} u_g(z_{g,t}) &= \sum_{t=g}^{g+N} \left( \frac{1}{1 + \hat{\rho}} \right)^{t-g} \frac{z_{g,t}^{1-1/\sigma}}{1 - 1/\sigma} \\
 \text{s.t. } z_{g,t} &= (\alpha c_{g,t}^\nu + (1 - \alpha) l_{g,t}^\nu)^{1/\nu} \\
 \sum_{t=g}^{g+N} p_{y,t} c_{g,t} &\leq p_{k,0} \bar{k}_g + \sum_f p_{f,t} \bar{z}_{f,g} + \sum_n p_{n,t} \bar{z}_{n,g} \\
 &+ \sum_{t=g}^{g+N} p_{l,t} (1 - \tau_L) \pi_{g,t} (\omega_g - l_{g,t}) + p_{y,t} \bar{\text{tr}}_{g,t} \\
 l_{g,t} &\leq \omega_g \\
 c_{g,t} &\geq 0, \quad l_{g,t} \geq 0,
 \end{aligned} \tag{1}$$

<sup>4</sup>We use “household” and “generation” interchangeably. Each household represents the number of individuals (with age 20 or older) in a given age group.

<sup>5</sup> $\omega$  is a constant income scaling factor, which is determined in the initial calibration procedure to reconcile household behavior with the aggregate benchmark data.

<sup>6</sup> $\gamma$  should be viewed as a combined growth rate representing exogenous population growth and labor-augmenting technological progress.

where  $\sigma$  is the intertemporal elasticity of substitution,  $\sigma_{cl} = 1/(1 - \nu)$  is the elasticity of substitution between consumption and leisure, and  $\alpha$  determines the relative importance of material consumption *vis-à-vis* leisure consumption.  $\hat{p}$  is the subjective utility discount factor, and  $p_{x,t}, x = \{y, k, l, f, n\}$ , denote the price for the output good, the purchase price of capital asset, the wage rate, the price for the fuel-related natural resource  $f = \{\text{Coal, Natural Gas, Crude Oil}\}$ , and the price of the resource for non-fuel electricity production  $n = \{\text{Nuclear, Hydro, Wind}\}$ , respectively.  $\pi_{g,t}$  is an index of labor productivity over the life cycle.  $z_{f,g}$  and  $z_{n,g}$  denote the endowment with natural resource  $f$  and resource for non-fuel electricity production  $n$  by generation  $g$ .  $\tau_L$  is the labor tax, which is imposed on the wage, and capital tax,  $\tau_K$ , is imposed on the rental rate,  $R_t$ , and depreciated capital as we see in the following equation describing the relationship between capital rental rate and price of capital asset:  $p_{k,t} = (1 - \tau_K)R_t + (1 - \delta)(1 + \tau_K)$ .

Households collect income from the endowments of capital, natural resource and time as well as government transfer ( $\bar{tr}_{g,t}$ ). They first decide how to allocate their lifetime income over time. Given the expenditure for  $z$ , households decide in a second stage how much to spend on consumption and leisure.

It is assumed that endowments of natural resource, resource for non-fuel electricity production and government transfers to households grow exogenously at the steady-state growth rate, and the corresponding income accrues to households in proportion to their population share, where  $\zeta_{g,t} = (1 + \gamma)^g / \sum_{i=t-N}^t (1 + \gamma)^i$ . This implies that endowments of natural resource, resource for non-fuel electricity production and government transfers are constant over the life-cycle.<sup>7</sup>

The allocation of time between leisure and labor as well as the composition of the full consumption between material consumption and leisure differs depending on age. We abstract, however, from age-specific preferences for material consumption.<sup>8</sup>

$\bar{k}_g$  denotes the capital holdings of generation  $g$ . Initial old generations, i.e., generations born prior to period zero, are endowed with a non-zero amount of capital. The initial distribution of capital across these generations is chosen so that the economy is on a balanced growth path (see Sec. 2.7 for details). We assume that newborn households enter with zero capital, i.e., we rule out intergenerational bequests.

## 2.2. Production

For each industry ( $i = 1, \dots, I$ ,  $i = j$ ), gross output ( $Y_i$ ) is produced in each period using inputs of labor ( $L_i$ ), capital ( $K_i$ ), natural resource for fuels including coal, natural

<sup>7</sup>We assume that at any given point in time, the ownership of natural resources is equally distributed among households based on population size. In reality, the distribution of resource ownership may be positively correlated with age and overall asset income. Thus, our estimates of welfare impacts may be biased — although the net impact remains unclear: old generations, on the one hand, may be affected more negatively due to owning disproportionately large resources in dirty energy production while, on the other hand, they may also be better off due to owning disproportionately large resources in clean (i.e., wind- and solar-based) energy production.

<sup>8</sup>Figure S.5 in supplementary material depicts the nested CES structure for material consumption.

gas, and crude oil ( $F_i$ ), and non-fuel resource for electricity production including nuclear, hydro and wind ( $N_i$ ), and produced intermediate inputs ( $X_{ji}$ )<sup>9</sup>:

$$Y_i = F_i(L_i, K_i, F_i, N_i; X_{1i}, \dots, X_{Ii}). \quad (2)$$

We employ constant-elasticity-of-substitution (CES) functions to characterize the production technologies and distinguish five types of production activities in the model: fossil fuels (indexed by  $f$ ), non-fuel electricity (indexed by  $n$ ), refined oil, fuel-generated electricity, agriculture, manufacturing, services, transport, and energy-intensive industries. All industries are characterized by constant returns to scale — except for fossil fuels and non-fuel electricity, which are produced subject to decreasing returns to scale — and are traded in perfectly competitive markets.<sup>10</sup>

As an example, we show the production function for fossil fuel  $f$ . A nested CES function is used to combine a fuel-specific resource, capital, labor, and intermediate inputs:

$$Y_f = [\alpha_f R_f^{\rho_f^R} + \nu_f \min(X_{1f}, \dots, X_{If}, V_f)^{\rho_f^R}]^{1/\rho_f^R}, \quad (3)$$

where  $\alpha, \nu$  are share coefficients of the CES function and  $\sigma_f^R = 1/(1 - \rho_f^R)$  is the elasticity of substitution between the resource and the primary-factors/materials composite. The primary factor composite is a Cobb–Douglas function of labor and capital:  $V_f = L_f^{\beta_f} K_f^{1-\beta_f}$ , where  $\beta$  is the labor share.

### 2.3. Aggregate demand and capital accumulation

The demand side of our aggregate economy in time period  $t$  is characterized by national account balances relating capital income ( $W_t$ ), labor income ( $L_t$ ), income from natural resource ( $Z_t$ ), government transfers ( $T_t$ ), private sector consumption ( $C_t$ ), public sector consumption ( $G_t$ ), investment ( $I_t$ ), net exports ( $NX_t$ ), and tax rates on capital, labor, consumption, output, and carbon emissions. These include the aggregate income balance

$$W_t + L_t + Z_t + T_t = C_t + G_t + I_t + NX_t. \quad (4)$$

In period  $t$ , gross investments ( $I_t$ ) add to the next periods capital stock ( $K_{t+1}$ ) according to the standard accumulation equation:

$$K_{r,t+1} = (1 - \delta)K_{r,t} + I_t, \quad (5)$$

where  $\delta$  is the constant depreciation rate and where  $I_t$  is a Leontief composite of inputs. For simplicity, the model abstracts from capital adjustment costs. Savings and labor are supplied as a results of intertemporal optimization decisions by the different generations of households.

<sup>9</sup>We abstract from the various tax rates that are used in the model for reducing notational burden. The model includes ad-valorem output taxes, corporate capital income taxes, payroll taxes (employers' and employees' contribution), and import tariffs. We also suppress the time index here.

<sup>10</sup>The nested CES structures for each sector are depicted in Figs. S.1–S.4 in supplementary material.

## 2.4. International trade

Domestic goods are differentiated with foreign goods following the [Armington \(1969\)](#) assumption in the context of the small open economy of the US. The price of the foreign goods is denominated by the foreign exchange rate. Following the small-open economy model of [Rasmussen and Rutherford \(2004\)](#), we assume that along the reference path, the current account deficit and GDP grow at the same rate. For the counterfactual policy scenarios, we hold the sum of present values of the current account deficits constant at the reference level by endogenously adjusting the foreign exchange rate.

The total supply of good  $i$  is a CES composite of a domestically produced variety and an imported one

$$X_i = [\psi_i^m ZD_i^{\rho_i^m} + \xi_i^m ZM_i^{\rho_i^m}]^{1/\rho_i^m}, \quad (6)$$

where  $ZD$  is domestic goods and  $ZM$  is imported goods. The  $\psi_m$ 's and  $\xi_m$ 's denote the CES share coefficients and the Armington substitution elasticity between domestic and the imported varieties in these composites is  $\sigma_i^m = 1/(1 - \rho_i^m)$ . Domestically produced goods,  $Y$ , are transformed into exports,  $ZX$ , and domestic supply,  $ZD$ , according to a constant elasticity-of-transformation (CET) function

$$[\psi_i^x ZD_i^{\rho_i^x} + \xi_i^x ZX_i^{\rho_i^x}]^{1/\rho_i^x} = Y_i, \quad (7)$$

where the  $\psi_x$ 's and  $\xi_x$ 's denote the CET share coefficients and  $\sigma_i^x = 1/(1 + \rho_i^x)$  is the transformation elasticity between domestic and exported varieties in these composites.

## 2.5. Emissions

We consider only the carbon emissions generated through fossil fuel combustion, which occurs in fixed proportions to the consumption of fossil fuels in industry and final demand sectors. A carbon pricing policy works to reduce CO<sub>2</sub> emissions through various channels: (i) reductions in sectoral output, (ii) switching toward fuels with lower carbon intensity, and (iii) substitution of fossil energy inputs with non-energy (e.g., capital, labor, other material) inputs.

## 2.6. Computational strategy

To approximate the infinite horizon economy by a finite-dimensional complementarity problem, we follow the “state-variable targeting” approach outlined in [Lau et al. \(2002\)](#). Assuming that households' utility functions are time-separable, one can decompose the infinite-horizon economy into two distinct problems with one running from  $0, \dots, T$  and the other one running from  $T + 1, \dots, \infty$ . Here,  $T$  denotes the last period of the numerical model. The level of post-terminal capital can then be computed endogenously by assuming that investment grows at the same rate as output:  $I_{r,T}/I_{r,T-1} = 1 + \gamma$ .

In addition, we need to determine the distribution of terminal assets, along with the paths for post-terminal consumption of generations which are alive in the post-terminal



years. We follow here [Rasmussen and Rutherford \(2004\)](#). While assets held at the start of the initial period are exogenous, a policy shock to the model may affect savings at a given interest rate and consequently the profile of asset holdings and the trade deficit in the new steady state. Assets held in year  $T$ , which are terminal assets, are therefore computed as endogenous variables such that the model is on a steady-state growth in  $T$ . This implies that the percentage change in welfare, as measured by the equivalent variation ( $ev_{\hat{g}}$ ) of each of the generations living post-terminal periods are of equal magnitude:  $ev_{\hat{g}} = ev_{\hat{g}-1}$ , where  $T - N < \hat{g} \leq T$  identifies generations living beyond the terminal period. Moreover, we need to ensure that consumption profiles of households living post-terminal periods are held at the steady-state level. Given the post-terminal consumption demands by these generations, this requires that the price path for consumption goods declines with the interest rate consistent with a steady-state projection of the terminal-period price of consumption.

We formulate the equilibrium of the OLG economy as a mixed complementarity problem (MCP) ([Mathiesen, 1985](#); [Rutherford, 1995](#)). Our solution approach comprises two classes of equilibrium conditions: zero profit and market clearance conditions. The former condition determines activity levels and the latter determines prices. Numerically, we formulate the problem using the General Algebraic Modeling System (GAMS) and use the Mathematical Programming System for General Equilibrium (MPSGE) ([Rutherford, 1999](#)) and the PATH solver ([Dirkse and Ferris, 1995](#)) to solve for equilibrium prices and quantities.

## 2.7. Data and calibration

We make use of social accounting matrices (SAMs) that are based on data from the Global Trade Analysis Project (GTAP) Version 9 ([Aguar \*et al.\*, 2016](#)).<sup>11</sup> Table 1 shows the primary factors of production and commodities in our model. The five energy commodities are directly taken from GTAP whereas the five non-energy commodities are aggregations of commodities detailed in the GTAP data. Primary factors in the dataset include labor, capital and natural resource. Benchmark expenditures on government services and the trade deficit are directly taken from the GTAP data. Based on [Congressional Budget Office \(2012\)](#), our central case assumes that benchmark labor and capital income tax rates are 30% and 17%, respectively. We follow the standard calibration procedure in multi-sectoral numerical general equilibrium modeling (see, for example, [Rutherford, 1995](#); [Harrison \*et al.\*, 1997](#); [Böhringer \*et al.\*, 2016](#)) according to which production and consumption technologies are calibrated to replicate a single-period reference equilibrium consistent with the SAM data in the base year.<sup>12</sup>

<sup>11</sup>The GTAP dataset provides consistent global accounts of production, consumption, and bilateral trade as well as consistent accounts of physical energy flows and carbon dioxide emissions. The dataset identifies 140 countries and 57 commodities, and we aggregate all the non-US countries and regions into an aggregate “Rest of the World” region which is used to calibrate international trade flows for the small open economy.

<sup>12</sup>A more detailed explanation can be found in, for example, [Rutherford \(2002\)](#).



Table 1. Model details.

Primary factors of production	Commodities (GTAP code)
Capital	Crude oil (OIL)
Labor	Coal mining (COA)
Resource	Natural gas extraction (GAS)
	Refined oil (P-C)
	Electricity (ELY)
	Agriculture <sup>a</sup>
	Energy-intensive industries <sup>a</sup>
	Transportation <sup>a</sup>
	Services <sup>a</sup>
	Manufacturing <sup>a</sup>

Note: <sup>a</sup>Indicates that the commodity is based on an aggregation of several commodities which are represented in the original GTAP data.

To describe the evolution of labor productivity over the life cycle, we assume the following age-dependent productivity profile:

$$\pi_{gt} = \exp(\lambda_0 + \lambda_1(t - g + 21) + \lambda_2(t - g + 21)^2 + \lambda_3(t - g + 21)^3).$$

The  $\lambda$ s are chosen based on the respective averages of age-specific labor productivity for households belonging to various income groups as provided in Altig *et al.* (2001).<sup>13</sup>

Table 2 provides the chosen values for the response parameters in the functional forms describing production and consumption technologies (see Figs. S.1 to S.5 in supplementary material for how each parameter enters the nested CES functions).

We create a “no carbon-policy” reference path of the economy which is consistent with the projections of the Annual Energy Outlook by Energy Information Administration (2016). This involves the following steps. First, we follow Rasmussen and Rutherford (2004) and solve the utility maximization problem of a reference generation along a balanced growth path. Second, we calibrate the model to a steady-state baseline which is set up based on the outcomes of the reference generation and an extrapolation of the 2015 Social Accounting Matrix using exogenous assumptions on the growth rate of output ( $\gamma$ ), the interest rate ( $\bar{r}$ ), and the capital depreciation rate ( $\delta$ ).<sup>14</sup> Third, we modify this steady-state path in two ways: (i) we modify the government deficit such that the ratio of government debt to GDP does not exceed 1<sup>15</sup> and (ii) we implement autonomous energy efficiency improvements (AEEI) such that energy demand for each fuel type is consistent with projections provided by the Annual Energy Outlook (Energy Information Administration, 2016).

<sup>13</sup>Specifically, the parameter values are:  $\lambda_0 = 1.0785$ ,  $\lambda_1 = 0.0971$ ,  $\lambda_2 = -0.0015$ , and  $\lambda_3 = 7 \times 10^{-6}$ . Figure S.6 in supplementary material shows the calibrated labor productivity profile over the life cycle.

<sup>14</sup>While the GTAP benchmark year is 2011, we do a forward calibration to 2015, which is the benchmark year in this model, by using the forecast of GDP and energy demand from the World Energy Outlook 2015 (IEA, 2015).

<sup>15</sup>Assuming that the debt/GDP ratio in 2015 is 70%, the government deficit has to be decreased from 2065 onward to maintain the debt/GDP ratio.

Table 2. Reference values of substitution elasticities for production and consumption technologies.

Parameter	Substitution margin	Value
$\sigma_{en}$	Energy (excluding electricity)	1.0 <sup>a</sup>
$\sigma_{enoe}$	Energy — electricity	0.5 <sup>a</sup>
$\sigma_{eva}$	Energy/electricity — value-added	0.5 <sup>a</sup>
$\sigma_{va}$	Capital — labor	1.0 <sup>a</sup>
$\sigma_{klem}$	Capital/labor/energy — materials	0 <sup>a</sup>
$\sigma_{cog}$	Coal/oil — natural gas in ELE	1.0 <sup>a</sup>
$\sigma_{co}$	Coal — oil in ELE	0.3 <sup>a</sup>
$\sigma_{nele}$	Resource — Capital/labor/energy/materials in non-fuel ELE	Calibrated
$\sigma_{rkln}$	Capital/labor/materials — resource	0 <sup>a</sup>
$\sigma_{gr}$	Capital/labor/materials — resource in primary energy	Calibrated
$\sigma_{govinv}$	Materials — energy in government and investment demand	0.5 <sup>a</sup>
$\sigma_{ct}$	Transportation — Non-transport in private consumption	1.0 <sup>a</sup>
$\sigma_{ec}$	Energy — Non-energy in private consumption	0.25 <sup>a</sup>
$\sigma_c$	Non-energy in private consumption	0.25 <sup>a</sup>
$\sigma_{ef}$	Energy in private consumption	0.4 <sup>a</sup>
$\sigma_i^D$	Foreign — domestic	4
$\Sigma$	Intertemporal elasticity of substitution	0.65
$\sigma_{cl}$	Leisure — material consumption	0.9
$A$	Weight on material consumption in full consumption	0.5

Note: <sup>a</sup>Parameter values are based on Paltsev *et al.* (2005) and Rausch (2013).

We solve the model for 150 years (i.e.,  $T = 150$ ) and assume that the deterministic lifespan of households is 50 years ( $N = 49$ ).<sup>16</sup> To reduce computational complexity, we solve the model with five-year time steps. Moreover, we assume that households are born into the economy at age 20 (and thus die at the age of 70).<sup>17</sup>

3. Assessing the Intergenerational Incidence of a Green Tax Reform

This section lays out the policy scenarios and provides some basic conceptual considerations for the main drivers shaping the inter generational incidence of a carbon tax swap. We then present and discuss our simulation results for the main policy scenarios.

3.1. Focus of the analysis: Policy design features of a carbon tax swap

We focus in our analysis on the following aspects of designing a carbon tax swap for the U.S. economy<sup>18</sup>:

- (i) the initial level of the carbon tax rate, considering \$25 or \$50 per ton of CO<sub>2</sub>,

<sup>16</sup>Given our computational strategy for terminal approximation, we have verified that  $T = 150$  is sufficient to achieve convergence towards a new steady-state equilibrium after policy shocks have been implemented.

<sup>17</sup>Households in our model thus live from age 20 to 70. We do not include persons older than 70 years as the fraction of the US population of this group is relatively small (9%) compared to the size of the working-age population between 20 and 70 (64%) (U.S. Census Bureau, 2016).

<sup>18</sup>While other aspects for policy design are conceivable, our choice is driven by the overarching policy scenarios studied in the EMF32 study.

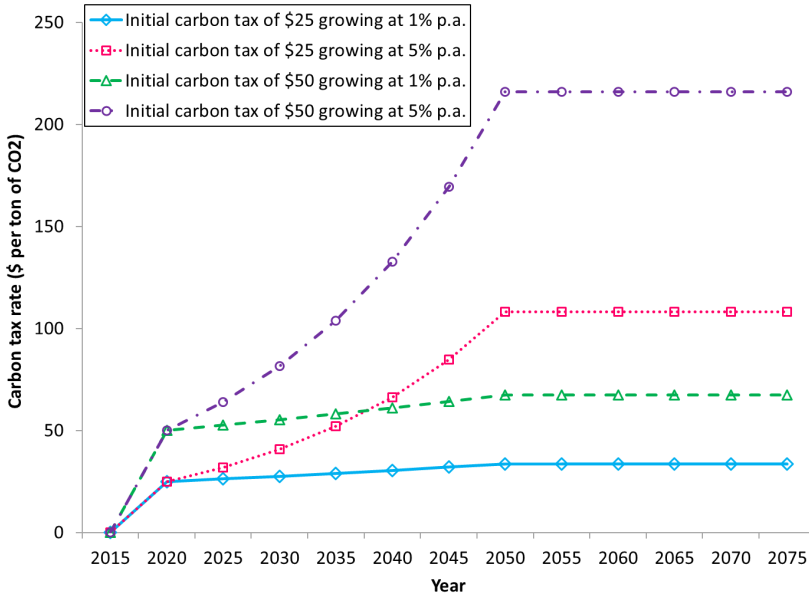


Figure 1. Carbon tax trajectories over time.

- (ii) the growth rate of the carbon tax trajectory, considering 1% or 5% growth per year, and
- (iii) alternative revenue recycling options comprising lump-sum, capital income tax, or labor income tax recycling as well the case of “no revenue recycling”.

With respect to (i) and (ii), we assume throughout that the carbon tax is announced in year 2015 and implemented in year 2020, and it increases at the respective annual growth rate until 2050; it is assumed to stay constant at 2050-level thereafter. We assume throughout that the tax shocks imposed are fully anticipated by agents. Figure 1 shows the different assumed carbon tax trajectories.

With respect to (iii), we assume that revenues raised by the carbon tax in a given year — net of what has to be retained to compensate for any tax-base erosion effects associated with other, pre-existing taxes — are returned to the economy. The equal yield constraint to determine the endogenous level of the recycling instrument assumes that real government spending in a given year is held fixed at the “no-policy” reference level. With “no revenue recycling” the carbon revenue increases government spending (which, given the absence of a public good, has no direct impact on households’ welfare).

### 3.2. Main drivers of the intergenerational incidence: Some basic conceptual considerations

The economic incidence of a carbon tax is generally determined by how households are impacted on their expenditure and income side (Atkinson and Stiglitz, 1980). Differences in impacts arise because in the OLG setting the composition of both expenditures and income varies depending on age. Given a humped-shaped labor

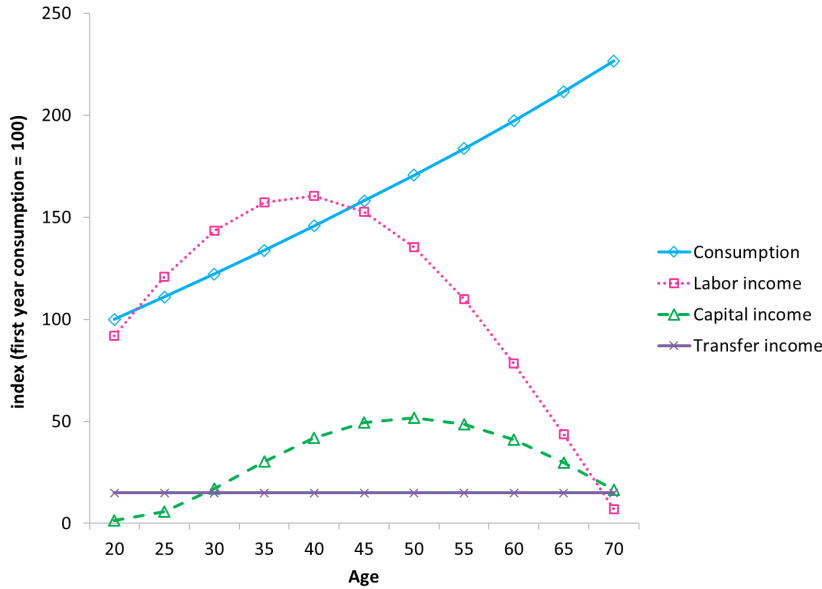


Figure 2. Calibrated life-cycle profiles for consumption and income (by type) along steady-state reference path.

productivity profile over the life cycle and the desire to smooth consumption over the lifetime, households derive a high share of their income from labor when young and accumulate savings which are then consumed when labor productivity declines with increasing age. Figure 2 shows the calibrated income profiles by age along the “no-policy” balanced growth path for “future” generations, i.e., those born after the first period of the model (i.e., year 2015). This implies that, for example, a drop in wages will hit middle-aged households with relatively high labor productivity more than old generations. Heterogeneous impacts can also arise on the expenditure side. First, households of different age differ with respect to their propensity to consume (or save). For example, if the price for aggregate consumption increases following a carbon tax, older generations with a higher propensity to consume are hit more (everything else equal) than younger generations which use a higher share of their income to accumulate future savings. Second, the impacts across generations may differ to the extent that households’ preferences for consumption goods vary by age.

Following a carbon tax policy, all households will be affected identically once the economy has reached a new steady-state equilibrium. The intergenerational incidence can, however, differ largely for generations alive during the transition period. For “current” generations, i.e., those who were born before or in the first period of the model (before year 2015), the main driver is the heterogeneity with respect to the composition of income. Figure 3 shows the composition of income by income source for “current” generations. Generations born before 2015 own shares of the existing capital stock of the economy at time  $t = 0$ . Consistent with the steady-state reference calibration of our model, we have inferred the distribution of capital assets among

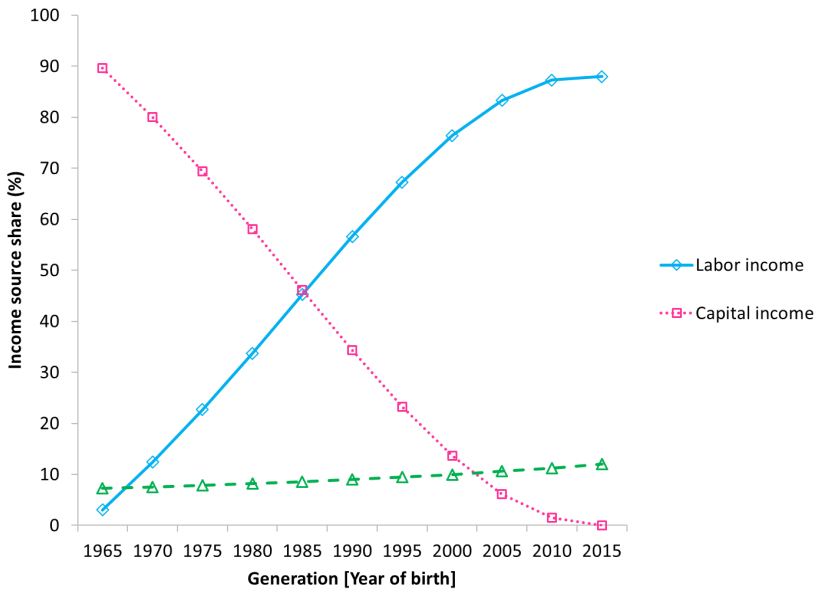


Figure 3. Composition of income by source for “current” generations, i.e., those alive at first period ( $t = 0$ ).

these generations from the calibrated life-cycle capital income profiles as shown in Fig. 2. As the share of capital income increase with age, generations born earlier derive a larger share of income from capital (for example, the generation 1965 has a higher capital income share than generation 2010). Similarly, the younger a generation, larger is the share of income from labor. Thus, for a given change in the rental rate for capital or the wage rate, “current” generations are impacted differently. In addition, the impacts may also vary as a carbon tax affects the returns to capital and labor differently.

As with “current” generations, the impacts of a carbon tax for “future” generations depend on the composition of income. As the income composition is identical for “future” generations along the reference path, differences in the impacts among households depend on when a household is born into the economy and how the household is exposed to the carbon tax over the (remaining) lifetime. The timing is important even for a carbon tax which is constant over time as the returns to capital and labor change over time along the transition of the economy to a new long-run equilibrium.

### 3.3. $CO_2$ emissions impacts

We begin by analyzing the annual  $CO_2$  emissions impacts relative to the “no-policy” reference scenario where there would be no carbon regulation (see Fig. 4).<sup>19</sup> Unsurprisingly, a higher carbon tax induces higher emissions reductions. Emissions reductions in year 2075 (relative to the reference level) range from 20% to 60% in the least

<sup>19</sup>When portraying the results from the numerical simulations we focus on the first 60 years which is sufficient to characterize the economy’s transition to a new long-run equilibrium.

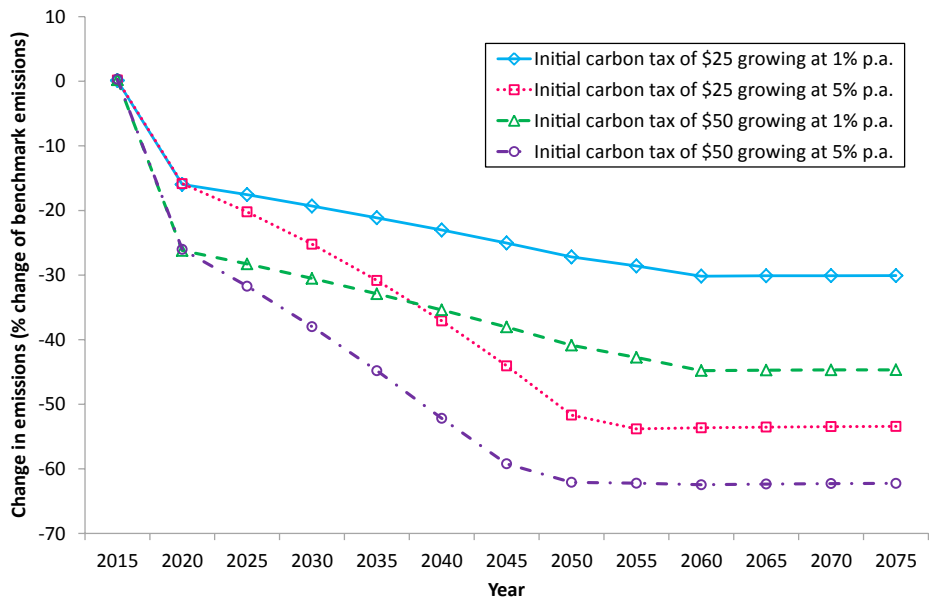


Figure 4. Impact on economy-wide CO<sub>2</sub> emissions over time for non-revenue recycling scenarios.

and most stringent case, respectively. Importantly, the differences in emissions impacts for different revenue-recycling options are negligible (not shown). We can hence compare the welfare impacts for alternative revenue recycling scenarios without discussing the differences in environmental impacts across these scenarios.

### 3.4. Carbon tax scenarios without revenue recycling

To better understand the intergenerational incidence of a carbon tax under different policy designs, we decompose the impacts by first looking at the scenarios without revenue recycling, focusing on the differences which arise when varying the initial carbon tax level and the growth rate of carbon tax trajectory.<sup>20</sup> In a second step, we then consider the impacts of policy proposal, which consider different ways of recycling the carbon tax revenues.

Figure 5 shows the welfare impacts by generation for different initial tax levels (i.e., \$25 and \$50 per ton of CO<sub>2</sub>) rising at 1% per year. Recall that, unless noted otherwise, the carbon tax is imposed from year 2020 onwards. It is evident that the welfare impacts of a carbon tax differ largely across generations.<sup>21</sup> Figure 7 shows the welfare

<sup>20</sup>As the government entity in our model does not employ any capital and labor, we do not capture the possible effects which a change in government spending may have on capital and labor markets.

<sup>21</sup>In addition to percentage changes in welfare, we also report welfare changes in \$. For the reference scenario, the present value of the full income (over the remaining lifetime) is 2.0, 18.2, and 12.9 trillion \$ for generations born in years 1965, 2015, and 2040, respectively. For the case of a carbon tax of \$25 rising at 1% per year, the welfare changes for these generations are 1.8, -45.2, and -28.2 billion \$, respectively.

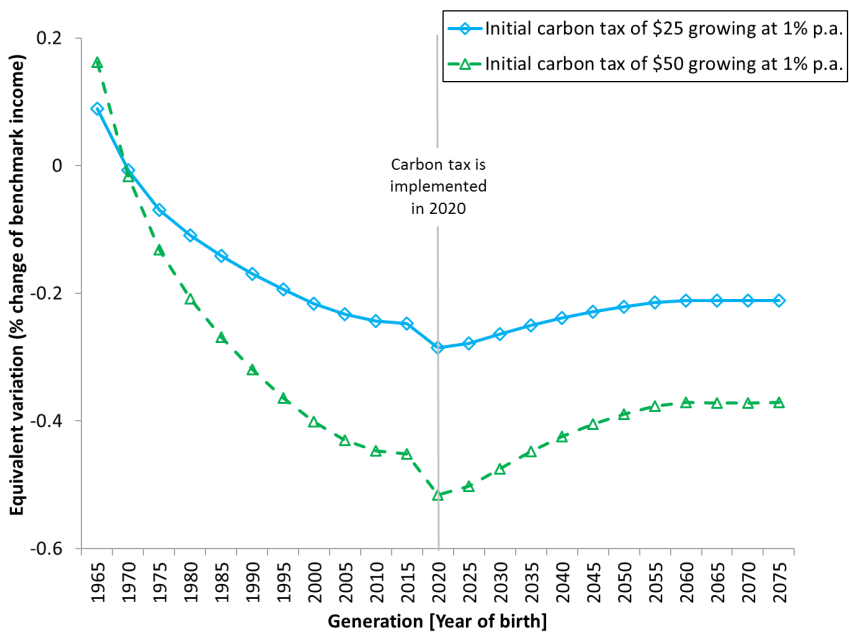


Figure 5. Welfare impacts by generation for carbon tax without revenue recycling for different initial tax levels.

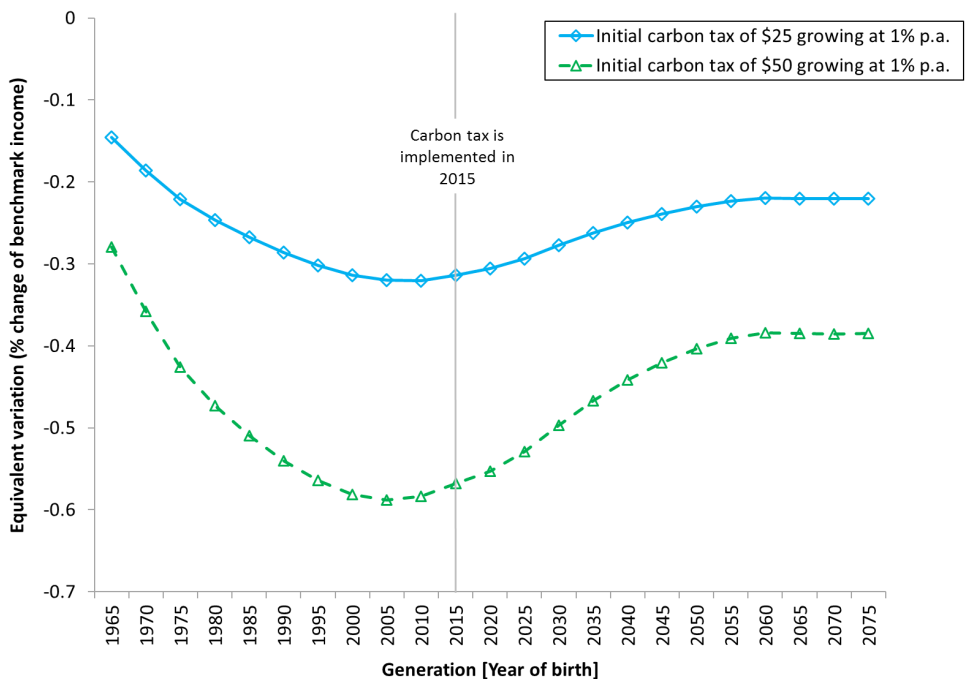


Figure 6. Welfare impacts by generation for carbon tax without revenue recycling for different initial tax levels when tax is introduced in 2015.



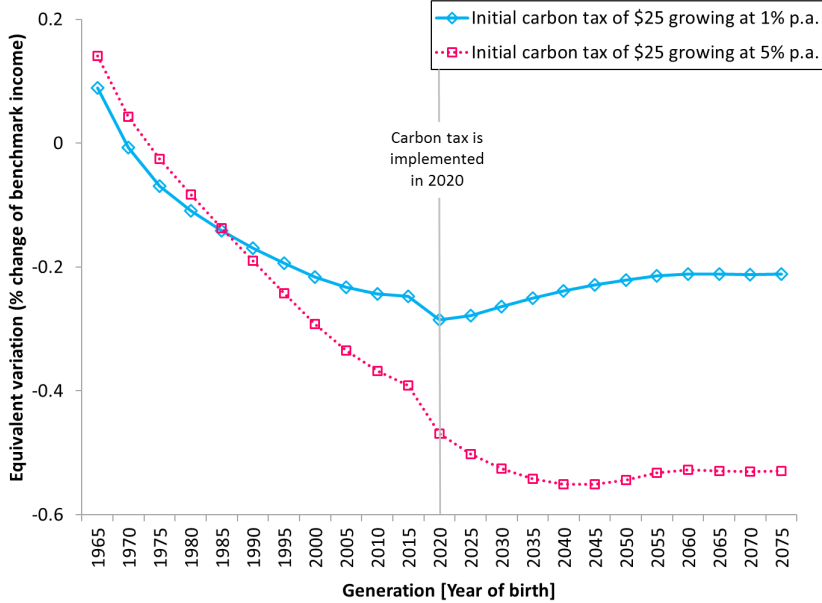


Figure 7. Welfare impacts by generation for carbon tax without revenue recycling for different rates of tax increase.

impacts by generations when the carbon tax rate, starting at \$25 in 2020, is increased by 1% and 5% per year.

**Result 1.** For a carbon tax policy without revenue recycling, the following pattern of intergenerational welfare impacts arises:

- (a) the size of the welfare loss increases for most, but not all, generations in the level of the initial tax rate and the annual rate of increase of the tax trajectory,
- (b) current old generations, i.e., those born before the tax is introduced, experience smaller welfare losses (or even gains) as compared to future generations born after the introduction of the tax,
- (c) for sufficiently low increases in the tax rate over time, the pattern of impacts across generations is U-shaped with the highest welfare loss occurring for the generation born when the tax is introduced, and
- (d) for sufficiently high increases in the tax rate over time, the losses for successive future generations increase.

The economic intuition for the intergenerational pattern of welfare impacts is as follows. First, the introduction of the carbon tax lowers the returns for capital and labor.<sup>22</sup> As the input cost for carbon-intensive fuels increase, the overall cost for production increase hence leading to lower output. This reduces demand for capital

<sup>22</sup>In addition, income is also affected through changes in the value of resources used for fossil-and renewable-based energy production. Relative to labor and broad-based capital these changes are, however, small.

and labor. In the short run, the limited ability to adjust the supply of factors of production, in particularly capital, thus leads to large decreases in the wage rate and the capital rental rate. Thus, generations born when the tax is imposed or shortly after experience large losses. As the capital stock can be adjusted to a lower level over time through reducing investments, the rental rate on capital recovers.<sup>23</sup> Hence, future generations born after 2020 are less strongly affected. As a higher carbon tax leads to a larger contraction of the economy both throughout the transition and in the long run, the welfare impacts are larger for a higher initial level of the carbon tax.

Second, current old generations experience smaller losses, or even gain, relative to the generation 2020 born when the tax is introduced. There are two reasons behind this finding. First, these generations are only exposed to higher prices for consumption for their remaining lifetime. The younger the age of a generation alive at year 2015, the less it is affected through this channel. Second, agents anticipate the introduction of the tax in year 2020 and already adjust their behavior in year 2015. As the tax increases the price of future consumption relative to current consumption, both income and substitution effects occur. The income effect indicates that households save more today because they will be poorer in the future. The substitution effect indicates that households consume more today and consume less in the future. The substitution effect appears to dominate the income effect, resulting in an increase in output and consumption today, in turn increasing the demand for capital and labor in year 2015. While the labor supply can be adjusted, initial-year capital supply is fixed. Higher capital demand with fixed supply means that there is an appreciation in the value of capital at year 2015. This disproportionately benefits current old generations who finance their current consumption to a large extent through capital income; the appreciation effect diminishes with the age of generations alive in year 2015 (see Fig. 3).<sup>24</sup>

Third, as already discussed in relation to Fig. 5, the appreciation of capital for current old generations reduces the adverse welfare impacts and yields even small gains for generations born in 1965 and 1970. The more stringent the carbon policy is in later years, the more pronounced is the capital appreciation effect. Thus, when the tax rate is increased at 5% per year current old generations born before 1985 are better off as compared to the case when the annual increase occurs at 1% only (see Fig. 7). Moreover, the burden for future generations relative to current generations is larger in the case of a higher growth rate of the carbon tax. This is, of course, unsurprising as higher future carbon prices imply higher cost of consumption in the future. As discussed before, under the 1% increase scenario, the adjustment of the economy after the tax is introduced in 2020 implies that the welfare loss for generation 2020 is the largest with future generation incurring smaller losses. When the tax rate is increased at 5%

<sup>23</sup>Note that by assuming perfect sectoral mobility of capital and no adjustment costs, we may underestimate the inertia in capital adjustments and overestimate the recovery of capital price.

<sup>24</sup>To verify the presence of the capital appreciation effect, we have implemented a carbon tax policy starting in the first year of the model, i.e., year 2015. Figure 6 shows that all current generations are worse off when the appreciation effect is absent.

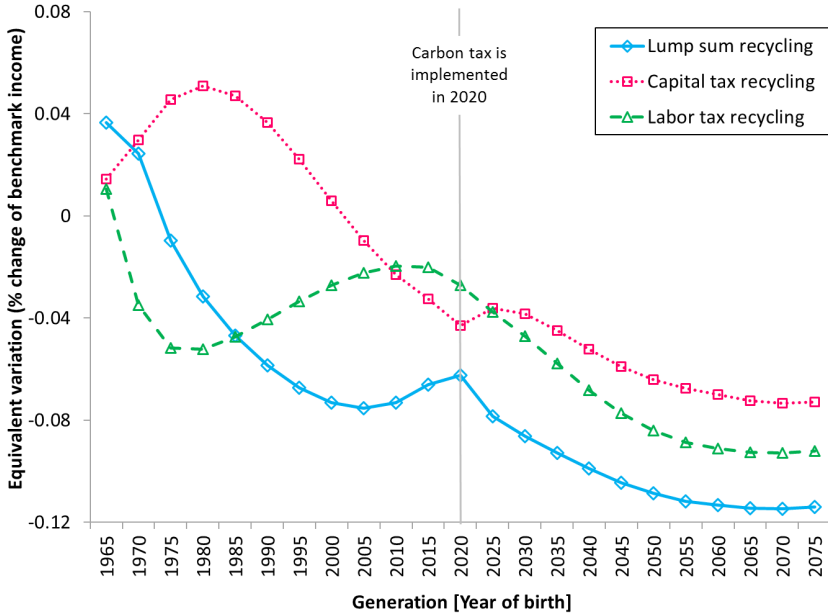


Figure 8. Welfare impacts by generation for alternative revenue recycling options relative to “no carbon policy” (for initial carbon tax \$25 growing at 1% p.a.).

per year, however, the economy stabilizes at a lower level implying that the welfare losses for generations born after 2020 increase further.

### 3.5. Carbon tax scenarios with revenue recycling

Equipped with the intuition for the intergenerational welfare impacts of a carbon tax policy without revenue recycling, we now turn to analyzing the green tax reform scenarios which involve reductions in pre-existing distortionary marginal income taxes which are financed through the carbon tax revenue.

Figure 8 shows the welfare impacts by generation for an initial carbon tax rate of \$25 growing at 1% per year for alternative revenue recycling options (per capita lump-sum rebates, capital income tax recycling, and labor income tax recycling).<sup>25</sup> To help focus on the welfare impacts due to revenue recycling, Fig. 9 plots the welfare impacts under revenue recycling relative to the case without revenue recycling.

**Result 2.** For a carbon tax policy with revenue recycling, the following pattern of intergenerational welfare impacts arises:

- (a) for future generations born after the introduction of the tax, the negative welfare impacts are the smallest (largest) when revenues are recycled through lowering

<sup>25</sup>As the patterns of the intergenerational incidence are largely similar for different initial carbon tax levels and growth rates of the tax over time, we focus in our discussion on the case presented in Fig. 8. Of course, the higher the initial tax rate and/or the growth rate the more negative the welfare impacts.

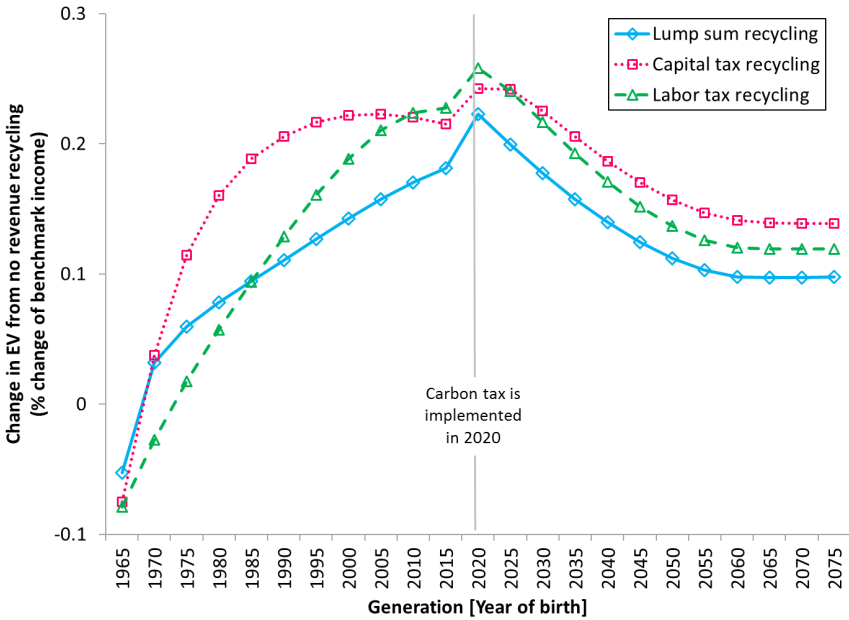


Figure 9. Welfare impacts by generation for alternative revenue recycling options relative to “no revenue recycling” (for initial carbon tax \$25 growing at 1% p.a.).

pre-existing capital income taxes (through per-capita lump-sum rebates); the welfare impacts under labor tax recycling fall in between these two cases, and (b) for current generations born before the introduction of the tax, no clear ranking among the three revenue recycling options emerges:

- (b1) lump-sum rebates favors very old generations;
- (b2) labor tax recycling favors very young generations; and
- (b3) capital tax recycling favors generations of intermediate age.

With regard to Result 2(a), the ranking of welfare impacts under alternative revenue recycling options reflects the efficiency cost of pre-existing taxes, which are largest with capital income taxes. While the efficiency cost associated with taxing labor income is smaller relative to taxing capital, still some efficiency gains can be achieved by lowering labor taxes. In contrast, recycling the carbon revenues through lump-sum rebates forgoes any efficiency gains associated with lowering pre-existing taxes. Hence, the welfare losses under lump-sum rebates are the largest. The welfare ranking is also consistent with the changes in the capital rental and wage rates (see Figs. 10 and 11). Both factor prices are affected most negatively among the three recycling cases under lump-sum. The long-run impact on the wage rate is roughly similar for capital and labor tax recycling, while the impact on capital rental rate is positive only for capital tax recycling.<sup>26</sup>

<sup>26</sup>In all three recycling cases, we see that the relative price of capital to labor increases. This is consistent with the fact that capital supply is more elastic than labor supply given the model specification.

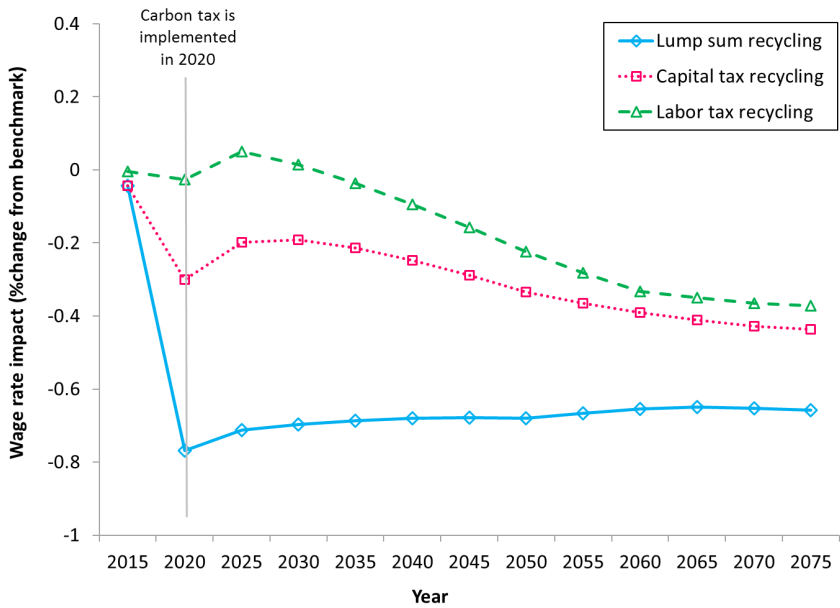


Figure 10. Wage impacts over time for alternative revenue recycling options relative to “no carbon policy” (for initial carbon tax \$25 growing at 1% p.a.).

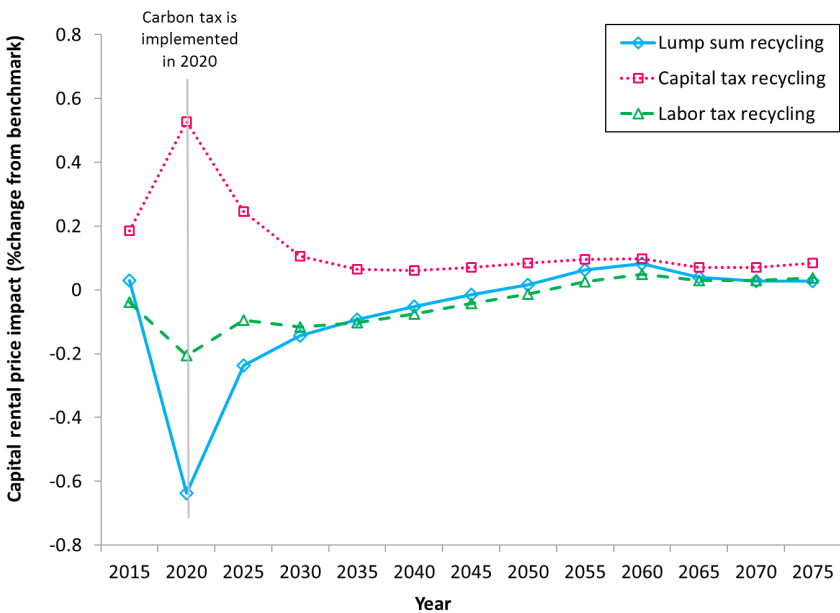


Figure 11. Capital rental rate impacts over time for alternative revenue recycling options relative to “no carbon policy” (for initial carbon tax \$25 growing at 1% p.a.).

With regard to Result 2(b), the reason for the difference in distributional impacts across current old generations lies in the age-specific heterogeneity of the income composition (see Fig. 3). Lump-sum rebates are only desirable for very old generations who do not care about generating future income. In this case, giving a direct rebate of the carbon revenue benefits these generations the most — despite the fact that the lump-sum recycling forgoes potential efficiency gains by leaving the distortionary income taxes unchanged. Using the carbon tax revenues to lower labor taxes benefits those generations most whose labor productivity is relatively high, i.e., younger generations building up assets at their beginning of their lifetime. The fact that impacts under labor tax recycling for generations born before the introduction of the tax are described by an U-shaped curve reflects the presence of the capital appreciation effect which positively impacts welfare; see discussion of Result 1(b). While this effect dominates for very old generations, it diminishes with age. For the cases of tax recycling, the pattern of factor price changes over time shown in Figs. 10 and 11 are consistent with the welfare changes of current old generations shown in Fig. 8; for the case of lump-sum recycling, the welfare effect due to the direct tax rebate also has to be taken into account.

Despite the different distributional effects for current generations across different revenue recycling options, our main insight is that recycling the carbon revenue via reductions in capital income taxes is most beneficial for the vast majority of generations. The reason is that the distortions associated with pre-existing capital income taxes are higher than for labor income. This also reflect that lowering the user cost of capital provides additional incentives for investment, in turn yielding positive growth effects which compound over time.

Table 3 takes another perspective at this insight. It shows the gross revenue collected from the CO<sub>2</sub> tax and the share of this revenue which is effectively available

Table 3. Gross CO<sub>2</sub> tax revenue, revenues recycled, and (changes) in equal-yield instruments.

	2015	2020	2050	2070
Gross CO <sub>2</sub> revenue [billion \$] <sup>a</sup>	0	113.4	141.1	180.0
Percentage share of gross carbon revenue available for recycling				
Lump sum	—	68.8	58.9	46.1
Capital income tax (%)	—	95.4	87.4	69.0
Laobr income tax (%)	—	107.5	92.2	69.8
Equal-yield instrument				
Lump-sum rebates in % of total consumption	0	0.6	0.3	0.2
Capital income tax rate	0.170	0.146	0.156	0.161
Labor income tax rate	0.300	0.288	0.294	0.296

Note: <sup>a</sup>Gross CO<sub>2</sub> refers to the total carbon revenue, i.e., the carbon tax rate times the emissions. The gross revenue is virtually identical across alternative revenue-recycling scenarios.

for recycling purposes. A value smaller than 100% means that parts of the gross revenue have to be retained to maintain government budget neutrality, i.e., to achieve the same level of real government spending. This effect arises as the carbon tax reduces economic activity thereby eroding the tax base and reducing revenues from the non-environmental pre-existing taxes.<sup>27</sup> The revenues available for recycling is by far the smallest under lump-sum recycling. It is larger when income taxes are reduced due to lowering the efficiency cost of pre-existing taxes. For all three revenue-recycling options, the share of the revenue available for recycling decreases over time due to fact that a higher carbon tax implies a larger reduction in the tax base and because the negative growth effects from a carbon tax compound over time.

#### 4. Concluding Remarks

This paper has examined the lifetime incidence and intergenerational distributional impacts of a carbon tax swap using a numerical dynamic general equilibrium model with overlapping generations of the U.S. economy. The analysis has focused on understanding how the intergenerational incidence of carbon tax policy is affected by fundamental policy design choices including the initial level of the carbon tax rate, the growth rate of the carbon tax trajectory of over time, and alternative ways of recycling the revenue back to the economy.

We find that the impacts of a carbon tax policy across generations crucially depend on policy design. Current generations born before the tax is introduced experience smaller welfare losses, or even gain, as compared to future generations born after the introduction of the tax. When the increase in the tax rate over time is moderate, the pattern of impacts across generations is U-shaped with the highest welfare loss occurring for the generation born when the tax is introduced. For sufficiently high increases in the tax rate over time, the losses for successive future generations increase. For future generations born after the introduction of the tax, the negative welfare impacts are the smallest (largest) when revenues are recycled through lowering pre-existing capital income taxes (through per-capita lump-sum rebates). For generations born before the tax is introduced, we find that lump-sum rebates favors very old generations, labor tax recycling favors very young generations, and capital tax recycling favors generations of intermediate age. Overall, our findings suggest that — considering both efficiency and intergenerational equity considerations — recycling carbon revenues through lowering pre-existing capital income is the preferred choice (among the revenue-recycling options considered here).

When assessing the intergenerational incidence of carbon tax with our model, a number of caveats have to be kept in mind. First, we do not consider the benefits from environmental protection. To the extent that these environmental benefits are

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<sup>27</sup>It is possible that this value is higher than 100% due to a strong positive response of labor supply following a labor income tax cut.



systematically linked to age and cohort — for example, health benefits for young and old households due to reduced air pollution — our ability to measure the welfare impacts is hampered. Second, we assume that each generation only cares about own consumption. We thus rule out that the intergenerational transmission of wealth through bequests may smooth some of the differential distributional impacts between generations. Third, by assuming that capital goods are homogeneous, our model adopts an extremely optimistic view with regard to the malleability of sector- and vintage-specific capital and the resulting frictions and cost for adjusting capital stocks in response to a carbon tax. We may thus underestimate the cost of controlling CO<sub>2</sub> emissions. Fourth, while our model incorporates endogenous efficiency improvements in response to changes in relative prices for given production and consumption technologies, we do not consider endogenous technical change which could boost the productivity of energy-saving capital in both the short and long run.<sup>28</sup> Fifth, we do not take into account the heterogeneity of households within each generation, thus abstracting from intra-generational equity considerations which may be associated with carbon pricing and various options of tax recycling. Sixth, the calibration procedure employed in this analysis, following much of the literature using quantitative OLG models (see, for example, Rasmussen and Rutherford, 2004; Rausch, 2009), derives life-cycle income source shares to be consistent with a balanced growth path of the economy. The sensitivity of the intergenerational incidence of a carbon tax with respect to the calibrated life-cycle patterns of capital and labor income has to be scrutinized in future work.<sup>29</sup> In sum, while there are reasons why our model may under- or overestimate the aggregate cost of climate policy through carbon pricing, future research has to investigate how extending our framework in these directions would affect the derived insights regarding the intergenerational incidence of a carbon tax.

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<sup>28</sup>For example, previous analyses using rational-expectations general equilibrium models suggest that the cost of climate policy can be significantly lowered when endogenous growth is driven by increasing gains from specialization within a sector (Bretschger *et al.*, 2011) or, in addition, through knowledge diffusion between sectors and regions (Bretschger *et al.*, 2017).

<sup>29</sup>Incorporating empirical life-cycle income patterns requires a non-steady state calibration of the model (see, for example, Wendner, 1999), which is beyond the scope of the paper.

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