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Overlapping Generations or Infinitely-Lived Agents

Intergenerational Altruism and the Economics of Global Warming

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Abstract. Do we need an overlapping generations model for the economics of global warming? To answer this question, an infinitely-lived agent (ILA) approach and an overlapping generations (OLG) model are contrasted. ILA and OLG can be viewed as polar representations of intergenerational altruism. With ILA an immortal agent acts through his investment/savings decisions as trustee on the behalf of the future generations. With OLG, agents need not behave altruistic. They simply save during working years and dissave completely during retirement. Nevertheless, ILA and OLG must not differ in their implication for greenhouse policy. Greenhouse gas abatement is a straightforward alternative to physical capital formation and, even without altruism, each age cohort has an incentive to provide current abatement in order to reduce future damages attributable to climate change. Indeed, under reasonable assumptions and parameter values, our simulations reveal such an invariance result. Provided carbon taxes are the only policy tool and tax revenues are recycled through socially mandated rules, projections of economic growth, climate change and energy consumption are only insignificantly affected by the choice of approach.

Key words: climate policy, intergenerational altruism, overlapping generations, infinitely-lived agents, computable general equilibrium

1. Introduction

That humanity is playing dice with the global environment and that the outcome of this play might be disastrous, is a commonplace in public debates. In fact, the present can affect the future in quite different ways. On one hand, by depleting natural resources and by polluting the environment a serious burden is placed on future generations. The most striking example is the expected climate change due to current carbon dioxide (CO_2) emissions. On the other hand, by investing into industrial plants, into infrastructure and knowledge the economic boundaries of the coming generations are significantly expanded.

There are different ways to focus on intertemporal decision making, intergenerational equity and efficiency. One option would be to employ an overlapping generations structure. A second possibility is to use a Ramsey approach and to start from the assumption that future generations are represented by a single infinitely-lived agent.

At first glance an overlapping generations (OLG) framework is best-suited. It is more than a mathematical curiosity. It allows for a realistic modelling of the demographic structure of a society. It provides a theoretically adequate treatment of humanity's finite life-span in an open-ended world. And it avoids the assumption that an immortal agent acts as a trustee on behalf of both the present and future generations. These features make the OLG approach applicable to a wide range of intertemporal phenomena just as the mentioned trade-off between intergenerational equity and economic efficiency of climate policy (see D'Arge et al. 1982).

However, although intergenerational justice and the principle of sustainability are the most prominent arguments in calling for climate policy, the economic literature on climate change has typically adopted the infinitely-lived agent (ILA) approach. Empirically oriented contributions (for example, see Manne et al. 1995; Nordhaus 1994; Peck and Teisberg 1992) are almost exclusively based on the Ramsey approach.

One could of course argue that a Ramsey model is the natural approach for studying the allocation of assets and resources across generations. The intergenerational equity issue is submerged in this framework. Equity between generations is represented simply by adding up the generations' discounted utility levels, where each generation's utility depends only on its own consumption, and the discounted sum of instantaneous utilities is taken as a measure of social performance (see Solow 1986).

There are, however, reasons not to share this standpoint and to reject the Ramsey approach. Schelling (1995) points out that it is difficult to believe in the fiction of an immortal principal agent who takes the increments into any future generation's utility as if they were increments in his own. Howarth and Norgaard (1992) argue that a Ramsey-type cost–benefit analysis is inadequate, since it is based on the assumption that the discount rate can be selected exogenously which, however, is determined endogenously and depends on the intergenerational distribution of assets. Marini and Scaramozzino (1995) reinforce these findings. They argue that only a framework which incorporates consumer heterogeneity and disconnectedness across generations gives enough space for considering the effects of different policy options on the trade-off between capital accumulation and environmental quality.

Does this mean that the overlapping generations approach is superior for the economic analysis of climate change? Or do situations exist in which a Ramsey framework can be plausible? To allow for a systematic comparison, this paper presents a simple version of a computable general equilibrium model of climate change. It is closely related to that of Manne (1996), but avoids his rather artificial assumption of perfect foresight and riskless choices by applying a recursive rather than an intertemporal treatment of expectations. Consequently, we can sidestep the issue of discounting consumption since discount rates are determined endogenously.

In this paper ILA and OLG represent polar viewpoints on intergenerational altruism. With ILA there is an immortal agent who acts as trustee on the behalf of the coming generations. At each point of time he determines through his investment/savings decisions both their physical and environmental capital endowment. With OLG, agents have no bequest motive and do not behave altruistically. They save during working years and dissave completely during retirement. Nevertheless, ILA and OLG do not differ in their implication for greenhouse gas abatement. They virtually lead to the same results with respect to carbon prices, the share of fossil fuels in energy consumption and economic damage due to climate change. But there can be slight differences with respect to relevant macro-economic variables such as gross production and investment. If carbon dioxide emissions are taxed and carbon taxes are recycled to the young, then OLG shows a small bias towards stronger economic growth. If the old receive the tax revenue, then the opposite is observed. Not surprisingly, then, there is a tax sharing rule between young and old generations such that the ILA and OLG are invariant.

Implicit here is the idea of a decentralized market economy into which greenhouse policies are implemented without major changes in the ownership of labor, capital and other conventional resources. Global climate is viewed as public good and agents cannot provide for the climate of their offspring by acting individually. Intergenerational wealth transfers can only accrue from socially mandated transfers of carbon taxes. Note, since carbon taxes and the redistribution rules have to be determined in a political process, these transfers must be viewed as collective action expressing society's degree of altruism toward the future generations.

Section 2 discusses two versions of the model: one in which intertemporal decisions are made by infinitely-lived agents, one that has an overlapping generations structure. Section 3 presents the results of our computational experiments under these two modelling formulations. Concluding remarks are found in Section 4.

2. Theoretical Setting

To present ideas in the most simple way, it is appropriate to aggregate highly. The world is described as though it were a single region operating as market economy. Among the various greenhouse gases, carbon dioxide (CO_2) is considered as the most relevant one and potential global warming is caused by increased atmospheric CO_2 concentration. It directly affects production, but not utilities.

Time is taken as discrete, and commodities of different periods are viewed as distinct. Agents behave as price takers. Consumers maximize utilities, and producers optimize profits. In the ILA approach there is an infinitely-lived agent, just as in a Ramsey model where a representative, immortal consumer maximizes utilities over an infinite time horizon. In the OLG approach, there is a sequence of overlapping age cohorts. Each generation lives for two periods and consists of a single, representative consumer indexed by date of birth.

We discriminate between just four commodities: capital and labor on one hand, greenhouse resources such as oil, gas or coal and carbon-free energy such as hydro or solar on the other. CO_2 emissions depend on the consumption of greenhouse resources. Global production possibilities are characterized by a nested constant elasticity of substitution (CES) function. Capital, labor and energy together produce the world's gross product which can be consumed, invested into future capital stocks or put into energy supply activities. Greenhouse resources are supplied at increasing marginal costs. Carbon-free resources are provided at constant, but high marginal costs.

The greenhouse issue is a public good problem and parent–offspring altruism cannot ensure improvements in future climate conditions. Instead, international agreements for abatement and for burden-sharing between regions and over time are required. Among the various policy tools, taxes on carbon dioxide emissions are considered as the only policy variable. Tax revenues are recycled through socially mandated redistribution schemes, where society decides how to redistribute CO_2 taxes among young and old generations.

2.1. Global climate and the greenhouse effect

To model the relationship between carbon dioxide emissions and economic damage it is necessary to specify, on one hand, how CO_2 accumulates in the atmosphere, and to evaluate, on the other, how an increased atmospheric CO_2 stock (concentration) feeds back into production.

Based on historical data, Nordhaus (1991) has estimated the actual stock, $Q(t)$, of atmospheric carbon dioxide as a linear function of the former one, $Q(t-1)$, and past-period global CO_2 emissions, $s(t-1)$

$$Q(t) = \Psi(Q(t-1) + \Theta s(t-1)). \tag{2.1}$$

Equation (2.1) takes two important effects into account. (1) Only a fraction Θ of current emissions will rest in the atmosphere. The other part is subject to oceanic uptake. (2) Due to the long-run transfer of CO_2 from the rapid mixing surface layers into the deep ocean, the stock of atmospheric CO_2 is per period reduced by factor Ψ.

Studies on the economic impact of climate change are based on case studies, educated guesswork and extrapolation (see Tol 1995). The most speculative feature is the specification of a damage-function which measures the economic effects of climate change as a function of the atmospheric CO_2 stock. Just as in the MERGE model (see Manne et al. 1995) economic losses are estimated through

$$\Phi(t) = 1 - (Q(t)/\Omega)^2. \tag{2.2}$$

$\Phi(t)$ is the so-called environmental loss factor, i.e., $1 - \Phi(t)$ percent of gross production are lost because of global warming. Ω marks the critical value of the

CO_2 stock. At this atmospheric carbon dioxide concentration, production is reduced to zero.

2.2. Greenhouse resources, carbon dioxide emissions and green output

CO_2 emissions are determined by the consumption of greenhouse resources. Therefore, there exist at least two possibilities to reduce CO_2 emissions. One is to replace greenhouse resources by carbon-free energy inputs. Another is to cut back greenhouse inputs, to increase the energy efficiency of production and to substitute between capital, labor and energy.

Typically, substitution possibilities between capital, labor and energy are small compared to interfuel substitution. Therefore gross production $y(t)$ is characterized by constant elasticity of substitution (CES) between two aggregates of inputs: value added on the one hand and energy on the other. Value added is produced by capital $K(t)$ and labor $l(t)$ through a Cobb–Douglas function. Energy is a Cobb–Douglas aggregate[1] of greenhouse resources $e(t)$ and carbon-free energy sources $n(t)$

$$y(t) = (\beta_1(l(t)^{\gamma}K(t)^{1-\gamma})^{\varepsilon} + \beta_2(e(t)^{\alpha}n(t)^{1-\alpha})^{\varepsilon})^{1/\varepsilon}. \tag{2.3}$$

α and γ are the Cobb–Douglas parameters and ε is the CES elasticity of substitution. β_1 and β_2 are coefficients derived from base year data.

As mentioned above, the environmental and the macro sub-model are linked through the concept of green output which is the product of the environmental loss factor $\Phi(t)$ times the conventional measured gross product $y(t)$. At any rate, green output $\Phi(t)y(t)$ can be invested, $b(t)$, consumed, $c(t)$, or used to supply either greenhouse resources $e(t)$ or carbon-free energy $n(t)$

$$\Phi(t)y(t) = c(t) + b(t) + \delta(t)e(t)^2 + \rho n(t). \tag{2.4}$$

Energy supply costs are measured in units of gross production. $\rho n(t)$ are the costs of carbon-free energy which are high, but proportional to the amount supplied. Costs $\delta(t)e(t)^2$ to provide greenhouse resources are quadratic in quantities and since the stock of greenhouse resources is limited the exogenous cost-parameter $\delta(t)$ rises over time.

2.3. Expectations and market structure

A significant part of the economic literature on global climate change is based on a clairvoyant or, expressed in more technical terms, an intertemporal equilibrium approach. With a clairvoyant model, agents make rational and consistent projections of future prices. This allows for considering systematically intertemporal substitution possibilities, and incorporates the Hotelling rule of exhaustible resources in a logically consistent way.

From an institutional, an empirical, a conceptual and a computational viewpoint, however, the clairvoyant approach leads to all sorts of difficulties. First, it requires the legal enforce-ability of contracts over a long-term time horizon. Since global warming is both an intertemporal and intratemporal public good problem, its solution would require at least two kinds of new institutions: international agreements for abatement and for burden-sharing between regions on one side, novel institutional arrangements such as emission taxes or tradable quota rights with markets for present or future tradable emission permits on the other (see Manne 1996).

Second, there is evidence that individuals are more sensitive to contemporaneous than future events, and we must recognize that a fully intertemporal model is much more difficult to solve numerically than a recursive one (see Stephan 1993). Finally, many economically relevant variables, like future endowments, technologies and tastes, are not certain or even not observable. Hence, ignorance arises naturally whenever agents cannot preclude unexpected changes during the time between making a choice and receiving its pay-off.

To avoid these difficulties, this paper assumes that agents are ignorant with respect to the future both in the ILA and the OLG case. Since restrictions in predictability can be revealed only as time evolves, the only way to proceed is to move sequentially. Indeed, sequential decision making by ignorant agents is logically consistent with a recursive dynamic structure. On spot-markets consumers can buy their current consumption bundles and sell their endowments of primary resources and capital goods. At the same time, they are able to 'insure' themselves by investing into future capital stocks, where investment is viewed as an option on future income, hence future consumption opportunities rather than real goods (see Stephan 1993).

2.4. Production and Greenhouse Policy

At each point of time, t, well-organized spot-markets for consumption and investment, labor and capital exist. $p(t)$, $w(t)$ and $r(t)$ denote the spot-market prices of consumption and investment, the wage rate and the price of capital services, respectively. Since producers have to take the atmospheric stock of CO_2 as given and act myopically,[2] in each period the representative producer maximizes the short-run profit function

$$\pi(t) = p(t)\Phi(t)y(t) - w(t)l(t) - r(t)K(t) - [p_e(t) + \tau(t)]e(t) - p_n(t)n(t), \qquad (2.5)$$

subject to Equation (2.3). $p_e(t)$ and $p_n(t)$ are the spot-market prices of greenhouse fuels and carbon-free energy, respectively.

The greenhouse issue is viewed as a public good problem and taxes on carbon dioxide emissions are considered as the only institutional arrangement applied for greenhouse policy. Since CO_2 emissions depend on the quantity and type of greenhouse resource used, it is feasible to interfere directly from the fuel's inputs on CO_2 emissions. Thus, instead of CO_2 emissions consumption of greenhouse resources is taxed at a politically determined, hence exogenously given rate $\tau(t)$ and tax revenue $T(t) = \tau(t)e(t)$ are recycled to the consumers (see below).

2.5. CONSUMPTION, CARBON TAX RECYCLING AND INVESTMENT

In the ILA case the economy is analyzed as though there were a single, immortal consumer who acts as a trustee on behalf of both the present and the future generations. Therefore, if taxes on CO_2 emissions are lump-sum recycled, and if the infinitely-lived consumer has the property rights on both the profits and the endowment of capital and labor, his decision problem can be formulated as a conventional utility maximizing problem: At the beginning of each period t the immortal consumer chooses a consumption bundle $c(t)$ and property rights on future durable $b(t)$ such that his instantaneous utility $U(c(t), b(t))$ is maximized subject to his budget constraint

$$p(t)(c(t) + b(t)) \leq w(t)l(t) + r(t)K(t) + \pi(t) + T(t). \tag{2.6}$$

$T(t)$ denotes the CO_2 tax collected during period t. $\pi(t)$ are short-run profits (see Equation (2.5)), and $l(t)$ is the consumer's labor endowment. Utility functions $U(c(t), b(t))$ are of the Cobb–Douglas type, parameterized against benchmark data (see Section 3, Table I).

$K(t)$ is the total capital stock at date t. As mentioned above, the consumer's decision to buy property rights $b(t)$ on future capital is viewed as a savings/investment decision by which, together with the depreciation rate λ, the capital stock $K(t + 1)$ of the following period is determined

$$b(t) + (1 - \lambda)K(t) = K(t + 1). \tag{2.7}$$

The OLG framework represents just the opposite view on intergenerational altruism. Agents have no bequest motive and no altruism toward future generations. They save during working years and dissave during retirement. Therefore, it is reasonable to assume that the young hold the society's endowment of the labor force, while the old generations own the society's capital endowment.

In the ILA framework the distribution of income is not an issue, but in an overlapping generations model the question, who gets what, becomes important. As mentioned above, we do not consider income transfers between young and old generations in general. Carbon taxes are implemented without proposing changes in the ownership of labor, capital and profits. But we allow for income transfers in so far, that society decides how to distribute the revenue of the carbon tax among young and old generations. Note, if carbon taxes are recycled to the young only, this expresses some kind of socially mandated intergenerational altruism.

Let ${}^1T(t)$ denote the young's share of the CO_2 tax revenue, and ${}^2T(t) = T(t) - {}^1T(t)$ to be the tax income transfers to the old generation, then

$$p(t)({}^1c(t) + b(t)) \leq w(t)l(t) + {}^1T(t) \tag{2.8}$$

is the budget constraint of generation t in its first period of life-time. As in the ILA approach, the young divide their income between consumption ${}^1c(t)$ and

Table I. Basic economic data.

Data	
GDP 1990 (US \$ trillions)	22.9
Investments 1990 (US \$ trillions)	5
Capital stock 1990 (US \$ trillions)	63
Annual potential growth rate GDP (%)	2.5
Investment expenditure share, ILA (%)	20.8
Investment expenditure share, OLG young generation (%)	28.2
Annual depreciation rate (%)	5
Labor value share 1990 (%)	72.4
Energy value share 1990 (%)	5
Fossil-fuels share 1990 (%)	89

savings, hence capital investment $b(t)$, to maximize their (period-related) utility ${}^1U({}^1c(t), b(t))$ which again is a Cobb–Douglas function.

At the beginning of period $t + 1$, generation $t(t = 0, 1, 2, \ldots)$[3] is in its second period of life-time. The old now have no labor endowment, but receive returns on their capital assets, i.e., the old generation holds the capital stock $K(t + 1)$ and receives profits $\pi(t + 1)$ from production. Given their budget constraint

$$p(t+1)^2c(t+1) \leq r(t+1)K(t+1) + \pi(t+1) +^2 T(t+1),$$

the old generation chooses a consumption bundle ${}^2c(t + 1)$ which maximizes its utility.

3. Computational Experiments

Computations cover a time horizon of 110 years divided into 11 periods of 10 years length, starting from 1990. They are carried out with MPS/GE (see Rutherford 1992).

3.1. Data

The model is benchmarked against 1990 data, taken from Manne et al. (1995) as well as Tol (1995). Economic key data are listed in Tables I and II. Parameters of the climate sub-model are displayed in Table III.

As in Manne (1996), annual potential growth rate (growth rate of the labor force measured in efficiency units) is set to 2.5% from 1990 through 2100. Even on a world-wide level this seems to be relatively high. We have experimented with lower growth rates (2%) as well as declining rates (from 2.5% to 1%), but the qualitative results did not change.

Table II. Elasticity of substitution.

Inputs	Elasticity
Labor vs. capital	1
Value-added vs. energy	0.37
Fossil vs. non-fossil fuels	1

Table III. Parameters of the climate sub model.

Parameter	Symbol	Value
Diffusion coefficient, per decade	Φ	0.9
Short-run oceanic uptake	Θ	0.5
Critical CO_2 concentration level (ppm)		1857
Emissions 1990 ($GtCO_2$)		22

3.2. Base case

In the base case or business-as-usual scenario the economy evolves without any policy intervention to prevent climate change. Economic growth is mainly driven by capital accumulation and the development of the labor force (measured in efficiency units). Under business-as-usual constraints, gross production, capital accumulation, energy consumption and CO_2 emissions do not significantly depend on the modelling approach, as our calculations unambiguously show. Furthermore, the development of the atmospheric CO_2 stock is very close to that calculated by Manne et al. (1995). In short, without policy intervention, it seems to make no difference, whether the OLG or the ILA approach is taken.

3.3. Climate policy

Does the empirical invariance between the OLG and ILA approach vanish, if climate policy is implemented? To answer this question, it is assumed that policy makers agree to impose a carbon tax on greenhouse resources. We report just one case. A 100% tax rate on fossil fuels prevents the atmospheric carbon dioxide stock from doubling its pre-industrial level by the end of the next century. This is equivalent to a CO_2-concentration limit of 550 ppm (see Houghton et al. 1995). Lower tax rates lead to higher atmospheric carbon stocks and exhibit smaller, but virtually similar, economic effects.

Carbon taxes are recycled to the consumers. In the ILA framework the immortal consumer will fully receive the tax revenues. In the OLG approach there exist several possibilities to redistribute the carbon tax. We consider just three cases: (1) The young get the revenue. This alternative will be called OLG TAX Y. (2) The old generations receive the tax revenue. This case is nicknamed OLG TAX O. (3) The carbon tax income is split between the old and the young generation. We choose a

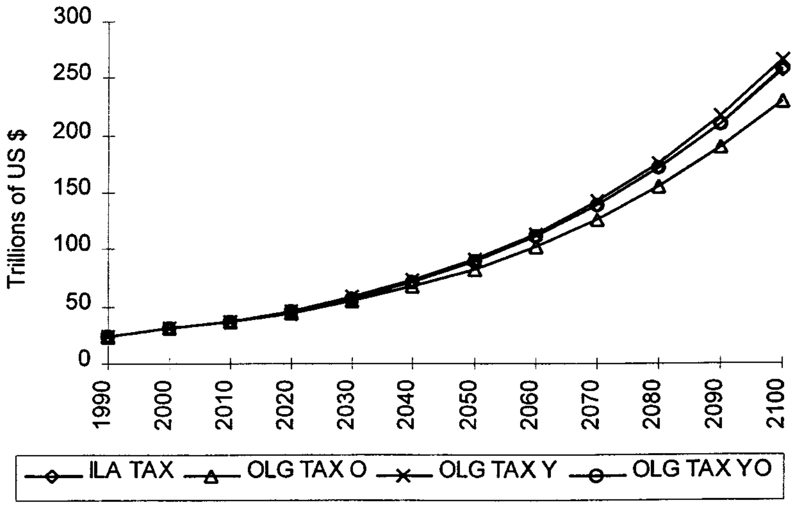

Figure 1. Green output with CO_2 tax.

25/75 rule: 25% go to the old and 75% are transferred to the young. This case has the acronym OLG TAX YO. Note, if the young receive the tax revenue, this can be viewed as a kind of intergenerational compensation for climate damage.

Figure 1 displays the development of green output (measured in trillions of US $). As under business-as-usual, the growth pattern depends in only a negligible fashion on the choice of the modelling approach as long as tax revenues are not transferred to the old generations. But there are significant differences between the OLG TAX Y and the OLG TAX O scenario. If carbon taxes are recycled to the young (see OLG TAX Y), then there is a small bias towards stronger economic growth. The opposite is observed, if the old receive the carbon tax income (see OLG TAX O). If carbon taxes are shared according to the 25/75 rule, then economic development under OLG TAX YO and ILA TAX coincide.

There is, of course, an economic explanation for the difference we observed between OLG TAX Y and OLG TAX O. Recall that in the overlapping generations framework the young play the role of investors. They split their income between consumption and investment, whereas the old generations spend their income completely on consumption. Imposing a tax on greenhouse fuels changes relative prices and withdraws purchasing power from both the young and old. The income effect is at least partially compensated, if carbon taxes are recycled. But depending upon the redistribution scheme the allocational impact can be quite different. If the old get the revenue of a CO_2 tax, this has a positive effect on their consumption only. If taxes are recycled to the young, then both investment and consumption are positively affected.

The development of the society's capital stock, and thus the long-run development of the economy (see Figure 2) is completely consistent to what we have

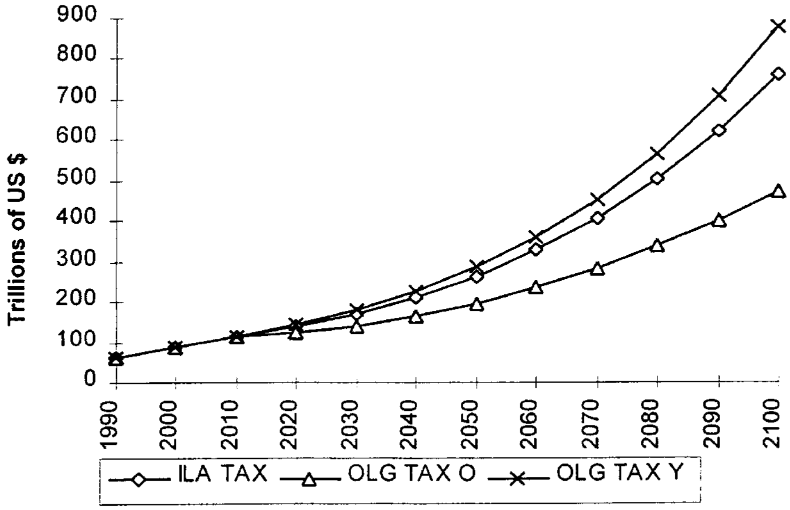

Figure 2. Development of capital stocks with CO_2 tax.

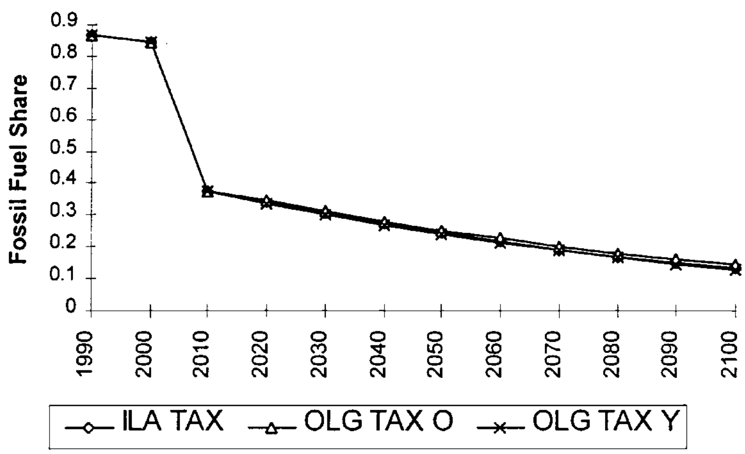

Figure 3. Share of greenhouse resources in energy consumption.

observed in Figure 1. If taxes on carbon dioxide are redistributed to the young, then the capital stocks (see OLG TAX Y) are slightly higher compared to ILA stocks (see ILA TAX). But if tax revenues are transferred solely to the old generations, then capital stocks stay significantly below ILA stocks. Again the OLG TAX YO and ILA TAX yield the same result.

The ILA and the OLG model formulation lead to virtually identical results with respect to the variables directly relevant to greenhouse policy: share of fossil fuels in energy consumption, energy prices and the environmental loss factor (see Figures 3 and 4). As we expect, taxing CO_2 stimulates to substitute away from greenhouse fuels (see Figure 3). At the same time, energy consumption grows

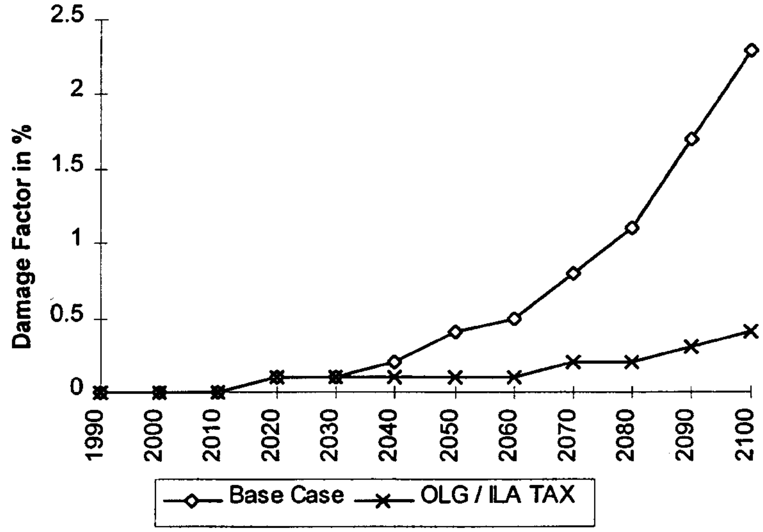

Figure 4. Economic losses of climate change.

significantly slower than gross production. Hence, taxing greenhouse resources leads to interfuel substitution on the one hand and decreases the energy-output ratio of the whole economy on the other.

Uncoupling energy consumption from economic growth and reducing drastically the share of fossil fuels in energy consumption means that carbon dioxide emissions decrease compared to business as usual. Hence, less CO_2 is accumulated in the world's atmosphere and economic damages due to climate change are reduced (see Figure 4).

4. Conclusions

Do we need an overlapping generations model for the economics of global warming? To answer this question, an infinitely-lived agent (ILA) approach and an overlapping generations (OLG) model are contrasted. These models represent polar views on intergenerational altruism. With OLG, generations do not privately take care about their offspring, whereas the ILA formulation delineates a model with perfect altruism. To see this contrariety remember that the ILA approach can be thought as characterizing an economy where there is a representative and infinitively-lived agent maximizing his and the future generations' utilities.

To stress the differences between both approaches, the demographic structure of our OLG model is kept very crude. Obviously it is not very realistic to assume that generations live for two periods only. And it is also doubtful to suppose that capital incomes and profits are solely distributed to the old generations. But for our issue, it is more important to stress the principal features, even if they are overstated, than to put much effort into appearing more realistic.

Under reasonable assumptions and parameter values, our simulations reveal some kind of a Coasian result. An ILA model formulation is appropriate to identify intertemporally efficient climate policies in a world where agents are altruists with respect to their offspring. Once the desired optimal abatement policy is identified, the OLG approach might be used to find an intergenerational carbon tax recycling scheme such that this allocation can be implemented into a decentralized market framework where agents have no altruism toward future generations. Seen in this way, it is possible to separate the issue of allocating resources from that of redistributing carbon taxes.

The Coasian-type of our result shows that OLG and ILA are not competing but complementary approaches for the economic analysis of climate change. Indeed, the analysis of distributional effects is a highly promising area for the OLG approach. This is indicated by the fact that the capital accumulation and thus economic development over the long term is very sensitive with respect to the redistribution of carbon taxes. Such effects can be crucial if democratic communities should agree on climate policy. Therefore, the outcome that the analysis of distributional issues can be carried through in an OLG framework which is compatible to the models, now standard in climate policy analysis, is of particular value.

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Notes

1. Note that a Cobb–Douglas aggregate for energy inputs fixes the value shares of fossil fuels and non-fossil fuels in energy production. But if we assume that marginal costs to supply carbon-free energy are constant and marginal costs of greenhouse resources develop with quantities, then rising demand for energy inputs increases the marginal costs to supply greenhouse resources and stipulates to substitute away from fossil fuels.
2. This means in particular that producers ignore the impact of current energy consumption on future climate conditions.
3. Note, $t = 0$ indicates the old generation, who is at the beginning of the economy's time horizon in its second period of life-time.

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