CARBON ABATEMENT, REVENUE RECYCLING AND INTERGENERATIONAL BURDEN SHARING [1]

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ABSTRACT: Carbon emissions abatement as proposed in the Kyoto protocol involves emission reduction and increasing permit prices or emission taxes over the next twenty or more years. We use an overlapping generations (OLG) to assess the equity effects of these policies. We find a significant trade-off between equity and efficiency for alternative revenue recycling policies. We also compare the OLG results with a representative agent model and find that the OLG model further provides less optimistic assessments of the positive efficiency effects of environmental tax reform.

KEYWORDS: Environmental taxes, carbon taxes, revenue recycling, overlapping generations, applied general equilibrium.

JEL CODES: D30, D58, D61, H21, H22.

1. INTRODUCTION

Global warming may cause significant adverse impacts for generations living in the 22nd century. Policy questions surrounding carbon abatement are understandably posed as a choice between well-being of current and future generations. Thomas Schelling (1996) reminds us that there are perplexing normative questions surrounding the global warming problem.[2] A related literature on environmental tax reforms suggests that taxes on carbon-based fossil fuels provide an opportunity for reducing distortionary taxes on labor or capital. The prospect of a Pareto improving policy is presented – lower carbon emissions benefit generations in the distant future, and less distortionary taxes increase welfare for generations today.

In this paper we argue that decisions about how to reduce carbon emissions have important implications for current as well as distant future generations. We consider the design of carbon tax policies which share the burden of abatement with our children. The analysis presented here takes as a starting point the emissions targets Germany as adopted as part of the Kyoto meeting in November, 1997. We show that an overlapping generations (OLG) model is the only appropriate framework for this analysis. In our calculations, we take the carbon abatement target as

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[2]For example, one may consider that if per-capita income continues to increase at even a modest rate over the next one hundred years, it is likely that carbon abatement today benefits the rich (those born around 2150) at the expense of the poor (those alive today).

given and set aside the question of what the ultimate carbon concentration should be. Instead we consider how alternative schemes for limiting carbon emissions can affect welfare of persons alive today. Our model employs a standard second-best representation of the public sector. Public goods and services are funded with tax revenue which has a marginal cost greater than unity. In this setting, carbon taxes raise revenue which can be used to reduce distortionary taxes (Goulder (1995), Böhringer et al. (1997)). (Note that in this analysis we interpret a "double dividend" as a policy reform in which a corrective environmental tax reduces the need for other distortionary taxes. We do not model the employment effects of the environmental tax reform.)

We begin by assessing the need for an OLG framework by comparing results arising from an OLG model and a second dynamic model based on the more commonly applied infinitely-lived agent (ILA) framework.[3] We conclude that even when using an aggregate measure of economic impact such as GDP,[4] an OLG model may be essential for evaluating the prospects for a double-dividend.

We then consider the intergenerational incidence of carbon taxes combined with alternative revenue-recycling strategies. Given the long-term nature of the global warming problem, any effective carbon abatement policy involves carbon emission constraints of increasing severity over several generations. This raises the issue of intergenerational burden sharing: how will abatement costs be shared between ourselves, our children and their children? For our quantitative illustration of how to approach these issues we use a multisectoral general equilibrium model calibrated to recent data for the German economy.

Some key insights from our analysis are as follows:

- When revenues are recycled using the a non-distortionary consumption tax, the OLG and ILA results match precisely. If, however, we consider revenue recycling through capital or labor taxes, the two models can produce substantially different estimates of the efficiency cost of abatement. The OLG model is therefore interesting not only because it provides insight into the distributional consequences of environmental tax reform, but also because it provides a more consistent assessment of the social cost of abatement.

- As in the public finance literature based on overlapping-generations models (Auerbach and Kotlikoff (1987), Keuschnigg (1994)), we find that tax re-

[3]The acronym "ILA" comes from Manne (1995) who also compares results from OLG and ILA models. In an long-horizon integrated assessment context, he argues that the two frameworks provide very similar abatement schedules.

[4]We acknowledge that GDP may be a misleading metric for measuring the efficiency cost of tax reform. An alternative measure might have been aggregate consumption or per-capita welfare approximated in each period on the basis of the generations living at each point in time. We have chosen to use GDP for purposes of exposition for the simple reason that it is the most commonly applied metric in the policy debate.

form can produce a uneven pattern of economic burden across generations. The intergenerational incidence of carbon taxes depends crucially on revenue recycling. In simple terms, capital tax recycling produces smaller GDP impacts, but it shifts the burden from older to younger generations. Labor tax recycling, on the other hand, provides a more even distribution across young and old, but it is considerably less efficient.

- In our initial calculations we assume period-by-period balance in the public budget, so the replacement tax rate varies over time. In a second set of scenarios we assess alternative time paths for the replacement tax, all of which produce sufficient tax revenue over the model horizon to cover the present value of public expenditures which remain constant on a per-capita basis. These results suggest that the specification of an efficient and equitable tax reform policy can be complex. Simple rules of thumb may not achieve an equitable outcome. For example, a time-varying labor tax replacement which equalizes changes in the real wage over time leads to a favorable outcome for new generations, but this policy leads to lower long-run GDP and it produces lower welfare for almost all older generations. Likewise a tax replacement which equalizes percentage changes in aggregate consumption over the model horizon leads to a substantial redistribution in income from old generations to the young.

Apart from providing the first multisectoral OLG analysis of an environmental tax reform, this paper provides some innovations in OLG modeling.[5] We employ an OLG model of the Auerbach-Kotlikoff (1987) type where different life stages (education, work and retirement) are explicitly represented. This provides an interesting point of comparison with models of the Blanchard type, such as in the analysis of carbon tax issues by Lau (1996) and Frederiksen (1996). (See also, Howarth (1998).) Second, the model has a disaggregated representation of energy goods and non-energy production to accomodate the analysis of structural change induced by carbon tax policies. The disaggregation of energy goods permits us to distinguish energy inputs by carbon intensity and degree of substitutability in production. In addition, the model features important carbon-intensive industries which are potentially most affected by carbon abatement policies.

[5]Credit for the numerical techniques used to solve the model are due to Ferris and Munson (1998) who have achieved substantial improvements in robustness of the PATH mixed complementarity solver. Our model is defined over 13 time periods for a 120 year time horizon, 19 generational cohorts, and ten production sectors. A typical scenario is solved in 30 seconds on a 200 MHz pentium processor.

2. MODEL STRUCTURE

Our overlapping generations model is based on the idea that generations born in each decade make independent decisions about the allocation of income between consumption and savings. There is no motivation for bequests. There are rational point expectations of future prices. Producers and consumers are perfectly competitive, i.e. they take market prices as given. Figure 1 provides an overview of the model structure for a single period.

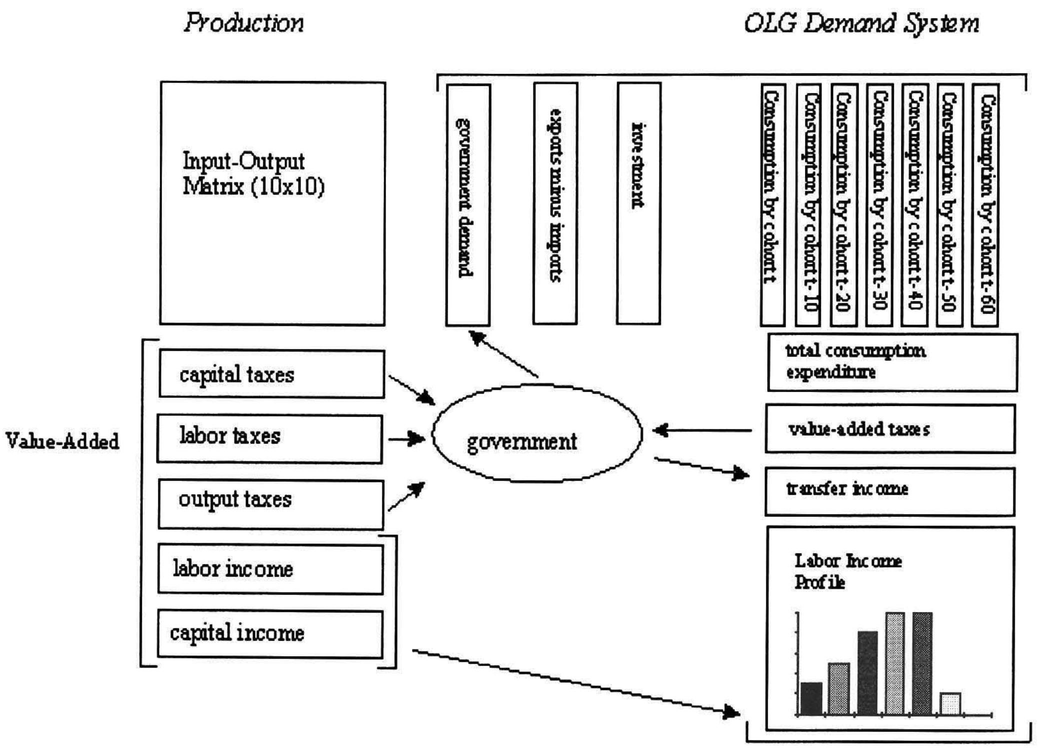

FIGURE 1. Economic Structure within a Single Period.

2.1. *Sectoral Disaggregation*

The model features a disaggregate representation of 10 industries based on the standard structure of German input-output-tables for 58 sectors (Statistisches Bundesamt (1994, 1997)). With regard to carbon emission constraints the sectoral disaggregation is chosen on the basis of carbon intensity, i.e. carbon-intensive sectors are as disaggregate as possible given the original data sources. To account for different carbon intensities and substitution possibilities across energy goods, the model identifies 6 primary and secondary energy goods: hard coal (HCO), soft coal (SCO), gas (GAS), crude oil (CRU), refined oil products (OIL) and electricity (ELE). In addition, the model incorporates three important carbon-intensive non-energy industries: chemical products (CHM), iron and steel (ORE) and an aggregate of other carbon-intensive sectors (OEI) including basic industries such as paper and pulp, ceramics, cement, plastics, etc. All other sectors are summarized in an aggregate rest of industry sector ROI. Table 1 summarizes the sectoral disaggregation.

2.2. *Production*

Competitive entrepreneurs minimize the costs of production and allocate investment across sectors in order to maximize the present value of firms. We distinguish between substitution possibilities for new and old capital stocks. All inputs to production with existing capital enter with fixed coefficients, whereas inputs to production with new capital may adjust depending on relative prices. These assumptions produce a model in which differences in ex-ante and ex-post substitution possibilities lead to differences in the short- dand long-run elasticities of demand for energy.

For each industry, a constant elasticity of substitution (CES) function describes the technological substitution possibilities in new vintage production (Y_{it}) between capital, labor, energy and intermediate materials (KLEM):

$$Y_{it} = f_i(K_{it}, L_{it}, E_{it}, m_{it}) = \min(m_{it}, KLE_{it})$$

and

$$KLE_{it} = \phi_i \left[\alpha_i E_{it}^{\rho} + (1 - \alpha_i) L_{it}^{\beta_i/\rho} K_{it}^{(1-\beta_i)/\rho}\right]^{1/\rho}$$

where the elasticity of demand for energy is given by $\rho = 1 - 1/\sigma$ with $\sigma = 0.5$.[6]

Production based on extant capital (X_{it}) is characterized by a Leontief technology, i.e.

$$X_{it} = \overline{X}_{it} \min\left(\frac{K_{it}^X}{\overline{K}_{it}}, \frac{L_{it}^X}{\overline{L}_{it}}, \frac{E_{it}^X}{\overline{E}_{it}}, \frac{m_{it}^X}{\overline{m}_{it}}\right)$$

in which bars indicate base year values.

[6]This value is consistent with aggregate estimates, such as those employed by Manne (1995). It would be appropriate to adopt differentiated values across sectors in extensions of this analysis.

Table 1: Sectoral Aggregation

Sector	SIO*	Description
extscele	3	Electric power & steam & warm water
extscgas	4	Gas
extschco	**	Hard coal
extscsco	**	Soft coal (lignite)
extsccru	8	Crude oil & natural gas
extscchm	9	Chemical products & nuclear fuels
extscoil	10	Oil products
extscore	16	Iron ore & steel
extscoei		Other energy-intensive goods aggregate, including:
	1	Agricultural products,
	2	Forestry and fishery products,
	7	Non-energy mining,
	11	Plastics,
	12	Rubber,
	13	Stone, lime and cement,
	14	Ceramic,
	15	Glass,
	32	Paper, pulp and board,
	33	Paper and board products,
	17	Non-ferrous metals,
	18	Casting products,
	19	Rolling products,
	20	Steel products,
	28	Metal and steel goods
ROI		All other sectors

* Classification according to the system of input-output tables.

** Hard coal (HCO) and soft coal (SCO) are subsectors of coal, sector 6.

Finally, energy inputs to sector i production with either new-vintage or extant capital involve a unitary elasticity of substitution between oil, coal, gas and electricity with value shares consistent with base year expenditure:

$$E_{it} + E_{it}^X = OIL_{it}^{\theta_{it}^{OIL}} GAS_{it}^{\theta_{it}^{GAS}} COAL_{it}^{\theta_{it}^{COAL}} ELE_{it}^{\theta_{it}^{ELE}}.$$

Nesting of the CES functions at different levels accomodates alternative assumptions regarding substitution possibilities in production, capturing interfuel substitution within the energy aggregate as well as substitution between energy and other production factors.

2.3. *Household Behavior*

The household side is disaggregated in overlapping households (generations or cohorts) which face an identical life cycle but different time profiles of labor and consumption prices over their lifetime. Each age cohort has a known and finite lifespan in which they engage in market activities for 70 years. New generations are endowed with an exogenous labor supply over the life cycle. Old generations enter the model endowed with labor and initial stocks of capital and debt. There is a perfect market for borrowing, and there is no risk of default.

Each period in the model represents a decade, and each cohort engages in economic activity over seven decades. Younger generations have less work experience and consequently have lower labor productivity, as reflected in our assumptions about their endowment of labor services in efficiency units. We model aggregate population as constant, but incorporate an exogenous growth over time in labor productivity due to an external accumulation of human capital by society.

Labor supply in efficiency units declines as cohorts age, reflecting exogenous assumptions about retirement behavior. No labor is supplied in the final decade of life, and in that period all consumption is financed out of accumulated savings.

Figure 2 illustrates our assumed exogenous distribution of labor endowment over the households life cycle. The horizontal axis represents a cohort of a given age. The curve labeled θ_L indicates each agegroups' share of aggregate labor services, θ_I represents the fraction of lifetime income provided at different ages in the steady-state equilibrium with an interest rate of 5%. The curve labeled θ_K represents each cohort's share of the economy-wide capital stock. These shares are negative for younger cohorts reflecting borrowing in early years when the value of consumption exceeds the value of labor income.

A Ramsey model characterizes each cohort's allocation of income to consumption and savings. An individual is assumed to allocate lifetime income to consumption over time in order to maximize the present value of welfare. We assume that the intertemporal utility function is convex, consistent with the idea that a household

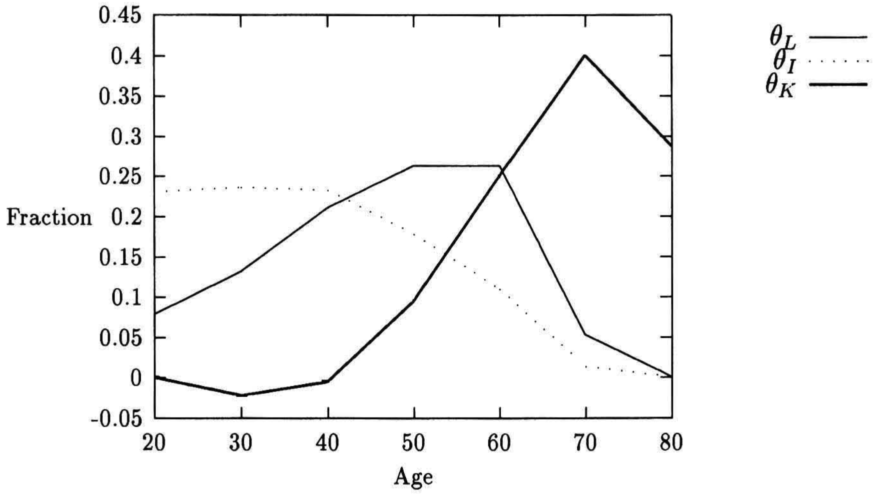

FIGURE 2. Steady-State Labor, Income and Equity Shares by Cohort.

smooths income by saving decisions, i.e. the household will save income in earlier periods to finance consumption during retirement. The specific form of intertemporal utility function is:

$$U_g = \sum_{t=g}^{g+T} \left(\frac{1}{1+\delta}\right)^{t-g} \frac{C_{gt}^{1-\theta} - 1}{1-\theta}.$$

Total consumption in period t then represents a composition of demands from all generations who are living in that period:

$$\hat{C}_t = \sum_g C_{gt}.$$

Within each period consumption demand represents an aggregate of energy and non-energy goods, with a constant elasticity of substitution between energy and non-energy goods equal to 0.5:

$$\hat{C}_t = \left[\frac{\beta_C}{E_{Ct}} + \frac{(1-\beta_C)}{\left(\prod_{i \notin E} c_{it}^{\alpha_i^c}\right)}\right]^{-1}.$$

Final demand for energy (E_{Ct}) has the same functional form as intermediate energy demand with a Cobb-Douglas aggregate across electric, oil, coal and gas.

2.4. *Goods Markets*

Domestic markets clear in every period, equating aggregate domestic output plus imports to aggregate demand, where demand arises from intermediate inputs, investment, private consumers and government. Market clearance for non-energy goods is given by:

$$A_i(D_{it}, M_{it}) = \sum_j a_{ij}(m_{it} + m_{it}^X) + I_{it} + C_{it} + G_{it}.$$

2.5. *Factor Markets*

We assume perfectly competitive factor markets in which factor prices adjust so that supply equals demand. Primary factors include labor, new vintage capital and extant capital. Labor and new-vintage capital are assumed to be homogenous and perfectly mobile between sectors. Extant capital is exogenous and sector-specific. Labor supply is inelastic and increases with labor force efficiency along a steady-state annual growth rate of 1%. At every point in time we have labor market clearance equating demand for labor by new vintage and extant production with supply of labor by generation:

$$\sum_i \left(L_{it} + L_{it}^X\right) = \sum_g \overline{L}_{gt}.$$

Extant capital stocks are sector-specific and depreciate geometrically:

$$K_{it}^X \leq \lambda^t \overline{K}_i$$

and new vintage capital stocks are assumed freely mobile across sectors:

$$\sum_i K_{it} = \hat{K}_t.$$

New vintage capital stocks depreciate at the same rate as extant capital, and they are increased through investment:

$$\hat{K}_{t+1} = \lambda \hat{K}_t + I_t.$$

The level of savings and investment is endogenously determined indirectly through households maximization of intertemporal welfare over their lifetimes. Capital markets function perfectly, and firm managers choose investment in order to maximize the present value of investment. The level of savings is thus determined joint with the consumption decisions of interacting cohorts. In equilibrium investment equates the marginal utility of consumption and investment.

2.6. *Government Sector*

The government distributes transfers and provides a public good which is produced with commodities purchased at market prices. Government expenditures are financed with tax revenues. The model incorporates the main features of the German tax and social transfer system. Table 2 provides a summary of taxes and transfers in the benchmark year. All of our simulations are based on revenue-neutral tax reforms. This is implemented by keeping the amount of the public good provision fixed, and recycling any residual revenue lump sum or through a reduction in existing taxes on labor, capital or consumption.

In our simulations we distinguish two alternatives for balancing the budget. First, we assume that the government must balance its budget on a period-by-period basis. Due to differences in the short- and long-run elasticity of demand for energy, the carbon tax rate changes through the transition to a new steady state. This causes changes over time in the replacement tax.

Second, we allow for balancing the public budget on an intertemporal basis, so that the public sector can run a temporary deficit which must be offset by equivalent surpluses over time. Assuming separability in welfare between public and private consumption, we may measure welfare changes through changes in the demand for private goods by holding public output fixed.

2.7. *Foreign Trade and Capital Flows*

In international trade Germany is treated as small relative to the world market. That is, we assume that changes in German import and export volumes have no effect on its terms of trade. Domestic and foreign products are distinguished by origin according to the Armington assumption. The Armington goods are aggregated with identical import shares for a given import good across all components of final and intermediate demand. On the export side, products of the Armington sectors destined for domestic and international markets are treated as imperfect substitutes, produced subject to a constant elasticity of transformation (CET).

Although Germany is open with respect to international capital markets, we assume in our calculations that net financial capital flows are zero in every period of the model. We make this assumption reasoning that if other OECD countries are adopting similar policies there would some change in the international interest rate, and it would therefore be inappropriate to assume that the international interest rate is fixed. We also refer to the stylized fact that net international capital flows are typically small relative to domestic savings and investment, so the imposition of a zero trade balance in each period may be more appropriate than assuming complete equalization of domestic and international interest rates.

Table 2: Taxes in the Benchmark Year (1993)

Tax Instrument	Incidence	Revenue
Corporate tax	Capital	27.8
Property tax	Capital	6.8
Income tax	Labor	258.0
Assessed income tax	Capital	33.2
Non assessed income tax	Capital	22.7
Trade tax	Capital	19.9
Other indirect production taxes	Output	12.7
Mineral tax	Output	37.5
Import tax and duties	Imports	28.5
Value added tax	Consumption	216.3
Social security payments	Labor	72.1*
Total tax payments		735.7

Source: Statistisches Bundesamt (1994, 1997)

* Social security payments indicated represent only those contributions which have the character of a tax. Contributions for which households receive well-defined services are not included in this amount.

2.8. *Carbon Backstop*

We model the application of a carbon tax which is sufficient to reduce carbon emissions by 15% from a growing baseline trajectory over a ten-year period and hold them at that level indefinitely. This policy is somewhat *less* ambitious than Germany official target of a 25% by the year 2005 taking 1990 as the base year, but it is roughly of the same order of magnitude as targets agreed upon at Kyoto. If we were to assume no change in technology apart from the possibility of substitution from energy toward other inputs along the production isoquant, then this policy scenario would result in a continuous increase in the cost of energy into the infinite horizon. In short, the model would never reach a new steady-state equilibrium.

When policy makers contemplate the Kyoto targets, it is commonly assumed that at some price there exists a non-carbon energy source which provides an upper bound on the tax rate required to achieve a constant level of emissions. In other words, it seems appropriate to consider the carbon abatement policy as one which moves the economy from an initial steady-state equilibrium to a new steady-state in which the price of energy is determined by a new technology.

There are a range of issues concerning how this transition might be modeled (see Lau, Pahlke and Rutherford (1997)), but for the present analysis we opt for a very simple representation of the new steady-state equilibrium. We assume that there exists a carbon backstop-technology which can effectively produce an infinite supply of carbon rights at constant marginal cost. In our core simulations we set the costs of the carbon backstop equal to a present value of DM 600 per ton of carbon. All of our simulations therefore involve a transition in which the application of a carbon limit causes a gradual introduction of the backstop activity as illustrating the introduction of new alternative sources of fossil fuels.

2.9. *Calibration*

As is customary in applied general equilibrium analysis, the model is based on economic transactions in a benchmark year, 1993 in this case. Benchmark data determines parameters of the functional forms from a given set of benchmark quantities, prices (expressed in present value), and elasticities.

Data for this model calibration stem from two different sources which are reconciled to provide a consistent benchmark data set. First is the input output tables of the statistical offices of Germany. The input-output data base covers the outputs and intermediate inputs of the 10 sectors of the model, the factor earnings, imports, and the final demand categories (consumption, investment, government expenditures and exports). Prices in the benchmark year are normalized to unity for calibration purposes, so monetary values can be interpreted as physical quantities in the benchmark year. The second data source is the statistical yearbook which reports tax revenues by type and social contributions.

Base year financial statistics indicate the value of payments to capital across sectors and the gross value of capital formation. Using these data, we infer the growth rate, the depreciation rate, the interest rate and the consumption path over the life cycle in order to assure consistency with a balanced steady-state growth path.

3. SCENARIOS AND RESULTS

3.1. *Policy Scenarios*

For our policy scenarios we consider a carbon abatement of 15% over a 10 year period, with a constant level of emissions thereafter. Alternative tax policies to achieve this cumulative reduction target can be distinguished with respect to

(i) revenue recycling. We impose revenue neutrality by multiplicative adjustment of one of three taxes in order to maintain a constant per-capita provision of the public good. The equilibrating taxes include the tax on capital (K), labor (L) and consumption taxes (C).

(ii) balancing the public budget: Public revenues and expenditures can be either balanced on a period by period basis or on an intertemporal basis. The latter implies that a government can run temporary deficits and surpluses. We use this degree of freedom for simulating a tax policy where carbon tax revenues are recycled by a constant cut in the replacement taxes over time.

3.2. *Results*

OLG versus ILA

The GDP impacts of carbon abatement with a non-distortionary tax replacement is identical in the OLG and ILA models, as is illustrated in Figure 3. OLG is based on an overlapping generations representation of consumption and savings demand, and ILA is based on a model with an infinitely-lived representative agent. In both models the government faces a period-by-period budget constraint, and an equal yield is maintained through adjustment of the consumption tax. GDP is measured as the sum of consumption plus investment, deflated by the consumer price index.

This result follows from homotheticity of the intertemporal utility functions and the fact that we adopt an equivalent elasticity of intertemporal substitution in the utility function of the infinitely-lived agent and in that of the individual cohorts which make up the OLG model.

Next we compare GDP impacts of an equivalent carbon abatement profile in the OLG and ILA models, maintaining an equal yield through adjustment of taxes

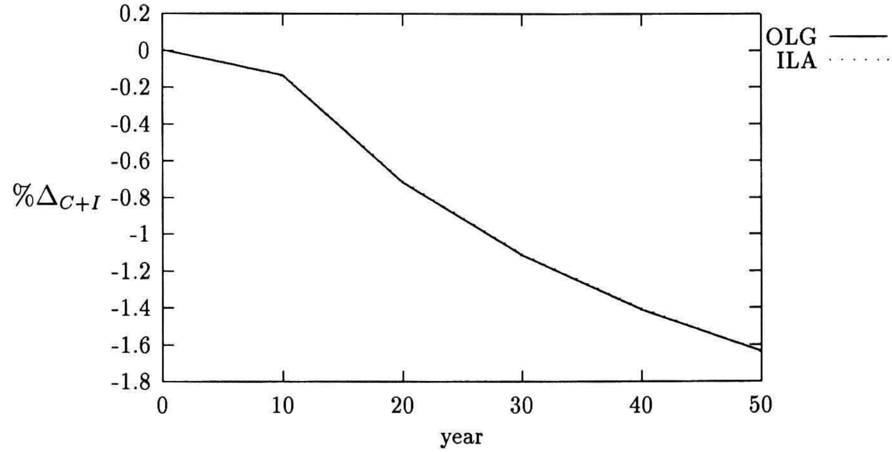

FIGURE 3. GDP Impacts with Consumption Tax Recycling.

on capital income. Figure 4 shows that in ILA model there is a substantial scope for a double dividend (replacement of capital taxes with carbon taxes produces an increase in GDP by almost 0.5% over a thirty-year horizon). In contrast, the OLG model predicts limited scope for a double dividend. The difference in the aggregate impact of carbon taxes in these models is attributable to differences in the feedback of factor income on final demand in the two models. In the ILA model increased returns to capital result in increased consumption demand over the full model horizon, whereas in the OLG model the tax reform produces a windfall gain for owners of the initial capital stock. As a consequence, GDP falls much more quickly in the OLG model, whereas the ultimate decline in GDP is postponed for several decades in the ILA model.

Revenue Recycling and Intergenerational Incidence

Figure 5 investigates the implications of carbon abatement for intergenerational equity using Hicksian equivalent variation in lifetime income (EV%) to measure welfare impacts. Three revenue recycline strategies are considered, based on replacement through labor, capital or consumption taxes. The revenue recycling instrument is an important determinant of welfare impacts. Recycling through the capital income tax benefits the middle-aged, while labor tax recycling is preferred by those born during the first 75 years of the model. In these experiments the government faces a period-by-period budget constraint. In all cases, those born twenty years or more in the future bear a larger share of the cost of abatement

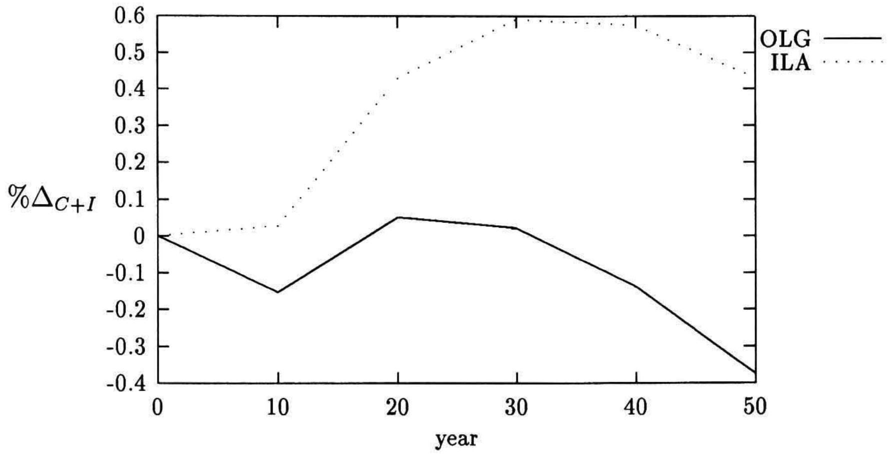

FIGURE 4. GDP Impacts with Capital Tax Recycling.

than do any generations who are currently alive.

Figure 6 illustrates the time path of replacement tax rates. A 15% reduction in carbon emissions over a 10-year horizon requires significant short-term taxes on energy use. Over the longer term alternative (backstop) technologies are developed and carbon tax revenues fall as a fraction of total government revenue. Here we compare consumption, capital and labor tax replacement tax indices which reflect differences in the associated tax bases. In these calculations the government maintains a balanced budget in every period.

An Intertemporal Public Budget

Our final calculations consider two models in which the government may run a period-by-period surplus or deficit, subject to the constraint of no change in net indebtedness over the model horizon. The purpose of these calculations is to illustrate the difficulty of defining a simple rule of thumb which equalizes the burden across generations. In our first calculation we vary the labor income tax period-by-period to equalize changes in the net of tax real wage. In the second model we constrain consumption tax varies over time in order to equalizes changes in *aggregate* consumption across time. Our intention here is not to compute an optimal tax, because such a calculation would require specification of an explicit social welfare function. Instead, we simply evaluate the welfare impact of some taxes which might be advocated on the basis of "fairness".

Figure 7 indicates the government surplus at different points along the transi-

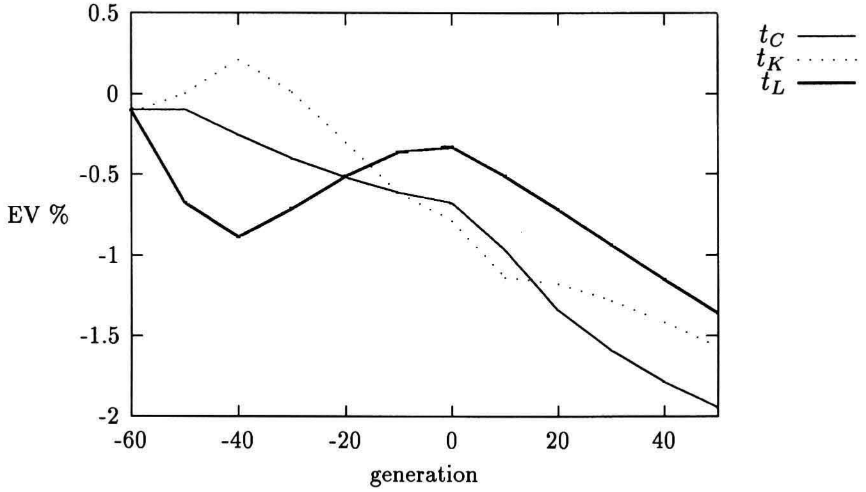

FIGURE 5. The Intergenerational Incidence of Carbon Taxes.

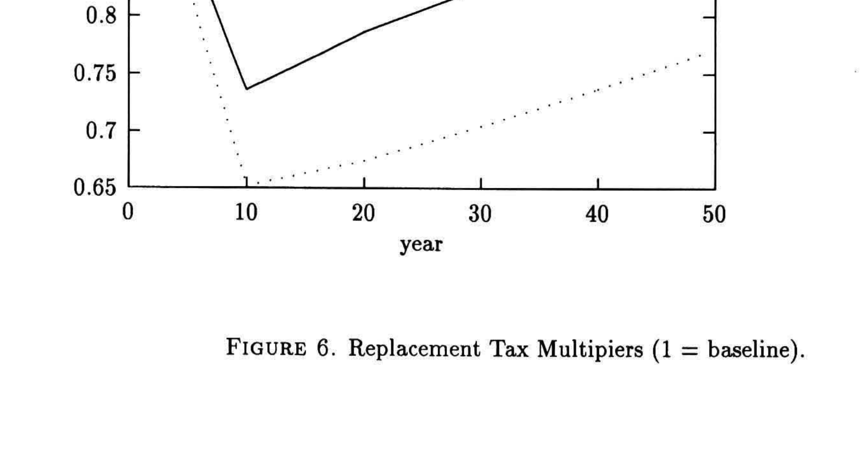

FIGURE 6. Replacement Tax Multipiers (1 = baseline).

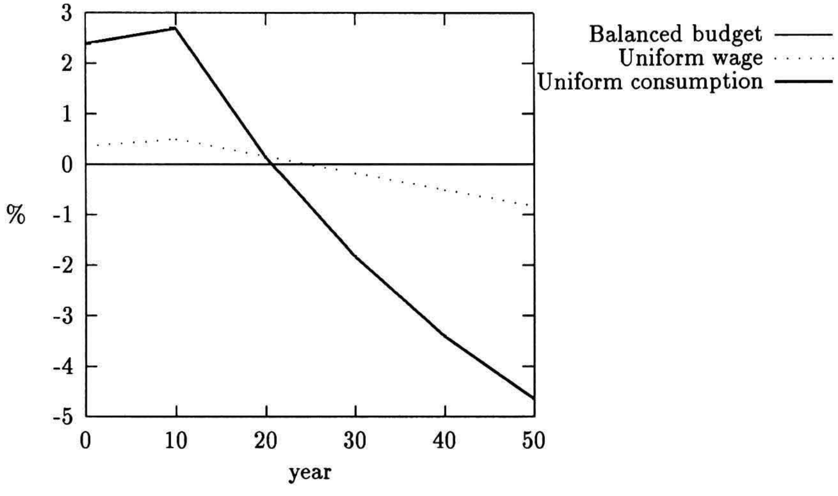

FIGURE 7. Models with an Intertemporal Public Budget.

tion path for three scenarios. The first, labeled "Balanced budget" is based on consumption tax recycling and a period-by-period government budget constraint. The plot labeled "Uniform wage" corresponds to wage tax recycling in which the labor income tax rate is adjusted to achieve a uniform change in the net of tax wage. (The real wage falls by 0.2% in this case). We see that this rule results in a small surplus in the public budget during the first 20 years and and a deficit thereafter. The plot labeled "Uniform consumption" corresponds to consumption tax recycling in which the consumption tax rate is varied over time to achieve a uniform percentage reduction in aggregate consumption. (Aggregate consumption falls by 0.4% in every period.)

The time profile of government surplus is suggestive about the time path of the replacement tax instrument. In the case of wage tax recycling, achieving a uniform wage impact requires a small initial increase in the labor tax, with a subsequent reduction, but not as much of a reduction as in the case of period-by-period public budget balance. A comparison of the time path for the "Balanced budget" scenario and the "Uniform wage" scenario is presented in Figure 8.

As one might expect, equalization of the real wage over time provides equalization of welfare impacts in the long run, but not in the short run. During the transition as carbon tax revenue is recycled through lower wage taxes, the value of equities declines and older generations bear a disproportional share of the burden, as is illustrated in Figure 9.

With a consumption tax replacement rule where adjustments in the rate equalize

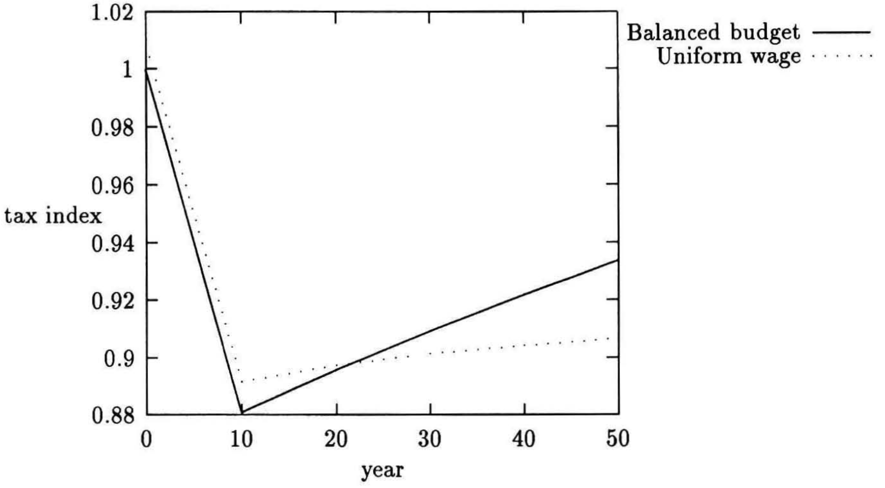

FIGURE 8. Wage Tax Replacement Profiles.

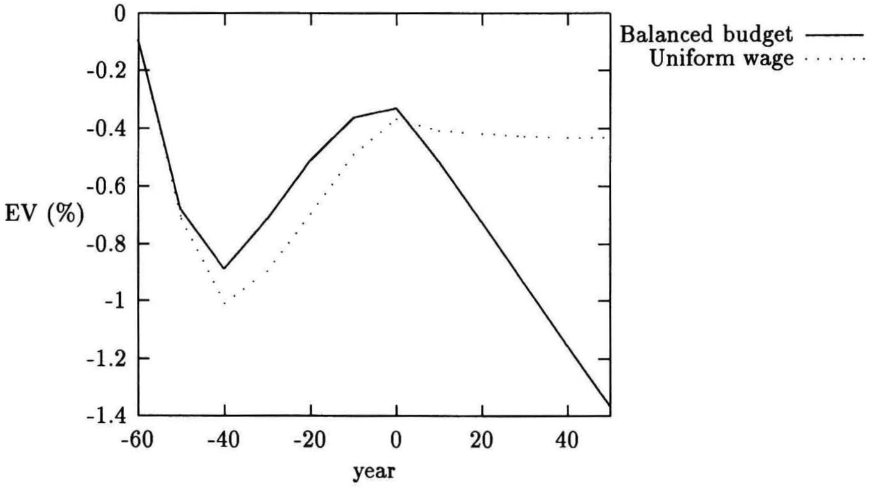

FIGURE 9. Intergenerational Incidence: Wage Tax Replacement.

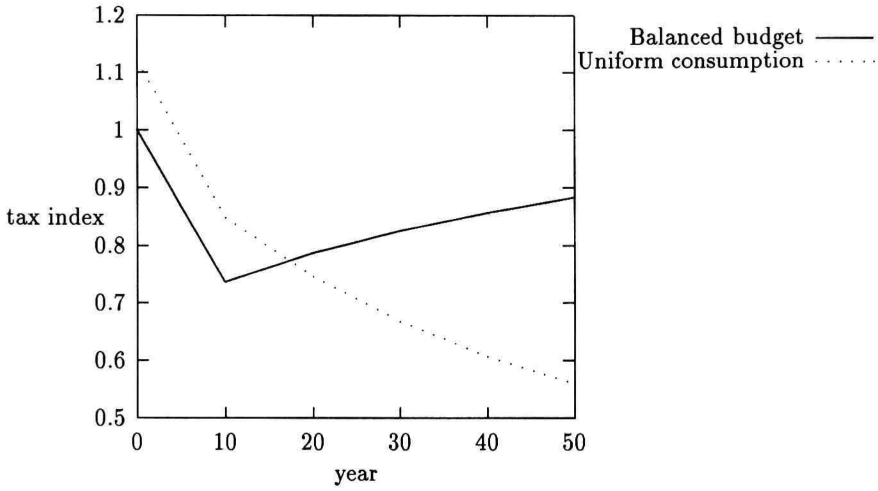

FIGURE 10. Consumption Tax Replacement Profiles.

the change in aggregate consumption over time, we have an even more pronounced redistribution from current generations to future generations. The reason for this is that equalization of consumption requires a declining consumption tax rate over time which (in the absence of international capital flows) results in a reduction in the interest rate. Figure 10 illustrates the resulting time path for the consumption tax rate, under a balanced budget rule and under the uniform consumption impact rule. In the later case, the consumption tax index must increase by 10% initially and fall gradually thereafter, reaching nearly one-half the initial rate after 50 years.

The net effect of this time path for consumption taxes is to reduce consumption of old generations entering the model as new generations move consumption from the future to the present. This continues into the future as the welfare of future cohorts increase in every generation, resulting in nearly a 2% increase in welfare for generations born 50 years in the future.

On the basis of these calculations, it seems that in the absence of targeted lump-sum transfers to specific generations, it may be quite difficult to design a tax reform which is "fair" to all age groups.

4. CONCLUSIONS

Rational decisions for long-term tax policies to reduce carbon emissions require an understanding of their potential economic impacts. In this paper we have shown that a model with overlapping generations is an appropriate analytical framework

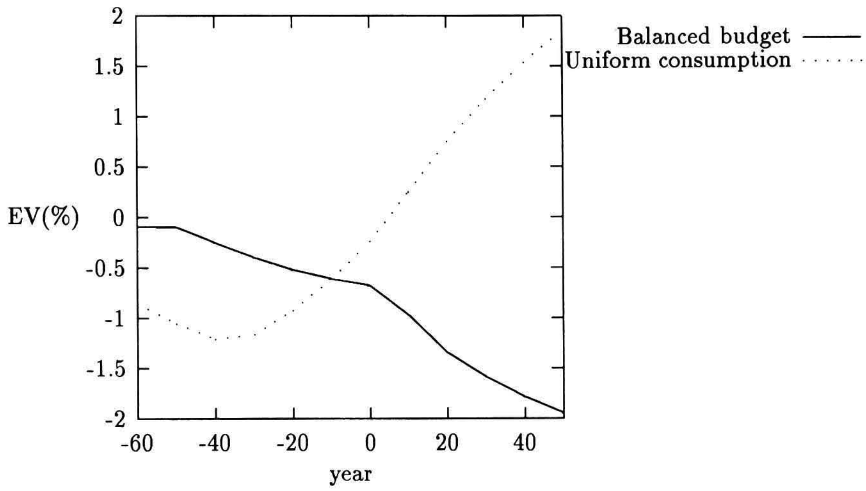

FIGURE 11. Intergenerational Incidence: Consumption Tax Replacement.

not only for studying intergenerational equity effects but also for evaluating the efficiency implications induced by alternative carbon tax policies. Comparing the OLG model with an otherwise identical infinitely-lived agent model of the sort commonly employed for the efficiency analysis of tax reforms, we find that the OLG model provides a more plausible description of savings and consumption responses in the medium term. Our numerical simulations for the German economy reveal significant differences in the assessed impact of carbon abatement on gross economic performance. Differences between the OLG and ILA analyses are attributable to importance of income effects on aggregate demand. We conclude that the prospects for a double-dividend of carbon tax reforms may be overstated in the ILA framework because efficiency gains from reducing distortionary (capital) taxes imply increased consumption over the full time horizon whereas in the OLG framework these gains might just be consumed by older generations resulting in a more rapid reduction in capital stocks and gross production over time.

A second theme emerging from our OLG calculations is that the recycling of carbon tax revenues can significantly affect intergenerational burden sharing and may produce a pronounced trade-off between equity and efficiency. Not surprisingly, revenue recycling through cuts in capital taxes yields smaller negative impacts on GDP as compared to lowering less distortionary taxes on labor or consumption. However, capital tax recycling shifts the burden from older to younger generation and produces a more uneven distribution of abatement costs across generations as compared to labor tax recycling.

Our final insights relate to flexible intertemporal public budget policies as a potential instrument for reducing efficiency-equity trade offs. We show that equalization of the impacts of the real wage on aggregate consumption over time does not lead to an equitable burden sharing across generations. We conclude that the specification of an efficient and equitable tax reform policy is a complex issue which provides interesting directions for future research.

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