Fiscal Consolidation and Climate Policy: An Overlapping Generations Perspective

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Abstract

We examine the distributional and efficiency impacts of climate policy in the context of fiscal consolidation in a dynamic general-equilibrium overlapping generations model of the US economy. The model includes a disaggregated production structure, including energy sector detail and advanced low- or zero-carbon energy technologies, and detail on government taxes and spending. In contrast to revenue-neutral carbon tax swaps, using the carbon revenue for deficit reduction implies a relaxation of future public budgets as debt repayment results in lower interest obligations. While we show that the intergenerational welfare impacts depend importantly on what tax recycling instrument is used, we find that combining debt consolidation with a carbon policy entails the possibility of sustained welfare gains for future generations. We thus argue that even in the absence of a strong double-dividend result, combining fiscal and climate policy may offer the chance for positive societal gains (without considering potential benefits from averted climate change). Importantly, this may enhance the political support for revenue-raising climate policies that are framed over the next couples of decades.

Keywords: Climate Policy, Fiscal Policy, Deficit Reduction, Carbon Tax, Overlapping Generations
JEL: H6, H23, C68, D91, Q43, Q54

1. Introduction

Putting a price on carbon—which is the most prevalent greenhouse gas—has the potential to address two long-term problems. One is the problem of growing debt in the United States with potentially detrimental implications for economic growth. The revenue from a carbon tax could be used to reduce the deficit or to finance reductions in marginal rates of existing taxes while holding the deficit constant (or a combination of both). The other problem is the build-up of carbon dioxide

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in the atmosphere–the principal anthropogenically sourced greenhouse gas (GHG)–contributing to global climate change derived from burning fossil fuels. Leaving this environmental externality unaddressed is expected to create costly damages.

While an extensive literature has studied the interactions of environmental taxes and the broader fiscal system and the double-dividend (see e.g., Bovenberg & Goulder, 1996)—largely focusing on revenue-neutral carbon tax swaps to fund marginal rate cuts in distortionary taxes—the economic effects of using revenue-raising climate policy to reduce government debt have not been investigated. This paper presents a first attempt to fill this gap by addressing a central question: in the light of weak political support for a greenhouse gas control policy in the United States, can a carbon pricing policy be socially desirable if combined with a fiscal policy aimed at reducing public debt? Using carbon revenues for deficit reduction implies a relaxation of future public budgets as debt repayment results in lower interest obligations. Recycling future budget surpluses by lowering distortionary taxes therefore entails the opportunity of positive and sustained welfare gains for future generations despite increased energy prices due to carbon pricing. Current young and subsequent generations, however, who do not live long enough to reap the benefits of relaxed future public budgets will likely have to bear the burden of deficit reduction.

To shed light on the efficiency and intergenerational distributional effects of such a combined climate and fiscal consolidation policy, we develop a dynamic general-equilibrium overlapping generations (OLG) model for the US economy that is uniquely well-suited to 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 & 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 both in terms of primary energy carriers and energy-intensive industries, and sector- and fuel-specific carbon inputs. The model thus combines elements of a standard Auerbach & 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).

With fiscal consolidation and climate policy as high-priority policy issues in the United States (and many European countries), it seems important to arrive at a better understanding of how the gains and losses from a jointly implemented climate and fiscal policy are determined. While different fiscal reform measures for debt consolidation are conceivable (including contraction in government spending, increases in average and marginal wage tax rates, and other taxes), we focus solely on debt consolidation through raising revenue from a carbon pricing policy. We consider two sets of policy scenarios. A first set of scenarios, following the typical setup found in the "double-dividend" literature, looks at the impact of revenue-neutral carbon tax swaps using either capital, labor, or consumption-based taxes as recycling instruments. A second set of scenarios uses the carbon revenue to repay government debt thereby in turn producing future budget surpluses as a result of reduced interest obligations. These surpluses are then used to fund cuts in capital, labor, or consumption taxes.[1]

Our model produces several surprising results. First, in the context of a conventional revenue-neutral carbon tax swap current old and all future generations incur welfare losses (regardless of the choice for the revenue recycling instrument). In contrast, if the carbon revenue is recycled via repayments of the principal debt the level of future tax rate can be reduced. We find that while elderly households and current young are worse off as compared to a revenue-neutral tax swap, that future generations stand the chance of sustained welfare gains. These gains are larger if future budget surpluses are used to fund rate cuts in marginal capital and labor taxes positively affecting capital and labor supply decisions of households. Second, when we evaluate these outcomes formally, using an explicit social welfare function, we find that revenue-neutral carbon tax swaps results in a negative societal assessment for virtually any combination of social discount rates and inequality aversion. The picture is changed dramatically if debt reduction is considered as a option to recycle the revenue from a carbon pricing policy. For social discount rates of less than 2%, we find that such a combined policy can indeed be desirable from a social standpoint (without considering potential benefits from averted climate change).

Finally, our analysis shows that the benefits from combining climate and debt consolidation policies are limited. While a more stringent carbon policy generates more revenue that can be used to repay government debt, and thus has the potential to result in large reductions of future interest obligations, an aggressive carbon policy at the same time reduces economic growth and brings about lower revenue from other tax sources. We find that moderate carbon policies (in combination with a debt consolidation program) starting with a carbon price of \$20 per ton of CO_2 yield societal welfare gains for social discount rates of up to 2.5% per year. Much lower social discount rates are required to support more stringent carbon policies.

The remainder of this paper is structured as follows. Section 2 presents our analytical framework and discusses issues related to calibration and numerical implementation of the model. Section 3 describes our scenarios and metric to assess efficiency and distributional consideration from a societal perspective. Section 4 present and discusses our results. Section 5 concludes.

2. The Model

2.1. Aggregate Demand and Government Budget

Time is discrete and extends from $t = 0, \dots, \infty$. There is no aggregate or household-specific uncertainty. 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 resources (Z_t), government transfers (T_t), private sector consumption (C_t), private sector net saving (S_t), public sector consumption (G_t), the government budget deficit (M_t), the trade deficit (E_t),

[1] Our analysis is somewhat related to Carbone et al. (2012) who in the context of the US economy examine the welfare impacts of stabilizing the long-term debt-to-GDP ratio at 60%. While their analysis also considers using the revenues from a carbon policy to fund tax cuts—as part of a larger fiscal reform package that includes cutting government spending—, they do not consider the option of debt repayment which results in lower future interest obligations.

investment (I_t), and tax rates on capital, labor, consumption, output, and carbon emissions. These include the aggregate income balance:

$$W_t + L_t + Z_t + T_t = C_t + S_t \tag{1}$$

and the savings-investment balance:

$$S_t - M_t + E_t = I_t\,. \tag{2}$$

The annual identity for the government budget states that the deficit run by the government through year t is equal to the change in the stock of debt (D_t) between (beginning-of-years) $t + 1$ and t:

$$p_t^G G_t + T_t - \Phi_t + rD_t = B_t - R_t = D_{t+1} - D_t\,, \tag{3}$$

where $p_t^G G_t$ is the value of public spending, Φ_t is the tax revenue, r the real interest rate, B_t is additional borrowing, and R_t is repayment of the principal.

Debt repayment affects the net public expenditures (N_t) in current and future periods according to the equation:

$$N_t = R_t + rD_t - B_t = R_t + r\left(D_0 - \sum_{\tau=0}^{t}(R_\tau - B_\tau)\right). \tag{4}$$

The public budget can then be written:

$$p_t^G G_t + T_t + N_t = \Phi_t\,. \tag{5}$$

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

$$K_{r,t+1} = (1 - \delta)\,K_{r,t} + I_{r,t}\,, \tag{6}$$

where δ is the constant depreciation rate and where I_t is a Leontief composite of inputs. Savings and labor are supplied as a results of intertemporal optimization decisions by the different generations of households.

2.2. Overlapping Generations Households

The economy is populated by overlapping generations. A household of generation g is born at the beginning of year $t = g$, lives for $N + 1$ years, and is endowed with $\omega_{g,t} = \omega\,(1 + \gamma)^g$ units of time in each period $g \leq t \leq g + N$, and $\pi_{g,t}$ is an index of labor productivity over the life cycle.[2] In each period over the life cycle households are endowed with units of time that they allocate between labor and leisure.[3] Households are assumed to be forward-looking individuals

[2] ω is a constant income scaling factor which is determined in the initial calibration procedure to reconcile household behavior with the aggregate benchmark data. For more details see Section 2.7.

[3] The size of the generation born at the beginning of year zero is normalized to unity. Note that there is no growth in time endowments over the life cycle. Thus, while the number of households across generations increases over time, the size of a cohort over its life cycle remains constant.

that form rational point expectations (perfect foresight) over the infinite horizon. γ denotes the exogenous steady-state growth rate of the economy. Leisure time, $\ell_{g,t}$, enters in a constant-elasticity-of-substitution (CES) function with consumption, $c_{g,t}$, to create full consumption, $z_{g,t}$. Lifetime utility of generation g in region r, $u_{g,r}$, is additively separable over time and is of the constant-intertemporal-elasticity-of-substitution form (CIES). The representative agent of each generation and type chooses optimal consumption and leisure paths over his life cycle subject to lifetime budget and time endowment constraints. The optimization problem for generation g in region r is given by:

$$\begin{aligned}
\max_{c_{r,g,t},\,\ell_{r,g,t}} u_{r,g}\left(z_{r,g,t}\right) &= \sum_{t=g}^{g+N} \left(\frac{1}{1+\rho}\right)^{t-g} \frac{z_{r,g,t}^{1-1/\sigma}}{1-1/\sigma} \\
s.t. \qquad z_{r,g,t} &= \left(\alpha c_{r,g,t}^{\nu} + (1-\alpha)\,\ell_{r,g,t}^{\nu}\right)^{\frac{1}{\nu}}
\end{aligned}$$

$$\begin{aligned}
\sum_{t=g}^{g+N} p_{r,a,t}\, c_{r,g,t} &\leq p_{r,k,t}\, \bar{k}_{r,g,g} + \sum_{z} p_{r,z,t}\, \bar{z}_{r,z,g} \sum_{t=g}^{g+N} p_{r,l,t}\, \pi_{g,t}\, (\omega_{r,g} - \ell_{r,g,t}) + p_{r,a,t}\, \zeta_{r,g,t} \\
\ell_{r,g,t} &\leq \omega_{r,g} \\
c_{r,g,t} &\geq 0 \quad , \quad \ell_{r,g,t} \geq 0\,. \qquad (7)
\end{aligned}$$

Here, material consumption c and leisure consumption ℓ are combined to form a composite consumption good z.[4] σ is the intertemporal elasticity of substitution, $\sigma_{cl} = 1/(1-\nu)$ is the elasticity of substitution between consumption and leisure, and α determines the relative importance of material consumption vis-à-vis leisure consumption. ρ is the utility discount factor, and $p_{r,x,t}$, $x = \{a, k, l, f\}$, denote the price for the output good, the purchase price of capital, the wage rate, and the price for the fuel-specific natural resource f (f = {*Coal, Natural Gas, Crude Oil*}, respectively. $\pi_{g,h,t}$ is an index of labor productivity over the life cycle. $\bar{z}_{r,f,g}$ denotes the endowment with natural resource f by generation g.

We assume throughout our analysis that endowments of natural resources grow exogenously at the steady-state growth rate, and that income from natural resource accrues to households in proportion to their capital income. Similarly, government transfers to households are assumed to be exogenous, also grow at the steady-state growth rate, and are allocated to each generation according to its share in the total population, where $\zeta_{r,g,t} = (1+\gamma)^g / \sum_{i=t-N}^{t} (1+\gamma)^i\, T_t$. This implies that transfer payments are constant over the life-cycle.

The present value of total consumption expenditure over the lifetime cannot exceed the present value of labor income. This rules out that households die in debt. In each period of the life cycle, time allocated to leisure consumption cannot exceed the total time endowment. Choices for

[4] Households 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. The assumption of multi-stage budgeting is innocuous if and only if the utility function u is weakly separable and the sub-utility functions z are nomothetic. Both conditions are satisfied in this model.

material and leisure consumption are restricted to be nonnegative.[5] Material consumption c is a CES composite of individual commodities shown in Table 1. We assume that each generation uses an identical consumption technology, i.e. we abstract from age-specific preferences. The nested CES structure for private consumption is depicted in Figure A.15 in the Appendix.

$\overline{k}_{r,g,g}$ denotes the capital holdings of generation g at the beginning of life $t = g$. 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 selected such that the economy is on a balanced growth path (for details on the calibration procedure see Section 2.7). We assume that newborn households enter with zero capital, i.e. we rule out intergenerational bequests: $\overline{k}_{r,g,g} = 0, \forall\, g \geq 0$.

2.3. Production

For each industry ($i = 1, \ldots, I,\ i = j$) in each region ($r = 1, \ldots, R$) gross output (Y_{ir}) is produced in each period using inputs of labor (L_{ir}), capital (K_{ir}), natural resources including coal, natural gas, crude oil, and land (R_{ir}), and produced intermediate inputs (X_{jir}):[6]

$$Y_{ir} = F_{ir}(L_{ir}, K_{ir}, R_{ir}; X_{1ir}, \ldots, X_{Iir})\,. \tag{8}$$

We employ constant-elasticity-of-substitution (CES) functions to characterize the production technologies and distinguish six types of production activities in the model: fossil fuels (indexed by f); refined oil, electricity, agriculture, and non-energy industries (indexed by n). All industries are characterized by constant returns to scale (except for fossil fuels, agriculture and renewable electricity, which are produced subject to decreasing returns to scale) and are traded in perfectly competitive markets. Nesting structures for each type of production system are depicted in Caron et al. (2012).

Fossil fuel f, for example, is produced according to a nested CES function combining a fuel-specific resource, capital, labor, and intermediate inputs:

$$Y_{fr} = \left[\alpha_{fr} R_{fr}^{\rho_{fr}^R} + \nu_{fr} \min\left(X_{1fr}, \ldots, X_{Ifr}, V_{fr}\right)^{\rho_{fr}^R}\right]^{1/\rho_{fr}^R} \tag{9}$$

where α, ν are share coefficients of the CES function and $\sigma_{fr}^R = 1/(1 - \rho_{fr}^R)$ 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: $V_{fr} = L_{fr}^{\beta_{fr}} K_{fr}^{1-\beta_{fr}}$ where β is the labor share.

[5]Note that due to the convex structure of CES-preferences the nonnegativity constraints on c and l are never binding in the optimum.

[6]For simplicity, we abstract from the various tax rates that are used in the model. 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.

2.4. Supplies of Final Goods

With the exception of crude oil, which is modeled as a homogeneous good, intermediate and final consumption goods are differentiated following the Armington (1969) assumption. Our Armington specification differentiates goods domestic and international origin. For each demand class, the total supply of good i is a CES composite of a domestically produced variety and an imported one:

$$X_{ir} = \left[\psi^{z}\, ZD_{ir}^{\rho_i^D} + \xi^{z}\, ZM_{ir}^{\rho_i^D}\right]^{1/\rho^{D}{}_{i}} \tag{10}$$

$$C_{ir} = \left[\psi^{c}\, CD_{ir}^{\rho_i^D} + \xi^{c}\, CM_{ir}^{\rho_i^D}\right]^{1/\rho^{D}{}_{i}} \tag{11}$$

$$I_{ir} = \left[\psi^{i}\, ID_{ir}^{\rho_i^D} + \xi^{i}\, IM_{ir}^{\rho_i^D}\right]^{1/\rho^{D}{}_{i}} \tag{12}$$

$$G_{ir} = \left[\psi^{g}\, GD_{ir}^{\rho_i^D} + \xi^{g}\, GM_{ir}^{\rho_i^D}\right]^{1/\rho^{D}{}_{i}} \tag{13}$$

where Z, C, I, and G are inter-industry (intermediate) demand, consumer demand, investment demand, and government demand of good i, respectively; and ZD, CD, ID, GD, are domestic and imported components of each demand class, respectively. The ψ's and ξ's are the CES share coefficients and the Armington substitution elasticity between domestic (including local) and the imported varieties in these composites is $\sigma_i^D = 1/(1-\rho_i^D)$.

The internationally imported varieties are represented by nested CES functions. The imported variety of good i is represented by the CES aggregate:

$$M_{ir} = \left[\sum_{t} \varphi_{isr}\, y_{isr}^{\rho_i^M}\right]^{1/\rho_i^M} \tag{14}$$

where y_{isr} are imports of commodity i from region s to r. π and φ are the CES share coefficients, and $\sigma_i^M = 1/(1-\rho_i^M)$ is the implied substitution elasticity across foreign origins.

2.5. Emissions

Carbon emissions are generated according to the stoichiometry of fossil fuel combustion, which occurs in fixed proportions to the consumption of fossil fuels by industry and final demand sectors. The carbon emissions in region r are defined by the expression:

$$\text{Emissions}_r = \sum_{f} \kappa_f \left(X_{ifr} + C_{fr}\right) \tag{15}$$

where κ_f is the carbon content of fuel f. While endogenous efficiency improvement are governed by the possibility to substitute capital and labor for energy in response to changing relative prices, our model abstracts—for simplicity–from any autonomous energy efficiency improvements.

2.6. Infinite-Horizon Approximation and Numerical Solution

To approximate the underlying infinite horizon economy by a finite-dimensional complementarity problem we choose a "state variable targetting" approach as proposed by Lau et al. (2002). The infinite horizon economy can be decomposed into two distinct problems where one runs from $0, \dots, T$ and the other one runs from $T+1, \dots, \infty$, where T denotes the last period of the numerical model.[7] Both subproblems are linked through the post-terminal capital stock in period $T+1$. The level of post-terminal capital is computed endogenously by requiring that investment grows at the same rate as output (or any other "stable" quantity in the model):

$$I_{r,T}/I_{r,T-1} = 1 + \gamma\,. \tag{16}$$

To compute a transition path to a new steady state of an infinite horizon economy, it is necessary to account for the special characteristics of generations alive in the post-terminal years (indexed by $\hat{g}$). We adopt the approach described in Rasmussen & Rutherford (2004) and impose two additional constraints on the model. Whereas assets held at the start of the initial period are exogenous, a shock to the model may change the demand and supply for 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 are therefore computed as endogenous variables chosen to ensure 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 beyond the terminal period are of equal magnitude

$$ev_{\hat{g}} = ev_{\hat{g}-1} \qquad \text{for } T - N < \hat{g} \leq T\,. \tag{17}$$

The second constraint ensures that consumption profiles of households living beyond T are held at the steady-state level. This requires that given the post-terminal consumption demands by these generations, the price path for consumption goods declines with the interest rate consistent with a steady-state projection of the price of consumption in period T.

Numerically, the equilibrium is formulated as a mixed complementarity problem (MCP) (Mathiesen, 1985; Rutherford, 1995). Our complementarity-based solution approach comprises two classes of equilibrium conditions: zero profit and market clearance conditions. The former condition determines a vector of activity levels and the latter determines a vector of prices. 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 & Ferris, 1995) to solve for non-negative prices and quantities.

2.7. Data and Calibration

This study makes use of social accounting matrices (SAMs) that are based on data from the Global Trade Analysis Project (GTAP, 2008). The GTAP dataset provides consistent global accounts of production, consumption, and bilateral trade as well as consistent accounts of physical

[7] Note that this method for approximating the infinite horizon relies on the assumption of time-separable utility functions.

Table 1: Model details.

Regions	Primary factors of production	Commodities (GTAP code)
USA	Capital	Agriculture (*aggr.*)
Rest of the World	Labor	Coal mining (COA)
	Coal	Natural gas extraction (GAS)
	Natural Gas	Crude oil (OIL)
	Crude Oil	Electricity* (ELY)
	Land	Refined oil* (P_C)
		Paper products, publishing* (PPP)
		Chemical, rubber, plastic products* (CRP)
		Ferrous metals* (I_S)
		Metals* (NFM)
		Non-metallic minerals* (NMM)
		Transportation (*aggr.*)
		Other energy-intensive industries (*aggr.*)
		Services (*aggr.*)
		Manufacturing (*aggr.*)

Note: "*aggr.*" denotes an aggregation of original GTAP sectors.[9]

energy flows and energy prices. Version 8 of the database, which is benchmarked to 2007, identifies 113 countries and regions and 57 commodities. Our model distinguished 5 energy and 10 non-energy commodities some of which are aggregates of original GTAP commodities, as shown in Table 1.[8] Primary factors in the dataset include labor, capital, and fossil-fuel resources, and regions include the United States and an aggregate representing the Rest of the World.

In addition to the GTAP data, further information is required to parameterize the model. To describe the evolution of labor productivity over the life-cycle, we use an age-related productivity profile according to:

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

where the parameters of this function are selected to minimize the difference from the profile arising by taking the average of multiple income groups as discussed in Altig et al. (2001). The coefficients used are: $\lambda_0 = 1.0785$, $\lambda_1 = 0.0936$, $\lambda_2 = -0.0015$, and $\lambda_3 = 7 \times 10^{-6}$.

Our estimate for the benchmark budget deficit is based on Congressional Budget Office (2012) long-run projection of 3% of GDP. The initial level of publicly-held debt is also based on the Congressional Budget Office estimate that existing debt represents approximately 70% of GDP in 2011. Benchmark expenditures on government services and the trade deficit are directly taken from the GTAP data. We calibrate the benchmark marginal labor tax rate to a value of 35.8% (Barro & Redlick, 2011) and the marginal capital tax rate to a value of 39.9% (Babiker et al., 2003).

As customary in applied general equilibrium analysis, we use economic value flows (=quantity × price; where all prices in the first year are normalized to one) of the dataset to calibrate the

[8]The exact aggregation scheme is available on request from the author.

value share and level parameters for the base year of the model. Response parameters in the functional forms which describe production technologies and consumer preferences are determined by exogenous elasticity parameters, the values of which are shown in Table 2. Symbols used in Table 2 to denote elasticity parameters correspond with those used in Figures A.10 to A.15 in the Appendix.

We calibrate the model to a steady-state baseline extrapolated from the set of 2007 social accounting matrices using a growth rate of γ. This ensures that solving the model without any shock gives a solution that replicates a balanced growth path. The steady-state assumption requires that benchmark investment expenditure covers growth plus depreciation on the capital stock and that the gross return to capital covers interest plus depreciation: $I(\bar{r} + \delta) = W(\gamma + \delta)$.

The choice of the annual interest rate ($\bar{r}$) is important for the results of a long-term analysis like the present one. I use a value of $\bar{r} = 0.04$ for the net of tax return.[10] The annual capital depreciation rate is set to 7%, but in contrast to $\bar{r}$ this parameter has little impact on the results. γ is set to 2%.

We solve the model for 150 years ($T = 150$)[11] and assume that the lifespan of households is 50 years ($N = 49$). Solving the model for a longer time horizon does not produce different results thus indicating that the model the model has been given enough time to settle on a new balanced growth path.

To calibrate the model to the SAM, it is necessary that the solution to the OLG households individuals maximization problems is consistent with the base year value for aggregate private consumption and income. We employ a steady-state calibration procedure for OLG models described in Rasmussen & Rutherford (2004) which imposes two additional constraints on individuals' maximization problems by endogenously solving for the time endowment parameter ω and the utility discount rate ρ.[12]

Figure 1 shows the calibrated income, consumption, and savings profiles for each generation along the baseline steady-state growth path. In the first period of the life-cycle, capital income is zero and consumption and savings are financed through labor income and exogenous transfers. The desire to increase consumption over the life-cycle (as is implied by the Euler equation) means that capital income is growing over the first 35 years of the life-cycle and then falls back to zero reflecting positive saving while young and subsequent dissaving. Labor income, as well as time devote to labor, is increasing for the first decades of the life cycle and is then decreasing consistent with the humped-shaped productivity profile and the tendency of leisure to increase with a constant productivity level.

[10] Altig et al. (2001) argue for using a value around 7-8% based on the historical real rate of return to capital, while others (e.g., Fullerton & Rogers, 1993) use a much smaller rate around 3-4%. With no account for risk in this model it is not clear which value should be used. Also it should be kept in mind that with these kind of models there is no "correct" value.

[11] To reduce computational complexity, we solve the model with a 5-year time step.

[12] Note that ω is a simple scaling factor with no economic significance. ρ is selected as the second calibration parameter as there is little evidence on what would constitute an appropriate value.

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

Parameter	Substitution margin	Value
σ_{en}	Energy (excluding electricity)	1.0^a
σ_{enoe}	Energy—electricity	0.5^a
σ_{eva}	Energy/electricity—value-added	0.5^a
σ_{va}	Capital—labor	1.0^a
σ_{klem}	Capital/labor/energy—materials	0^a
σ_{cog}	Coal/oil—natural gas in ELE	1.0^a
σ_{co}	Coal—oil in ELE	0.3^a
σ_{rnw}	Resource—Capital/labor/energy/materials in renewable ELE	*Calibrated*
σ_{nr}	Resource—Capital/labor/energy/materials in nuclear ELE	*Calibrated*
σ_{am}	Materials in AGR	0^a
σ_{ae}	Energy/electricity—materials in AGR	0.3^a
σ_{er}	Energy/materials—land in AGR	0.6^a
σ_{erva}	Energy/materials/land—value-added in AGR	0.7^a
σ_{rklm}	Capital/labor/materials—resource in primary energy	0^a
σ_{gr}	Capital/labor/materials—resources	*Calibrated*
σ_{govinv}	Materials—energy in government and investment demand	0.5^a
σ_{ct}	Transportation—Non-transport in private consumption	1.0^a
σ_{ec}	Energy—Non-energy in private consumption	0.25^a
σ_{c}	Non-energy in private consumption	0.25^a
σ_{ef}	Energy in private consumption	0.4^a
σ_i^D	Foreign—domestic	GTAP, version 8
σ_i^M	Across foreign origins	GTAP, version 8
σ	Intertemporal elasticity of substitution	0.5
σ_{cl}	Leisure—material consumption	0.8
α	Weight on material consumption in full consumption	0.6

Note: [a]Parameter values are taken from Paltsev et al. (2005).

3. Evaluating Fiscal Consolidation with Climate Policy

To evaluate the efficiency and distributional effects of fiscal consolidation with climate policy we consider two sets of scenarios. The first one recycles the revenue from a carbon pricing policy through lowering marginal tax rates on capital, labor, and consumption. The level of the respective tax recycling instrument is determined endogenously in equilibrium by the public budget (Eq. (5)), re-stated here for convenience:

$$p_t^G G_t + T_t + N_t = \Phi_t \,, \tag{18}$$

while the other tax instruments are held fixed at their benchmark level. Here Φ_t denotes all tax receipts including the revenue from imposing a carbon tax. A second set of scenario consider using the carbon revenue to repay the principal debt. Deficit reduction implies a relaxation of future public budgets as debt repayment results in lower interest obligations (as can be seen from Eq. (4)). Lower interest obligations are then recycled as a reduction in marginal tax rates on capital, labor, and consumption, where the level of the endogenous tax instrument is again determined

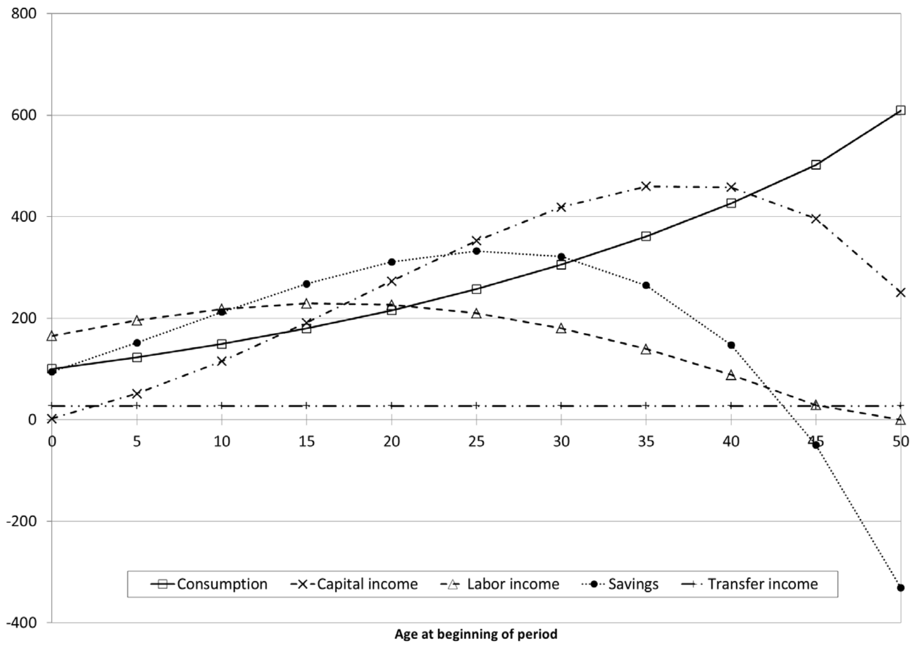

Figure 1: Baseline income, consumption, and savings profiles for each generation (first period consumption = 100).

by Eq. (18). The difference with respect to the first set of scenarios—that simply represent a revenue-neutral tax swap—is that debt repayment affects net public expenditure according to the equation:

$$N_t = R_t + rD_t - B_t = R_t + r\left(D_0 - \sum_{\tau=0}^{t}(R_\tau - B_\tau)\right). \quad (19)$$

In the baseline growth path, we have calibrated the model such that there are no repayments on the principal, nor is there additional borrowing. In the fiscal consolidation scenarios, the carbon revenue raised in each period is recycled via R_t therefore impacting current and future net public expenditures.

Throughout our analysis we assume that government expenditure (G) and government transfers (T) grows exogenously with the steady-state growth rate. This assumption helps us to isolate the impacts of tax rate changes due to a carbon tax swap with or without fiscal consolidation.

We limit our analysis of climate policy to a carbon pricing scheme that imposes a carbon price of \$20 per ton of CO_2 in the first period of the model with a price path for future periods increasing at 4% per year. The carbon policy runs for 50 years after which carbon emissions are allowed to increases without further policy constraints. Our scenario design is motivated by the following considerations. First, limiting the carbon policy to a finite number of periods helps us to obtain a clearer picture of the intergenerational impacts of the policy as the economy gradually returns to a steady-state equilibrium in periods after the policy is discontinued. Second, based on the current political debate in the United States surrounding the issue of fiscal reform and the potential contribution of a carbon tax, such a set-up seems to be relevant and not too unrealistic. Third, a (binding) carbon policy continuing for an infinite number of periods is not consistent with a situation in which the economy converges towards a balanced growth path. A final steady state of the model, however, is necessary to apply the above-mentioned methods for approximating the infinite-horizon economy.

Our analysis will enable us to quantity the intergenerational welfare impacts of climate policy with and without fiscal consolidation. As fiscal consolidation policies involve trading-off short-term costs with potential long-term welfare gains from reduced future levels of public debt, we are also interested in evaluating the welfare impacts using "social" preferences. For this purpose, we apply a very direct social welfare function (SWF) approach assuming that aggregate welfare can be measured as:

$$EV_{\text{SWF}} = \left(\sum_{g} \theta_g u_g^{\rho} \right)^{1/\rho} \tag{20}$$

where $\epsilon = 1/(1-\rho)$ is an index of the elasticity of substitution across welfare gains for different households, and θ_g is a weighting factor that accounts for population and discounting:

$$\theta_g = N_g (1 - \Delta)^g \,. \tag{21}$$

N_g is the number of households represented by the generation g, and Δ is a parameter that discounts the contribution of future generations to aggregate social welfare.

When Δ is larger, then the welfare of future generations plays a smaller role in defining social welfare; contrariwise, when Δ is small, then it is mainly impacts on current generations that matter for social welfare. Social welfare is also influenced by the inter-household substitution elasticity which captures trade-offs in welfare for households born at different times. ϵ is related to the inequality aversion parameter ρ. $\rho = 1$ represents the utilitarian (Bentham) social welfare function corresponding to no inequality aversion in which the societal equivalent variation is a weighted sum of equivalent variations over all households. Lower values for ρ imply larger a societal concern for inequality. If $\rho \longrightarrow 0$, Eq. (20) represents the Nash social welfare function, and $\rho \longrightarrow -\infty$ represents the Rawlsian case where the society is solely concerned with maximizing the utility of the household with the smallest welfare.

4. Results

4.1. Revenue-neutral Carbon Tax Swaps

We begin our analysis by investigating the impacts of using the carbon revenue for cutting marginal tax rates on capital, labor, and consumption (without reducing government debt). The corresponding scenario labels are *Tax_Capital*, *Tax_Labor*, *Tax_Consum*, respectively. Figure 2 shows the benchmark tax rates (horizontal lines) and the required tax level to satisfy the government budget constraint (Eq.(18)). In all three cases, the government budget allows for substantial reductions in tax rates for periods in which the carbon policy is active and revenue is generated. In the year 50 when the carbon tax is removed from the economy, the respective tax rates jump back to their respective benchmark level (in fact they slightly increase above the benchmark level

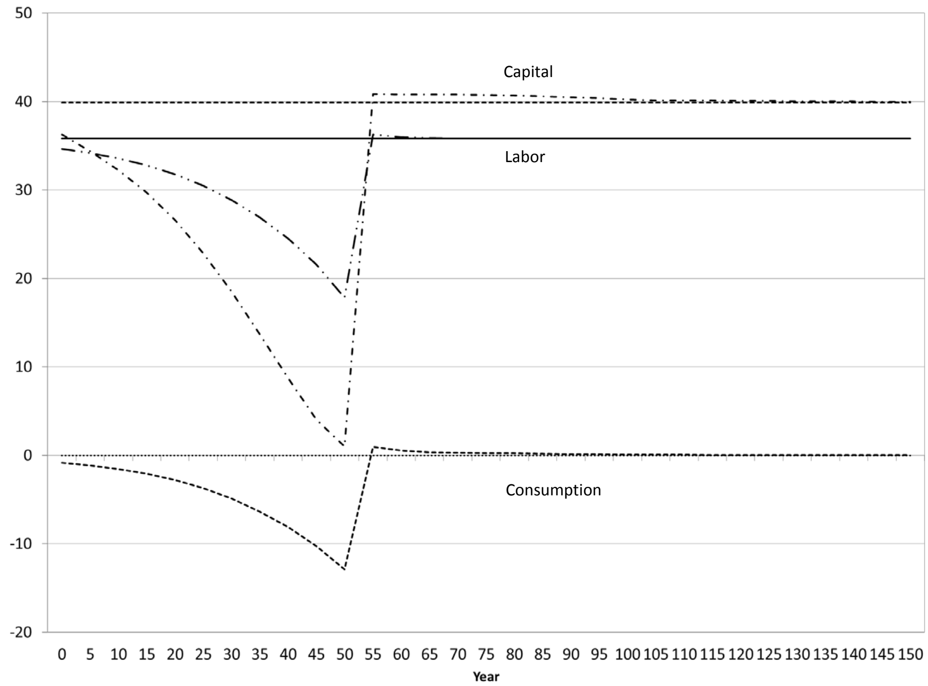

Figure 2: Model tax rates for revenue-neutral carbon tax swap cases (%).

to raise sufficient revenue as the growth in the tax base has been slowed down due to the carbon policy in the periods before). In the long-term the rates converge back to their benchmark level. Differences in the magnitudes of reductions reflect the width of the tax base for each instrument.

These trajectories offer no additional insights into explaining the gains and pains from putting a price on carbon. Figure 3 shows the utility changes for the different generations as measured by the equivalent variation.[13] Reductions in capital and consumption taxes benefit the initial elderly who have large consumption shares and high capital income. The positive effect of lower consumption taxes turns out to dominate the higher cost of consumption goods for the older portion of generations living in 0, i.e. those born before year -10. Lowering labor taxes makes all generations worse off. As the carbon tax increases over time, current young and future generations are first made progressively worse off up to a point where welfare losses for future generations begin to decrease as these households increasingly live into future periods without a carbon policy.

As is evident from Figure 3, different tax instruments have different implications in terms of both efficiency and intergenerational equity. Recycling carbon revenues through lower consumption tax rates produces the largest difference in utility across generations with elderly households benefiting and future generations between incurring substantial welfare losses. At the same time, lowering consumption taxes forgoes any positive efficiency effects from increasing labor or capital supply as is achieved by cutting marginal tax rates on labor and capital, respectively. Comparing

[13]For generations alive when the abatement policy is introduced in period zero, the equivalent variation measures the change in the value of remaining lifetime utility as opposed to total lifetime full consumption.

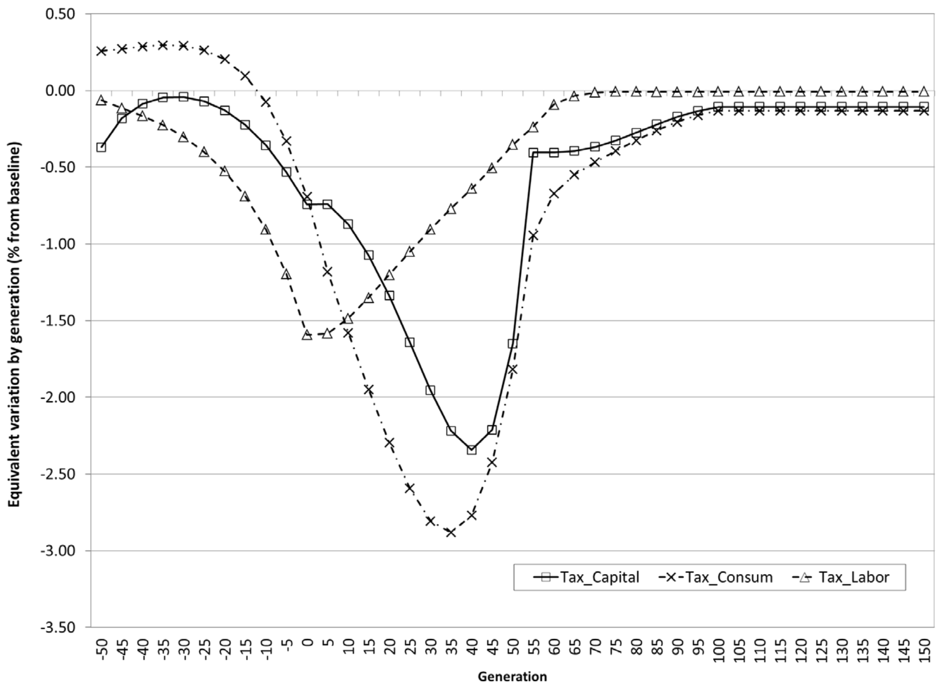

Figure 3: Equivalent variation by generation for revenue-neutral carbon tax swaps (% change from baseline).

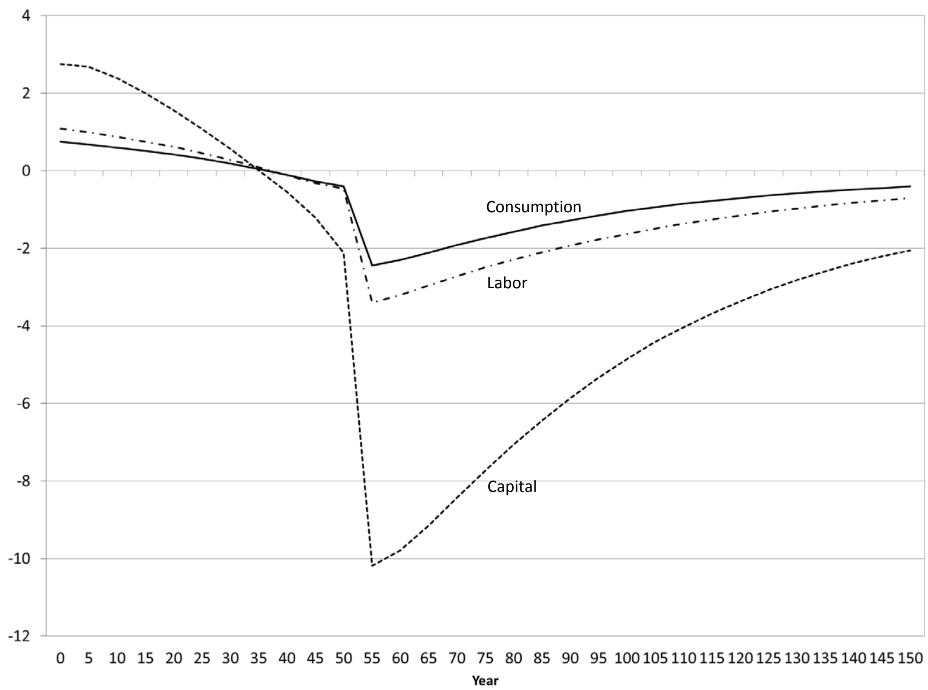

Figure 4: Percentage-points difference in model tax rates for debt repayment vs. revenue-neutral carbon tax swap cases.

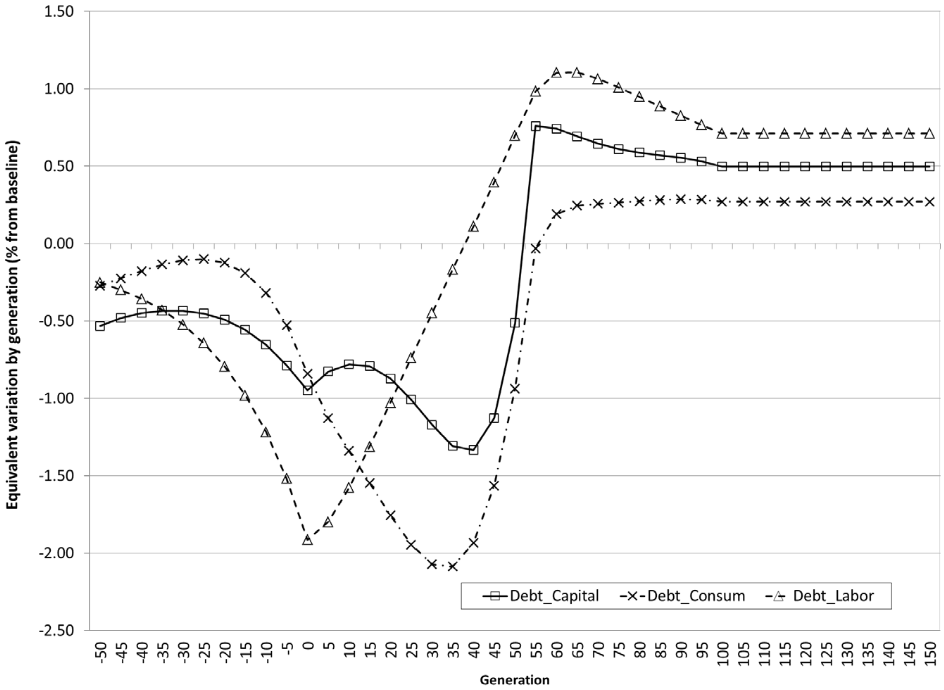

Figure 5: Equivalent variation by generation for debt repayment (% change from baseline).

the capital and labor tax recycling options, the latter one turns out to produce a more equitable outcome across generations while also being more efficient vis-à-vis a cut in capital taxes. Current generation benefit immediately from lower labor taxes by increasing labor supply with positive effects on savings and lifetime income whereas lower capital taxes does not benefit them as capital is low than labor income over the first half of the life-cycle (compare with Figure 1).

4.2. Fiscal Consolidation with Climate Policy

Efficiency and intergenerational distributional impacts are altered substantially if the carbon revenue is used to reduce the public debt relaxes future public budgets and thus basically acting as an intergenerational redistribution mechanism. We consider three cases that differ with regard to how the receipts from deficit reduction are recycled. A scenario labelled *Debt_Capital* uses the receipts to lower marginal tax rates on capital, a scenario *Debt_Labor* cuts marginal labor taxes, and a scenario *Debt_Consum* lower the consumption tax rate.

Figure 4 shows the percentage-points difference for each model tax rate under debt repayment relative to the corresponding revenue-neutral carbon tax swap case. If the carbon revenue is used to repay the principal debt, tax rates in all cases are higher throughout almost the entire period when the carbon policy is active (until year 50). The percentage-points difference turns negative from year 40 onward as cumulative receipts from lower interest payments relaxes public budgets and begins to produce surpluses. Importantly, all three tax rates converge eventually to a new steady-state level below the respective benchmark tax rates.

The pattern of initially higher but then lower long-term tax rates suggest quite a different pattern in terms of the intergenerational incidence of burdens from a combined climate and fiscal policy (Figure 5). Elderly households, current young generations, and all future generations born before the last period of the climate policy incur welfare losses, whereas subsequent future generations born after year 50 are made better off due to sustained lower tax rates after the fiscal consolidation period. Not surprisingly, comparing the debt reduction with the tax swap cases shows that the costs of fiscal consolidation are borne by the elderly and current young households, while for subsequent generation enjoy welfare gains (or smaller losses under debt reduction as compared to the tax swap cases if measured against the no-policy baseline).

As for the tax swap cases, recycling revenue through lower labor taxes has the most immediate impact on welfare: current old generations incur losses as their labor income relative to capital income and consumption is financed by drawing down savings, whereas current young and subsequent generations increasingly benefit from lower after-tax wages by increasing their labor supply. Recycling future public budget surpluses through lower capital taxes produces long-run welfare gains falling in between the labor and consumption tax-recycling cases.

4.3. Can a Fiscal Reform Package with Carbon Pricing be Socially Desirable?

Figure 6 and Figure 7 take a first stab at considering whether climate policy as part of a fiscal consolidation package is desirable from a social standpoint. Figure 6 suggests that for all revenue-neutral carbon tax swaps produce negative societal equivalent variation when assuming a utilitarian SWF, i.e. $\rho = 1$.[14] As social discount rates increase welfare losses become initially larger before decreasing again for relatively high rates. This patterns thus reflects the U-shaped profile for households' equivalent variations from Figure 3. The picture is changed dramatically if debt reduction is considered as a option to recycle the revenue from a carbon pricing policy. For social discount rates of less than 2%, Figure 7 shows that such a combined policy can indeed be desirable from a social standpoint. If a lower weight is placed on the contribution of future generations, the social welfare assessment is less favorable and eventually turns negative.

It is worthwhile pointing out that of the three revenue recycling options we consider, only the capital and labor tax cuts support a positive societal welfare assessment. If future government budget surpluses are recycled through a consumption tax, the societal equivalent variation index is negative for virtually any assumed social discount rate. This implies that understanding fiscal consolidation as an intergenerational redistribution mechanism neglects important efficiency considerations. Choosing a tax recycling instrument that positively impacts households' labor and capital supply decisions at the margin has the potential to induce positive growth effects that in turn increase the size of the economy and the tax base (and therefore the size of the total "pie" that can be redistributed).

Figure 8 explores the questions how the desirability to implement a combined climate and fiscal consolidation policy depends on the stringency of the climate policy. We consider four climate policy starting with an initial carbon price of 5, 10, 20, and 40 $ per ton of metric CO_2 and the rising at 4% per year. For this graph we assume that revenues from deficit reduction are recycled via labor taxes and that the inequality aversion parameter is equal to 1. The striking result

[14] The results are not much changed if the social welfare metric places greater weight on equity as long as $0 \leq \rho < 1$.

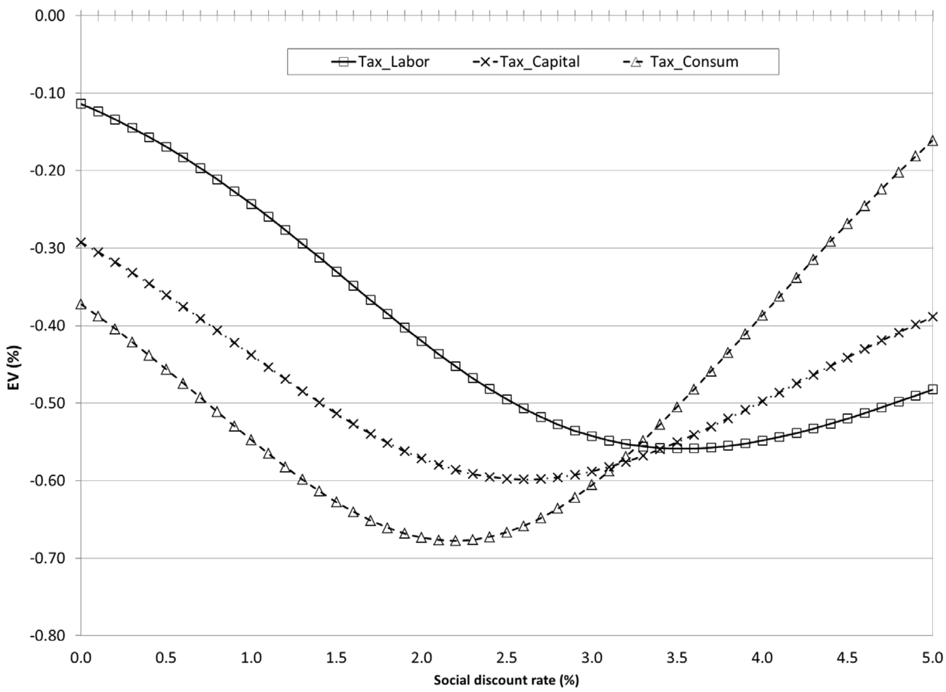

Figure 6: Social welfare assessment of revenue-neutral tax swap cases (for $\rho = 1$).

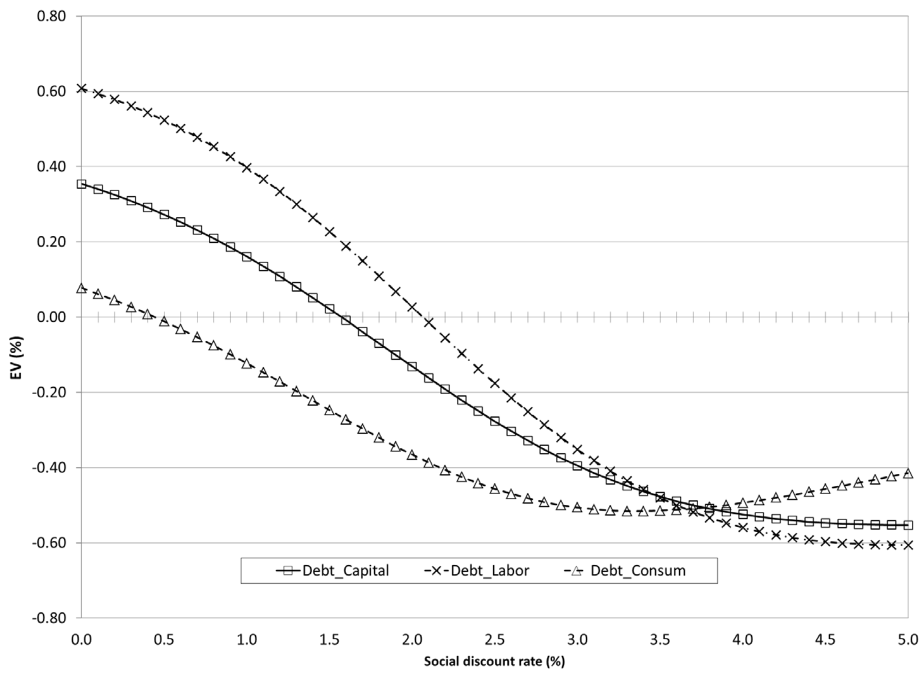

Figure 7: Social welfare assessment of debt repayment cases (for $\rho = 1$).

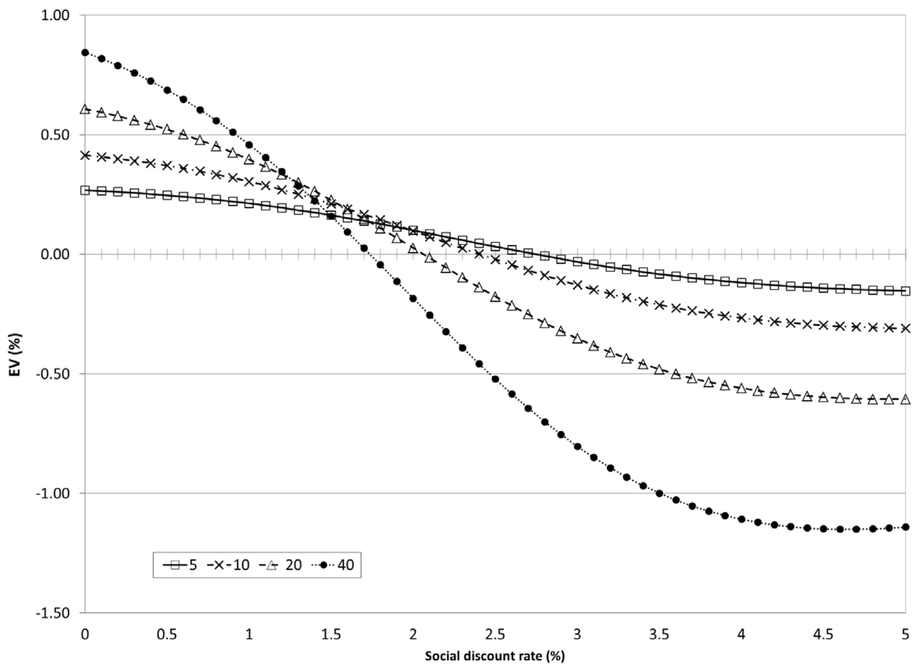

Figure 8: Social welfare assessment of debt repayment cases for different stringency of carbon policy (wage-tax recycling and for $\rho = 1$).

is that less stringent climate policies seem to be desirable for a larger range of social discount rates that those that aggressively reduce CO_2 emissions. This can be traced to two counteracting effects. On the one hand, a higher carbon price path generates more revenue that can be used to pay back public debt and relax the stress of future public budgets. Ceteris paribus this implies a lower level of the endogenous tax instrument with positive effects on welfare. On the other hand, a more stringent carbon policy impacts growth negatively, lowers the revenue from non-CO_2 taxes, and therefore increases the need to raise additional revenue. This implies a higher level of the endogenous tax instrument with detrimental effects on welfare. Figure 8 suggests that the beneficial link between a jointly implemented climate and fiscal consolidation policy breaks down for very aggressive climate policies.[15]

Figure 9 concludes with a simple comparison of SWF results for alternative cardinalizations of welfare. This figure reminds us that the SWF by itself does not automatically judge the desirability of a joint climate and debt consolidation policy. As such a combined policy measure involves both winners and losers, we first have to decide how gains by some households and generations should be traded off with losses by others. Figure 9 shows that if the societal assessment is more concerned with equity, i.e. has a higher inequality aversion reflected by increasingly negative values for ρ, then a combined climate and fiscal consolidation policy is desirable for any social discount rate

[15] Another way to look at this would be to say that the fiscal consolidation period is not long enough to ultimately reap the benefits of debt reduction

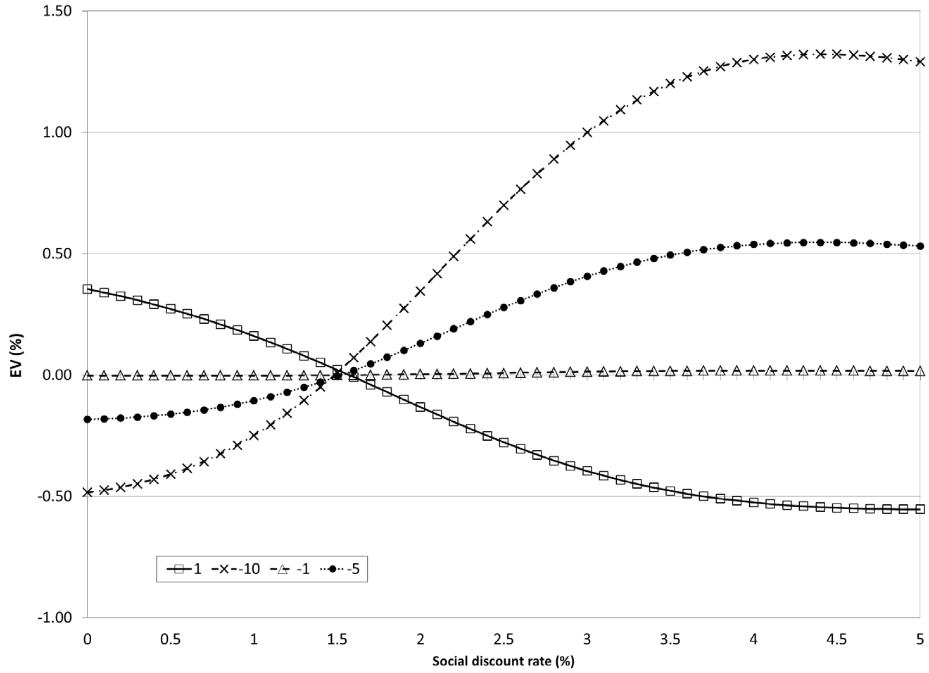

Figure 9: Social welfare assessment for debt repayment with capital-tax recycling for alternative degrees of inequality aversion ($\rho = \{1; -1; -5; -10\}$).

higher than 1.5%.

5. Conclusions

In view of the current stance of public finances in the United States (and many other nations), a revenue-raising climate policy can help relax future public budgets. An extensive literature has examined the interactions of environmental taxation and the broader fiscal system typically focusing on the efficiency effects from using the carbon revenue to fund rate cuts in distortionary taxes. The interactions between a revenue-raising climate policy and a debt consolidation programm have, however, not been investigated. Such a combined fiscal and climate policy package can potentially address the two long-term problems of growing public debt and the build-up of greenhouse gas emissions.

This paper has examined the efficiency and intergenerational distributional impacts of a jointly implemented fiscal and climate policy package that uses the revenue from putting a price on carbon to repay the principal government debt. Using carbon revenues for deficit reduction implies a relaxation of future public budgets as debt repayment results in lower interest obligations. While any debt reduction programm raises concerns of intergenerational equity between generations living through the fiscal consolidation period and those future generations who can reap the benefits of future public budget surpluses, our analysis suggests that a carbon policy combined with a fiscal consolidation program is likely to receive a more favorable societal assessment than just a carbon policy alone. Importantly, this may enhance the political support for revenue-raising climate policies that are framed over the next couples of decades.

This analysis represents a modest first step towards a more complete assessment of the interactions of climate policy and public debt reduction alternatives in an economy with large-scale government. There are a number of shortcomings of our model. We do not incorporate any notion of (aggregate, household-specific or climate-related) risk, demographic projections, nor do we introduce features of the system of direct taxation or consider energy-saving technological progress. Moreover, including environmental benefits of CO_2 abatement will address the important fact that climate change policy involves important intergenerational effects. Despite all of these deficiencies, we find the results to be quite thought provoking, as it is clear that the design of fiscal consolidation programmes requires a careful balance between intergenerational fairness. Further work is clearly needed to provide an assessment of the conclusions based on the simple model analyzed in this paper.

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Appendix A. Structure of Production and Consumption Technologies

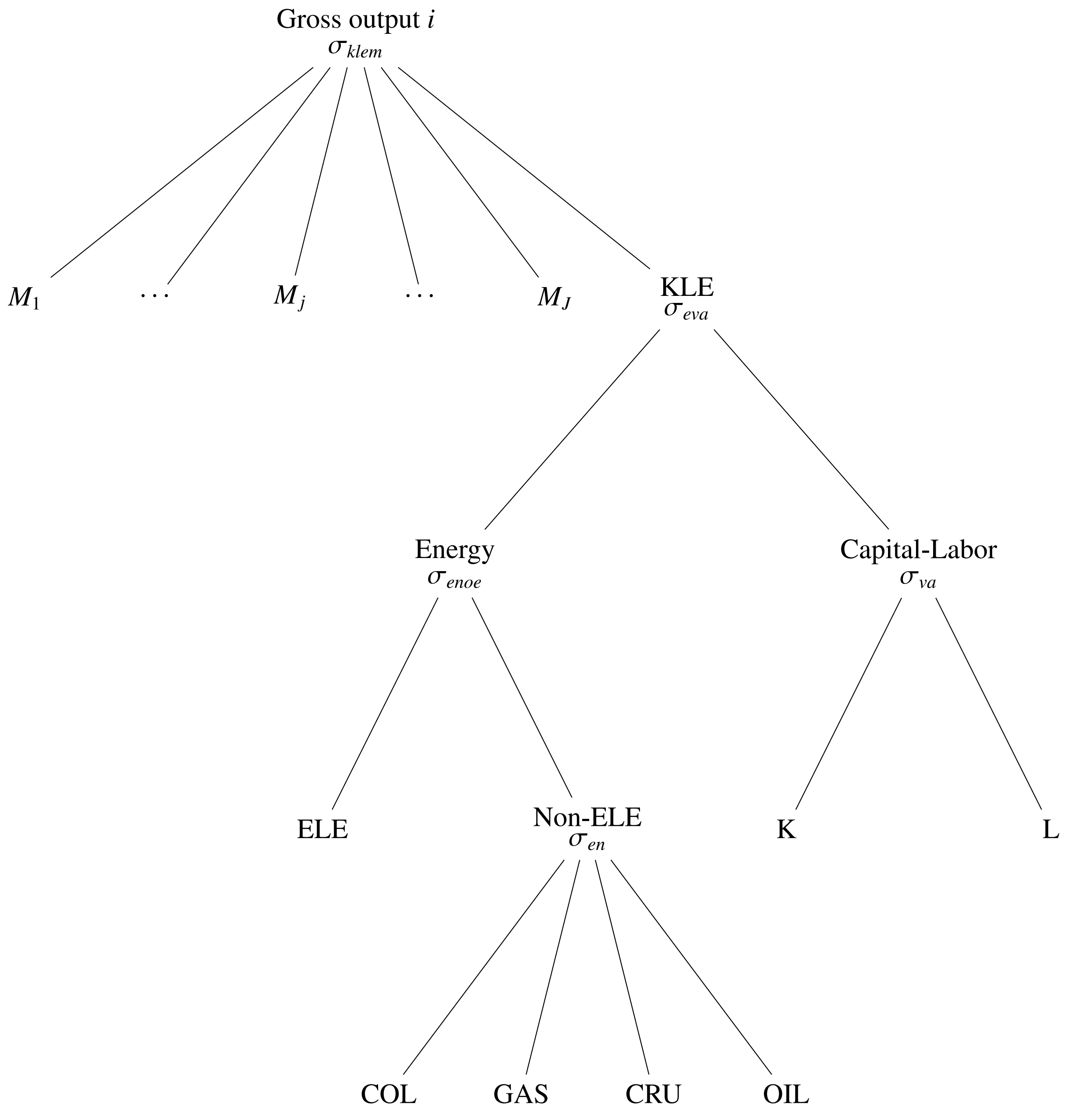

Figure A.10: Structure of production for $i \in$ {TRN,EIS,SRV,CRP,I_S,NFM,NMM,PPP,MAN}.

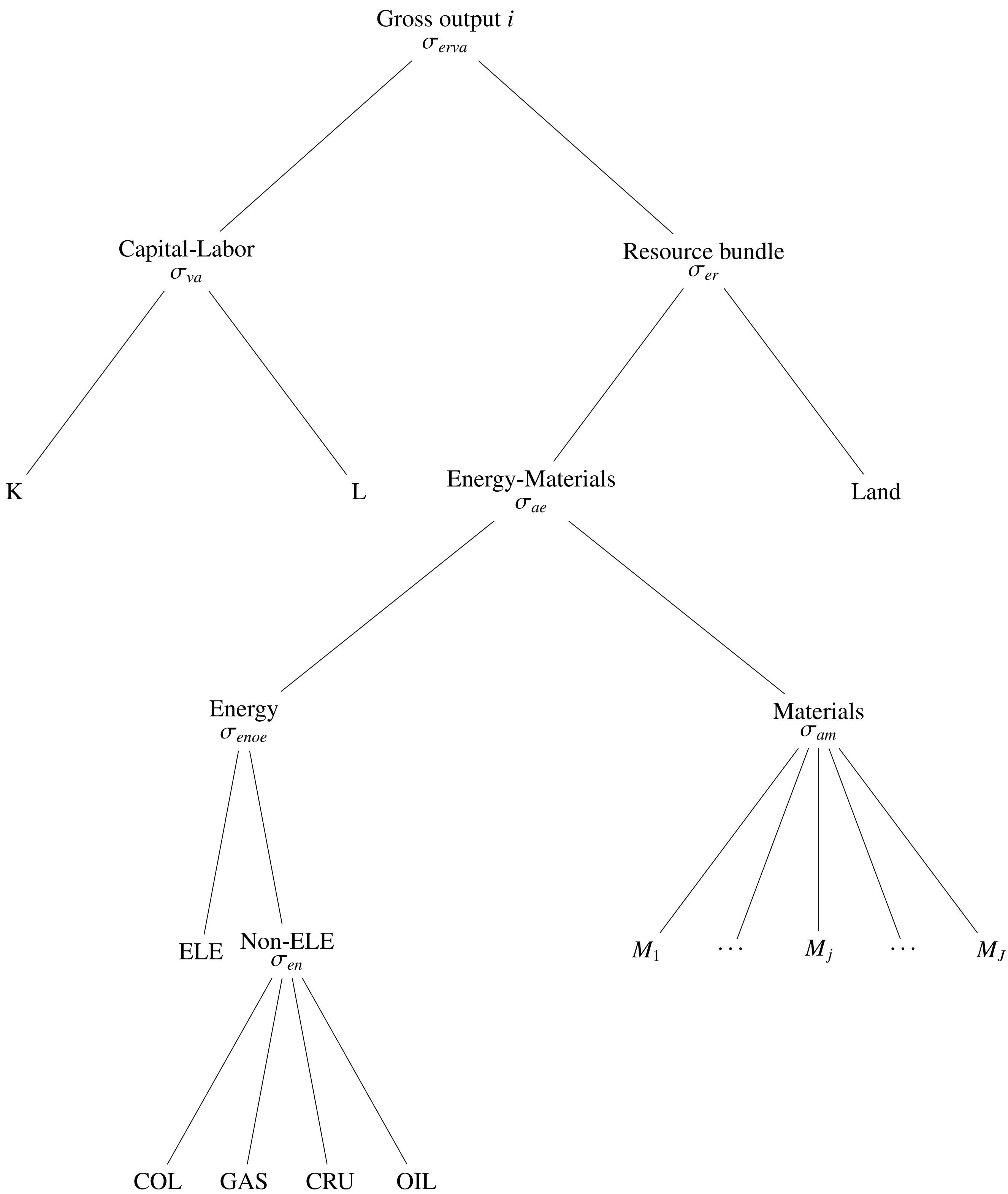

Figure A.11: Structure of production for $i \in \{\text{AGR}\}$.

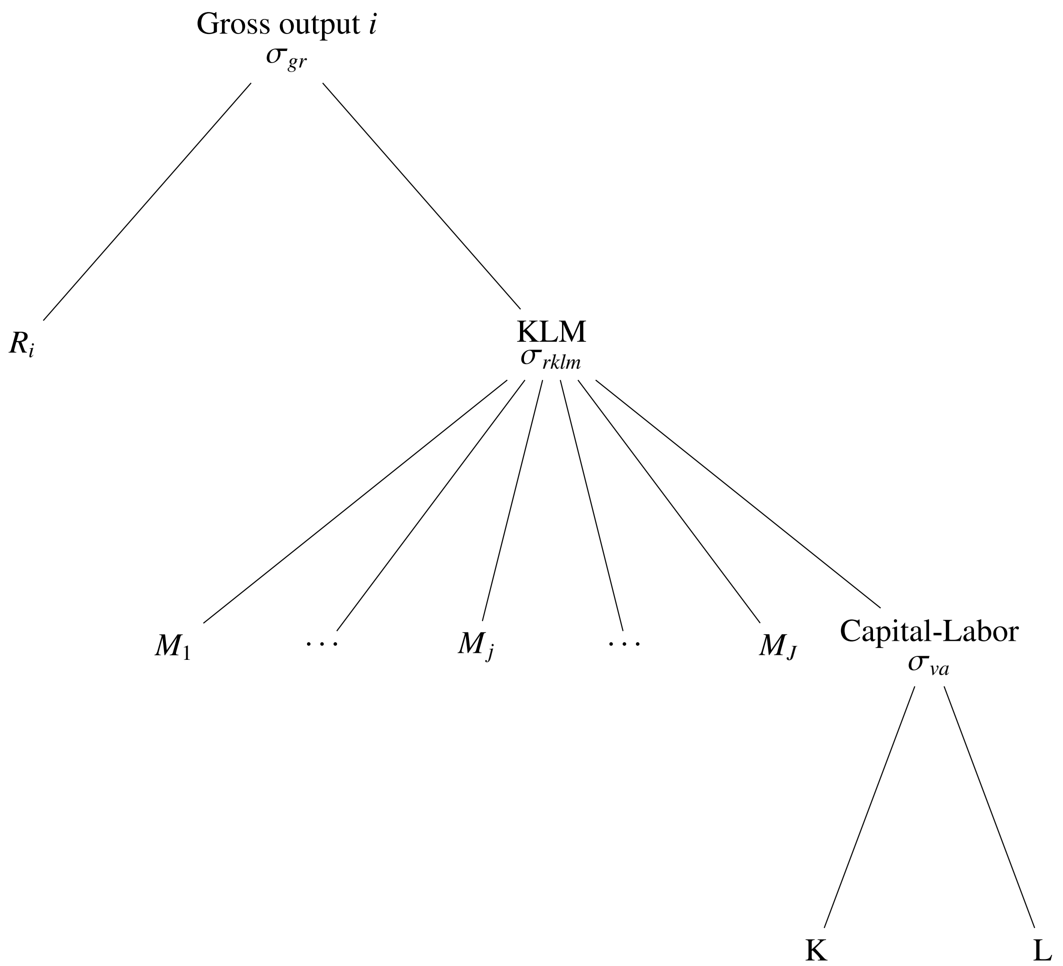

Figure A.12: Structure of primary energy sectors $i \in \{\text{COL,CRU,GAS}\}$.

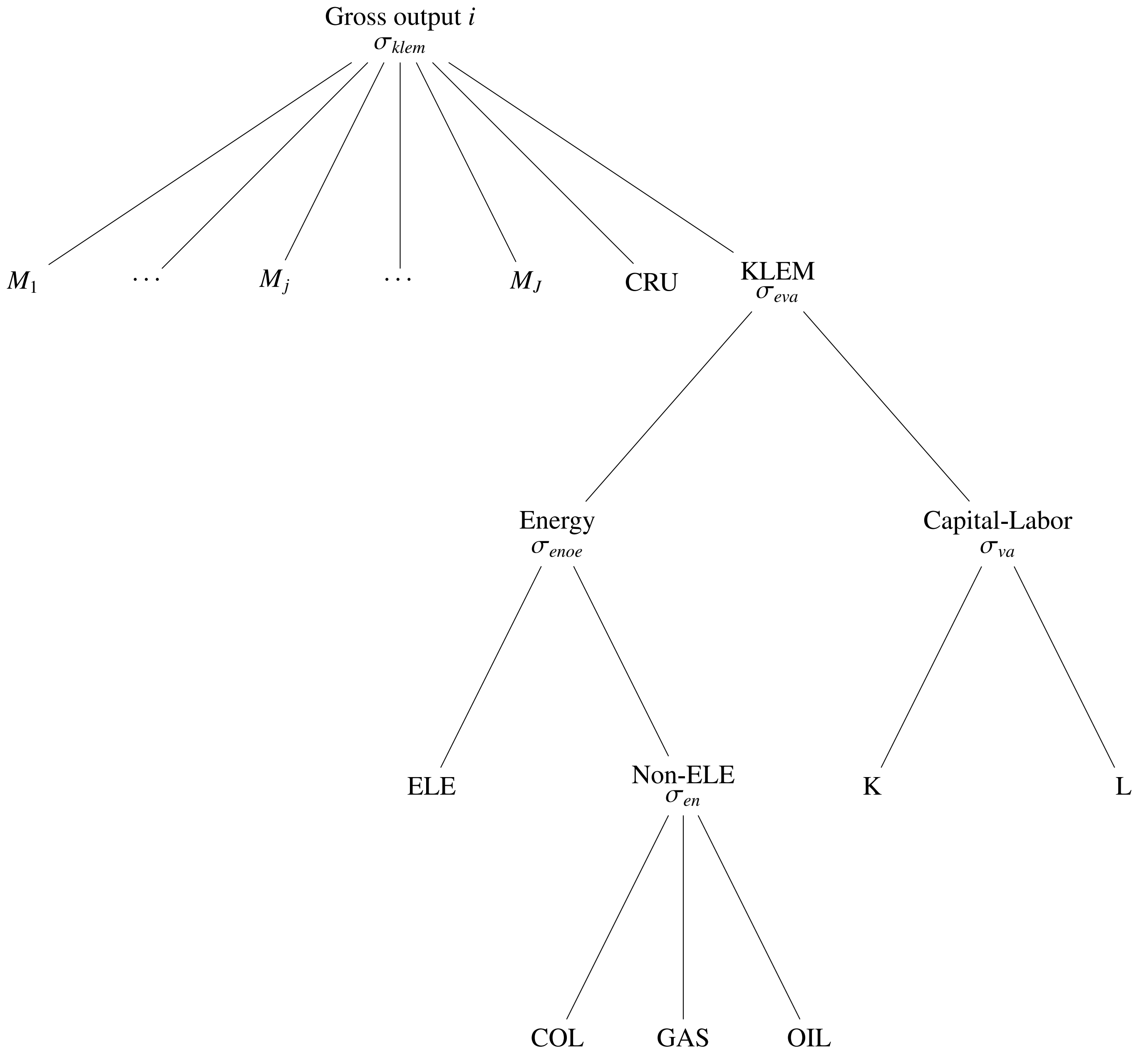

Figure A.13: Structure of production for $i \in \{\text{OIL}\}$.

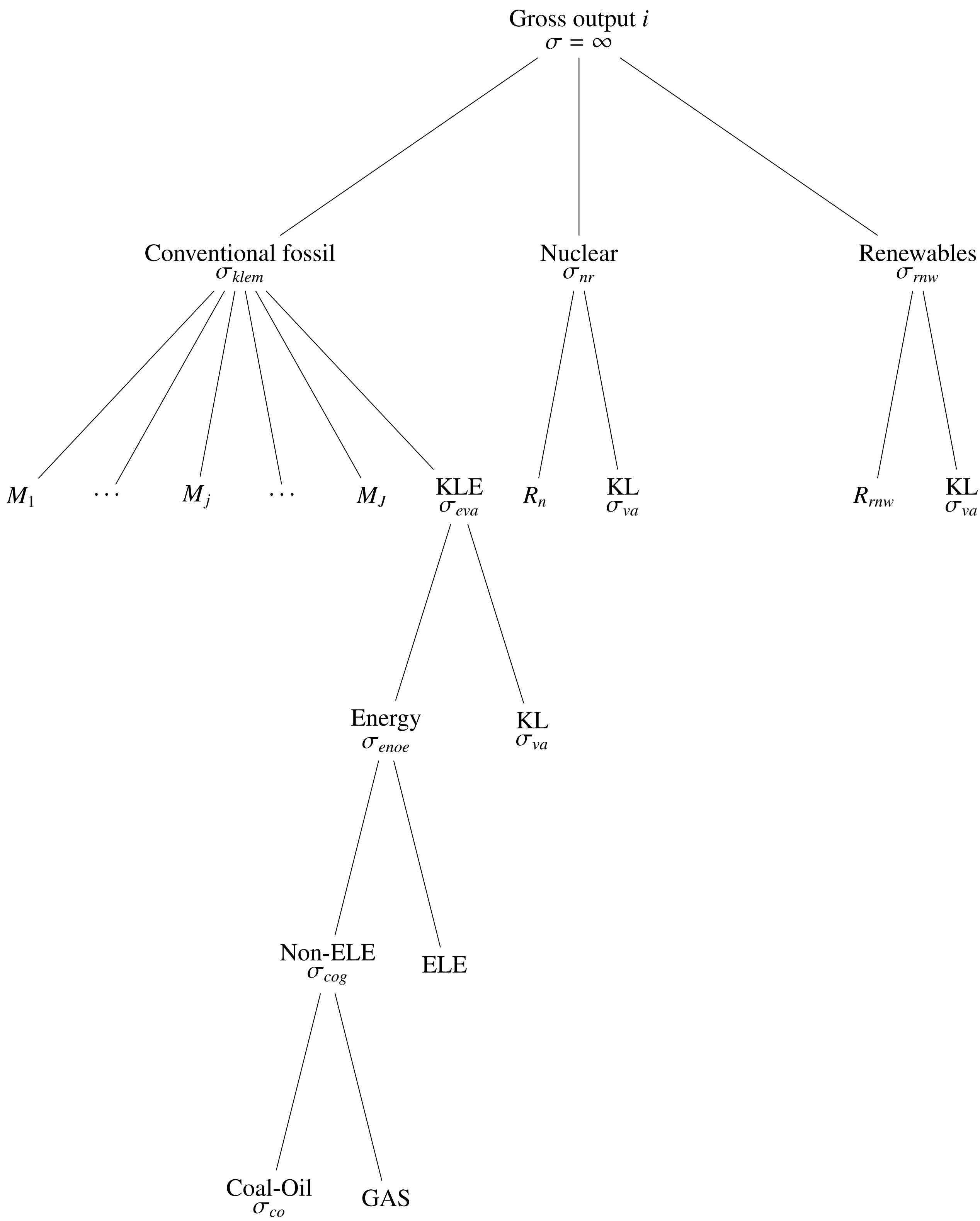

Figure A.14: Structure of electricity production $i \in \{\text{ELE}\}$.

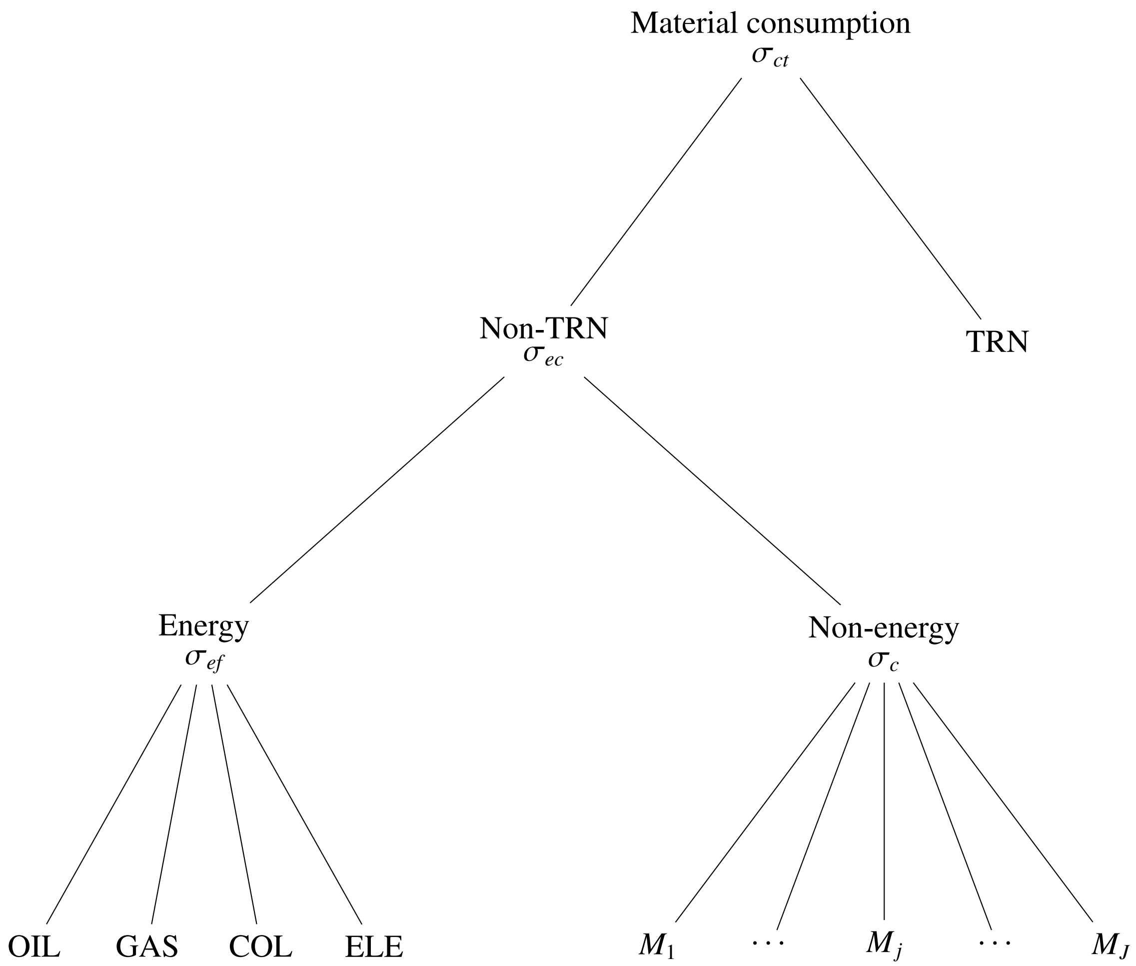

Figure A.15: Structure of private material consumption.