NORTH-HOLLAND

Journal of Policy Modeling
23 (2001) 25–50

Journal of Policy Modeling

An applied dynamic general equilibrium model of environmental tax reforms and pension policy

Ronald Wendner*

Department of Economics, University of Graz, Universitätsstraße 15, A-8010 Graz, Austria

Received 1 March 1998; accepted 1 September 1999

Abstract

This paper is concerned with the analysis of environmental tax reforms within the framework of a dynamic computable general equilibrium model. The main policy option to be considered consists of using the revenues from CO_2 taxation to partially finance the pension system. It is shown that CO_2 reduction and financing the old-age pension system may be mutually compatible rather than conflicting policy objectives. Compared with other policy simulations, which also aim at lowering CO_2 emissions, the "CO_2-cum-pension" option shows itself to be the most favorable policy in terms of growth, demand of labor services, private investment and consumption. © 2001 Society for Policy Modeling. Published by Elsevier Science Inc.

Keywords: Computable general equilibrium; Overlapping generations; Dynamics; Carbon abatement; Pension policy

1. Introduction

The threat of a marked climate change as a consequence of anthropogenic CO_2 emissions and the financial requirements of the old-age pension system in the face of an aging population are commonly perceived as two of the most

* Tel.: +43-316-380-3458; fax: +43-316-380-9520.
E-mail address: ronald.wendner@kfunigraz.ac.at (R. Wendner).

0161-8938/01/$ – see front matter © 2001 Society for Policy Modeling.
PII: S0161-8938(00)00025-9

dominant problems of the future. Both problems are addressed in this paper and investigated within the framework of a dynamic computable general equilibrium model.

Projections of the age structure of the population show a significant increase in the ratio of older people to the total population in all industrial countries. In the United States, the percentage of the population older than 65 years was 10.5% in 1975 and is expected to reach 12.4% in 2000, with a rising trend predicted for the future (WRI, 1998). This development is even more marked in Europe. In Austria, for example, the increase was moderate in the past (from 14.9% in 1975 to 15.0% in 1995) although a strong growth in this ratio up to 25.3% is projected by the year 2030 (ÖSTAT, 1996). Since the social security system is not funded in most countries, it is argued that the shift in the age structure strongly affects the social security's impact on individual saving and consumption decisions and also on labor supply decisions (Feldstein, 1974). The "pay-as-you-go" method of financing social security is often seen as possibly leading to one of the major problems of our society in the future. This "implicit form of deficit finance" (Auerbach & Kotlikoff, 1987, p. 145) not only redistributes wealth from current younger towards current older generations with adverse effects on saving and capital accumulation, but because of the changing age structure of the population, it also requires either a marked increase of the social security tax rate or a benefit cut or both.

A second threat of major concern is the increase of the CO_2 concentration in the atmosphere. It has steadily increased from a pre-industrial level of 280 parts per million by volume (ppmv) to a level of above 363 ppmv today. Yearly, world fossil CO_2 emissions stemming from industrial processes amount to 24 billion metric tons of which 6 billion tons can be attributed to North America and another 6 billion tons to Europe. Austria's volume of CO_2 emissions amounts to about 60 million metric tons per year. Because of CO_2's greenhouse characteristics, experts fear an increase of the global mean temperature with widespread stratospheric cooling, an increase in global mean surface precipitation, reduction of sea ice, arctic winter surface warming and a rise in global sea level (OECD, 1992).

While the existing literature focuses on either environmental tax reforms or on social security tax reforms, this paper brings together both policy agendas within the framework of one model. By means of an intertemporal applied general equilibrium model, policies are investigated, which aim at a lowering of CO_2 emissions on the one hand and a reduction of the growth of the social security tax rates on the other hand. The framework employed is based on the overlapping generations models tradition as found first in the works of Allais (1947), Diamond (1965) and Samuelson (1958). In a computational context, the model is based on the applied overlapping cohort models as developed in Auerbach and Kotlikoff (1987), Keuschnigg and Kohler (1994) and Rutherford (1998). Based on perfect foresight, 55 overlapping cohorts choose consumption bundles and decide on saving for each period during their lifetime. Nonetheless, there are several distinguishing features with regard to existing, dynamic CGE models. These include the joint consideration of a dynamic OLG structure, many sectors, forward-looking expectations and the inclusion of a bequest motive. Special attention is given to the analysis of two energy sectors, which are a key to the assessment of CO_2 emissions on the one hand, and to the modelling of a "pay-as-you-go" old-age pension system on the other hand.

Three policy simulations, which aim at analyzing the impact of taxing CO_2 emissions, are investigated. It is examined whether CO_2 reduction and financing the social security system may be mutually compatible rather than conflicting policy objectives. The simulations differ in terms of respective usage of the emission tax revenue. In the first place, the full amount of the tax revenue is used to increase transfer payments to households. Secondly, the subsidization of wage costs by means of the tax revenue is simulated. Both simulations aim to reduce CO_2 emissions to the levels stated in the Kyoto Agreement and to provide the basis upon which an integrated policy is developed while leaving the social security system unaffected. The third simulation then integrates CO_2 reduction and pension policy in that part of the revenues of the emission charge is employed to partially finance social security retirement benefits.

While the "transfer option" is capable of reducing CO_2 emissions to the desired level, it is associated with a distinctly lower demand for labor and thus with lower wages. The "labor cost option" is shown to stimulate demand for labor, which does not fall short of the labor demand given by the benchmark solution. Nonetheless, this policy also lowers (real) lifetime income, which results in lower real consumption demand and capital accumulation. These unintended impacts can be avoided by the "pension option". The strength of this option is seen to follow from its impact on the social security tax rate. While the social security tax rate increases due to the aging of the population, its growth is mitigated when the pension option is pursued. Net labor income therefore is higher compared with the other policies, which positively affects lifetime income, consumption, saving and capital accumulation.

The paper is structured as follows: Section 2 describes the model structure, and the main equations are set forth. Section 3 then shows how the social security system is implemented in the simulation model and it is indicated in which ways the pension system interacts with the rest of the economy. Section 4 describes the benchmark solution to the model. In Section 5, the policy experiments are defined. Section 6 confronts the simulation results with the benchmark solution. Starting with an outline of announcement effects, the impacts of both the transfer as well as the labor cost option are discussed. The first two policy simulations reveal shortcomings that are then taken into account in the design of an integrated "CO_2 cum old-age pension" policy (pension option). This is discussed in Section 6 of the paper. Conclusions and an appendix showing the list of variables complete the paper.[1]

2. The structure of the age model

The structure of the dynamic model is described in the following section. First, the household sector, emphasizing the forward-looking behavior of the cohorts, is described followed by the technology and firm behavior. Foreign trade, the public sector and the evolution of the capital stock are then outlined. The exposition ends with the derivation of a necessary closure condition.

2.1. The household sector

The household sector consists of 55 overlapping cohorts, 15 of which cover the retired. The economic lifetime of each cohort is 55 periods. Each cohort enters the model (i.e., starts deciding about economically relevant issues such as saving) at the age of about 20, works for 40 periods and then retires for another 15 periods.

Different cohorts are not equal in size; retired cohorts consist of fewer members than working cohorts in the base year of 1990. Hence, each year, fewer households "leave" the economy than enter their retirement period. There is therefore a shift towards a higher average age of the population in the age structure. Additionally, a decline in birth rate is assumed to take account of actual projections for Austria. For the simulation period from 1990 to 2020, this results in a significant increase in the ratio of retired households to the total population (as is observable for almost all industrial countries).[2]

Each cohort faces an intertemporal budget constraint and chooses bequests and those consumption and saving trajectories that maximize its utility over the whole lifetime of 55 periods. The budget constraint (Eq. (1)) does not preclude the possibility of temporary indebtedness (negative net worth), neither does it preclude dissaving. The left-hand side shows the discounted value of all expenditures, i.e., consumption (of seven consumer goods), as well as bequests

---

[1] Due to space considerations some of the material, including an outline of the equations of the GE model, the results of systematic sensitivity analysis, as well as a more detailed description of the base data set, is relegated to a separate appendix, which is available from the author upon request.

[2] The following scenario was assumed for the simulations. Within the period from 1990 to 2020, the growth factor of the youngest cohort is 0.99. It takes a value of 0.995 thereafter and becomes 1 as of the year 2050. Since active cohorts become smaller, the old-age dependency ratio increases from an index number of 100 (1990) to 148 in 2020 or 164 in 2050. At the same time there is a (small) decline in population. After the year 2050, births equal the number born in the previous year. Therefore, the age structure becomes stationary after another 55 periods. As of the year 2105, the old-age dependency ratio index value amounts to 132.

at the end of the 55th period for a cohort born in year s. On the right-hand side, the present value of lifetime income is shown.[3]

$$\begin{aligned}
&\sum_{t=0}^{54} \prod_{\sigma=s+1}^{s+t} (1+r_\sigma)^{-1} \sum_c P_{s+t,c} c_{s+t,t,c} + \prod_{\sigma=s+1}^{s+55} (1+r_\sigma)^{-1} a_{s+55,55} \\
&\quad = \sum_{t=0}^{54} \prod_{\sigma=s+1}^{s+t} (1+r_\sigma)^{-1} \\
&\quad \times \left[(1 - \tau^{dir}_{s+t} - \tau^{pens}_{s+t}) w_{s+t} \times l_{s+t,t} + t_{s+t,t} + b_{s+t,t} \right] \\
&\quad + (1+r_s) a_{s,0} \qquad (1)
\end{aligned}$$

It covers inherited assets (a), wage income (net of wage taxes and the social security tax), as well as transfers (t) and social security retirement benefits (b).[4] Variable l denotes labor supplies from each cohort, which becomes zero at the beginning of the 41st period. Social security retirement benefits become positive as of the 41st period and are zero before.

Preferences are described by means of a logarithmic, additively separable utility function. For a cohort born in year s, utility is specified as follows:[5]

$$U_s = \sum_{t=0}^{54} \left\{ \beta^t \sum_c \gamma_c^{cons} \ln[c_{s+t,t,c} - \bar{c}_{s+t,t,c}] \right\} + \beta^{55} \nu \ln(a_{s+55,55}) \qquad (2)$$

Households derive utility from consuming the seven consumer goods over a specified minimum level ($\bar{c}_{s,t,c}$), as well as from bequest giving. Labor supplies from each cohort are assumed to be exogenous. Leisure therefore does not enter the utility function. The parameter β (subjective discount factor) is lower than 1 and shows the strength of time preference, γ^{cons} are fixed consumption shares (utility elasticities) and ν denotes the strength of the bequest motive. Utility gained from bequeathing is assumed to be independent of the subsequent utility

[3] The first subindex "s" always indicates the actual year (s=...1990, ..., 2020, ...), the second index "t" shows the "age" of a cohort (t=0, ..., 54), the third (second) index "c" stands for commodity or sector (c=1, ..., 7). Therefore, $c_{s,t}$ shows the consumption of a cohort with age t in year s. The next year's consumption of the same cohort is therefore denoted as $c_{s+1,t+1}$ (per cohort variables are written in lower case letters). A list of variables and indices is given at the end of the paper.

[4] The social security system, as implemented in this model, focuses on the old-age pension system (see Section 3). Contributions to the other parts of the social security system as, e.g., health insurance, is taken into account by (addition to) the direct tax rate. Therefore, the social security tax rate coincides with the rate of contribution to the old-age pension system in this specification.

[5] This specific utility function is derived from the following more general utility function:

$$U_s = \frac{1}{1 - 1/\sigma} \left\{ \sum_{t=0}^{54} \beta^t \left[\prod_{c=1}^{7} (c_{s+t,t,c} - \bar{c}_{s+t,t,c})^{\gamma_c^{cons}} \right]^{1-\frac{1}{\sigma}} + \beta^{55} [a^{\nu}_{s+55,55}]^{1-\frac{1}{\sigma}} \right\}$$

As the intertemporal elasticity of substitution σ approaches a value of 1, function (2) follows.

of the heirs. This formulation of the bequest motive is used, for example, in Ballard and Goulder (1985); Blinder (1974) or Neusser (1993).[6]

Maximizing utility function (Eq. (2)) subject to the intertemporal budget constraint (Eq. (1)) shows the optimum (aggregate) consumption expenditures per cohort (Eq. (3)), as well as optimal bequests (Eq. (4)). Inserting Eqs. (3) and (4) into the intertemporal budget constraint (Eq. (1)) gives the optimal initial consumption per cohort. The consumption function (Eq. (3)) shows that consumption demand increases with the age of a cohort if the interest rate exceeds the subjective discount rate. An increase of the subjective discount rate (i.e., a decrease of β) shifts consumption from the future to the present. With decreasing lifetime income, consumption decreases as well; e.g., with increasing social security tax rates, disposable income decreases as does consumption. Aggregate consumption expenditures (per sector) in one period equal the sum of all cohorts' consumption expenditures.

$$c_{s+1,t+1} - \overline{c}_{s+1,t+1} = \beta(1 + r_{s+1})(c_{s,t} - \overline{c}_{s,t}), c_{s,t} \equiv \sum_c P_{s,c} c_{s,t,c} \quad (3)$$

$$a_{s,55} = a_{s+1,0} = \beta\nu(c_{s,54} - \overline{c}_{s,54}) \quad (4)$$

Eq. (4) shows each cohort's bequests at the end of the 55th period. It is proportional to the last period's consumption and increases with the bequest motive and declines with the discount rate. The propensity to consume in any period is lower the higher the strength of the bequest motive. Subsequently, the higher the bequest motive, the more assets are accumulated and the higher capital accumulation and growth of the GDP are. At a second stage (essentially simultaneous when simulating), households decide on the sectoral structure of consumption demand according to equation system (Eq. (5)). A minimum amount $\bar{C}$ of each good is consumed, the remaining consumption budget spent depends on the sectoral prices of consumption goods.

$$P_{s,c}C_{s,c} = P_{s,c}\overline{C}_{s,c} + \gamma_c^{cons}\left\{\sum_c P_{s,c}(C_{s,c} - \overline{C}_{s,c})\right\} \quad (5)$$

From the demand equation (Eq. (5)), we find the pattern of financial wealth accumulation or saving for all individual cohorts (Eq. (6)).

$$a_{s+1,t+1} = (1 + r_s)a_{s,t} + (1 - \tau_s^{dir} - \tau_s^{pens})w_s l_{s,t} + t_{s,t} + b_{s,t} - c_{s,t} \quad (6)$$

The change of the financial wealth of an individual may be positive or negative during any period, so intertemporal consumption profiles need not

[6] Modeling the household sector without a bequest motive results in an implausibly high level of dissaving when retired. It may seem restrictive not to account for inter-vivos transfers, but empirical studies reveal that bequeathals (transfers from the eldest to the youngest cohort) account for the largest fraction of wealth transfers (Neusser, 1993).

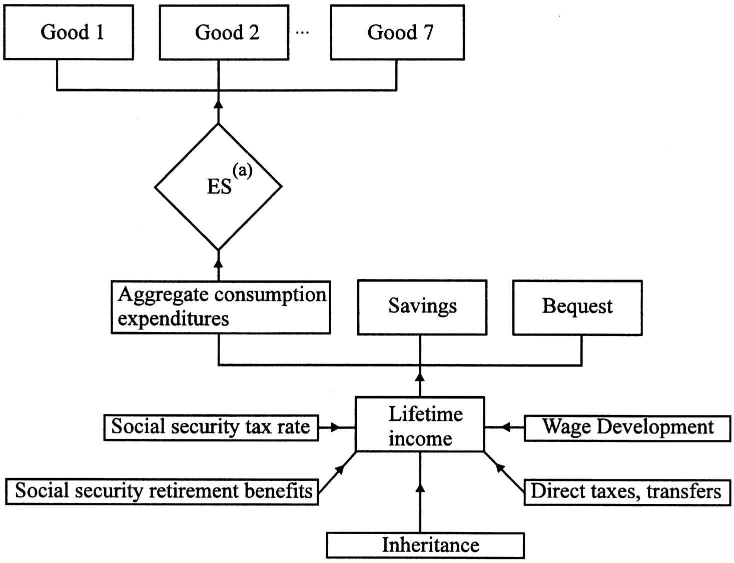

Fig. 1. The household sector. (a) Expenditure system as given by Eq. (5).

necessarily follow the development of income of a cohort. Aggregate wealth at time s simply follows from summing up all individual cohorts' assets at this point of time. Fig. 1 summarizes household behavior.

2.2. Technology and firm behavior

Seven sectors, two of which are energy sectors, produce seven single goods. Table 1 shows the industries distinguished within the model. These industries offer one type of product each and all operate in a competitive environment. The technology employed is described via a nested, time invariant, linear homogenous production structure for the five non-energy sectors. At the industry level, technology can be illustrated as shown in Fig. 2. In sectors one (EMISS) to five (OTHER), producers decide on the cost minimizing energy mix (Q) at the lowest nest. At the next level, the cost minimizing mix of energy and capital services (H) is determined, finally, this capital-energy composite is combined with labor in a cost minimizing way. At the highest level, the energy-factor composite (Y) is combined with intermediate goods (other sectors' outputs) in fixed proportions to produce the final output. Energy (i.e., sectors ELEC and FOSS) is produced via Leontief technology. Substitution between factors or intermediate goods is not assumed to take place in the two energy sectors (the assumption is adopted here that the technologies chosen for substitute energy generation, i.e., whether based on hydro or calorific power plants, e.g., are mainly a political decision and will not vary over the simulation period). The quantity produced at home in the fossil

Table 1
Production sectors

Production sectors		Covering
(1) EMEXP	high export and emission intensity	paper, printing, stone, clay, glass, base metal
(2) EMISS	high emission but low export intensity	agriculture, forestry, mining
(3) EXPO	high export but low emission intensity	textile, apparel, leather, lumber, chemicals, metals, machinery
(4) LABIN	sectors with high labor intensity	construction, trade, storage, transportation, communication, other services, public services
(5) OTHER	other sectors, often net importers	food, water supply, lodging, finance, insurance, real estate
(6) FOSS	fossil energy sector	
(7) ELEC	electricity sector	

energy sector is constant and equals the 1990 production level; demand in excess of home production is met via imports.[7]

From the above assumptions about technology in the "non-energy sectors", and given cost minimizing behavior of firms, the conditional demand functions for factors and composite goods are derived. Exogenous technological progress is considered as energy saving technological progress on the one hand (composite Q) and as labor augmenting technological progress on the other hand (composite Y). The cost functions for the composite goods Q, H and Y directly follow from the conditional demand functions. Due to the constant returns to scale production functions, marginal costs equal average costs.

The costs of the final goods are made up of costs of the composite Y, costs of the intermediate goods, as well as an indirect tax differentiated according to sector. Intermediate demand for goods, as well as demand for the energy-factor composites are (due to the Leontief technology employed) proportional to sectoral gross production. Due to the CES technology, all other demands depend on prices as well. Competitiveness requires that either prices be equal to marginal costs or the supply is zero, therefore, the following conditions hold (Eq. (7)):

$$(P_{s,c} - MC_{s,c}) \leq 0,\ X_{s,c} \geq 0,\ (P_{s,c} - MC_{s,c})X_{s,c} = 0 \tag{7}$$

2.3. International relations

As Austria is seen to be a small open economy, it follows from the (uncovered) interest parity condition that the interest rate (r) is determined abroad. It is therefore exogenous to the model. Foreign trade is modelled according to the Armington (1969) assumption, which treats identical goods

[7] This may seem a special assumption, but it describes the situation in Austria fairly well.

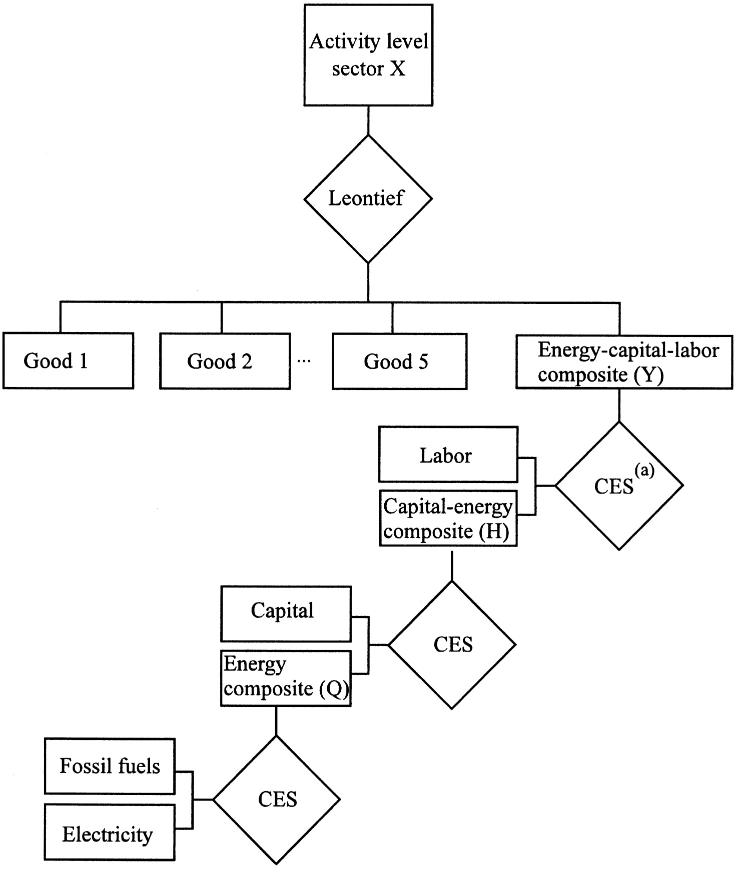

Fig. 2. Nested production structure. (a) Constant elasticity of substitution.

produced in different countries as heterogeneous rather than homogenous. Based on this assumption, prices can differ across countries and cross hauling prevails. Exports and imports, starting from exogenously specified levels, are sensitive to price changes and grow additionally with exogenous growth factors. Exports of electricity are close to imports. Net exports of electricity are thus assumed to be zero. A constant level of fossil fuels is produced at home. Excess home demand for fossils is met by imports.

Furthermore, Austrians may borrow from abroad or lend abroad. The current account and the development of (the foreign fraction of) government debt determine the accumulation of net foreign assets.

$$(1 - \zeta)A_{s+1}^{gov} + ER_{s+1}A_{s+1}^{\mathrm{f}} = (1 + r_s)[(1 - \zeta)A_s^{gov} + ER_sA_s^{\mathrm{f}}] - \sum_{c=1-7} P_{s,c}(X_{s,c}^{\mathrm{ex}} - X_{s,c}^{\mathrm{im}}) \quad (8)$$

The parameter ζ denotes the fraction of government bonds issued at home, A^{gov} stands for public debt, ER is the nominal exchange rate and A^{f} is net foreign wealth (debt).[8]

2.4. Public sector, financial wealth, capital and investment

Public consumption is proportional to the gross domestic product. The parameter γ_c^{gov} shows the consumption structure across sectors (see Eq. (9)).

$$P_{s,c}X_{s,c}^{gov} = \Gamma_s \gamma_c^{gov} \mathrm{GDP}_s \tag{9}$$

Revenues are generated by indirect taxes (T^{ind}) and direct taxes (T^{dir}), as well as by a carbon tax ($T^{\mathrm{CO_2}}$) in the counterfactual simulations below. The government can also borrow by inducing government bond sales. Public debt henceforth develops essentially according to Eq. (10).

$$A_{s+1}^{gov} + T_s^{ind} + T_s^{dir} + T_s^{\mathrm{CO_2}} = (1 + r_s)A_s^{gov} + \sum_c P_{s,c}X_{s,c}^{gov} + T_s + S_s \tag{10}$$

The variable T on the right-hand side of Eq. (10) shows aggregate transfer payments and variable S denotes a subsidy (contribution) from the public sector to the old-age pension system. To prevent the government debt from growing to infinity the government consumption quota Γ is adjusted endogenously such that the intertemporal constraint (Eq. (10a)) holds.[9]

$$A_0^{gov} + \sum_{s=0}^{\infty} \left[\prod_{i=0}^{s} (1 + r_i)^{-1} \right] \left[\sum_c P_{s,c}X_{s,c}^{gov} + T_s + S_s \right] = \sum_{s=0}^{\infty} \left[\prod_{i=0}^{s} (1 + r_i)^{-1} \right] [T_s^{ind} + T_s^{dir} + T_s^{\mathrm{CO_2}}] \tag{10a}$$

Aggregate wealth A is made up of capital and bonds, i.e., the home fraction of government bonds and private (household) foreign assets (Eq. (11)).

$$A_s + ER_s A_s^{\mathrm{f}} = K_s + \zeta A_s^{gov} \tag{11}$$

[8] Iterating Eq. (8) forward gives the intertemporal constraint on the development of foreign wealth:

$$(1 - \zeta)A_0^{gov} + \mathrm{ER}_0 A_0^{\mathrm{f}} = \sum_{s=0}^{\infty} \left[\prod_{i=0}^{s} (1 + r_i)^{-1} \right] \left[\sum_{c=1-7} P_{s,c}(X_{s,c}^{\mathrm{ex}} - X_{s,c}^{\mathrm{im}}) \right]$$

When starting with foreign debt, e.g., a country must incur future trade surpluses. The constraint is satisfied if foreign wealth accumulates with a rate below the interest rate r.

[9] This equation follows from iterating Eq. (10) forward and imposing the condition that government debt grows with a rate below the interest rate r.

The accumulation of bonds together with aggregate wealth from households' optimization determines the optimal stock of capital (see Eq. (12)). Since capital is treated as value-capital aggregate in the present framework, there is no need to distinguish investment by sector of destination. The portion of total investment over sectors of origin, i.e., where investment demand becomes effective, is taken as constant from the social accounting matrix of 1990 (see Breuss & Steininger, 1995).[10]

$$P_{s,c}I_{s,c} = \gamma_c^{inv}[K_{s+1} - (1 - \delta)K_s] \tag{12}$$

2.5. Macroeconomic closure

Market clearing is assumed for all goods, services and factor markets. However, the model is not yet closed in the sense that net production equals factor payments plus indirect taxes. The specific structure of the model inhibits the formulation of usual no-arbitrage conditions. Instead, an alternative condition has to be inferred from the system. This condition follows from jointly considering the budget constraints of all cohorts, the wealth equation, the budget deficit equation, the investment equation, as well as the basic macroeconomic (GDP) identities.

$$(r_s + \delta)K_s = \mathrm{PK}_s\tilde{K}_s \tag{13}$$

Eq. (13) closes the system in that Walras' Law holds. The right-hand side shows the value of aggregate capital services ($\tilde{K}$) demanded, PK denotes the price of capital services and the parameter δ is the exogenous rate of depreciation. The price of capital services (=numeraire) PK is exogenously fixed at 1. Due to Walras' Law, the equations defining the equilibrium conditions are not all independent; one equation must be dropped. For the simulations below Eq. (8) was deleted.

3. The old-age pension system

At and beyond the model age of 40 ($t \geq 40$), households no longer offer labor services and, hence, no longer earn labor income. However, they still yield interest payments when holding assets and they enjoy social security retirement benefits. The pension system is organized as a pay-as-you-go system (unfunded), thus requiring yearly balanced budgets. This balance is achieved by adjusting the social security tax each year.[11] During its first 40 periods, each active cohort is obliged to pay a contribution to the old-age pension system at a rate proportional to its respective gross labor income. This tax rate is the same for all cohorts in any given

[10] This framework is used, e.g., in Bergman (1991) or Farmer and Steininger (1998). A detailed analysis of this OLG framework can be found in Farmer and Wendner (1999).

[11] The following specification is based on Holzmann (1988) and Neusser (1993).

period. By contributing to the pension system, households are entitled to receive social security retirement benefits when they retire. This pension is financed on the one hand by the concurrent active households and by a subsidy from the public sector, S, on the other hand. Legislation fixes participation in the pension system. The yearly pension per cohort (b) is calculated as follows (Eq (14)):

$$b_{s,t} = \Omega_s \tilde{w}_{s|t=40} \frac{w_s}{w_{s-t+40}}, 41 \leq t \leq 54 \tag{14}$$

The replacement rate Ω is a politically determined parameter displaying the ratio of old-age pension income to a weighted average of earnings over the (last) active years of each cohort. This weighted average (or average index of earnings $\tilde{w}$) is used to calculate each cohort's first pension, i.e., the pension at the (model-) age of 40. The first pension is then adjusted each successive year to account for the rise of wages and prices. The average index of earnings is calculated as follows:

$$\tilde{w}_{s|t=40} = \sum_{i=s-15}^{s-1} \Theta_i w_i l_{s,s-40} \tag{15}$$

The variable $\tilde{w}$ corresponds to a weighted average of all past labor incomes per cohort with the weights being Θ. For each year s, it is calculated for the cohort, which becomes "40" that year. The previous 15 years are taken into consideration. Index i therefore ranges from $s-15$ to $s-1$. Labor incomes for different years are weighted differently. Incomes earned earlier are revalued (by a factor d) to account for price increases.

$$\begin{aligned} \Theta_i &= \begin{Bmatrix} 1/p & s-2 \leq i \leq & s-1, \ 2 \leq p \\ (1/p)d^{s-i-2} & & s-p \leq i < s-2 \end{Bmatrix}, \quad 2 \leq p \leq 15 \\ \sum_i \Theta_i &= 1 \end{aligned} \tag{16}$$

The weights are calculated according to the formula above (Eq. (16)). Parameter p indicates the number of years taken into consideration when calculating the average index of earnings. The two most recent incomes are weighted equally, all other incomes are revalued. Finally, the weights are normalized. According to Eq. (15), the more years considered in calculating the average index of earnings, the smaller will be the initial impact of a (carbon tax induced) change of the wage rate on $\tilde{w}$.

The organization of the old-age pension system as a pay-as-you-go system corresponds to a balance of benefits against contributions from young households and the public sector (Eq. (17)):

$$\tau_s^{pens} w_s \sum_{t=0}^{39} l_{s,t} + S_s = \sum_{t=40}^{54} b_{s,t} \tag{17}$$

By treating the government's subsidy to the pension system as exogenous, this equation endogenously determines the social security tax rate τ^{pens}.

4. The benchmark solution

The benchmark solution, against which the counterfactual solutions are measured, is briefly described in the following section. The model was programmed in TABLO language and solved by means of the General Equilibrium Modeling Package (GEMPACK) software tools. Harrison and Pearson (1996a); Harrison, Pearson, and Powell (1996b) or Wendner (1997) give a detailed account of the solution method employed. The model is calibrated such that it endogenously reproduces the full set of data of the base year 1990 for the year 1990.[12]

7A period from 1990 to 2020 is investigated. Since cohorts are assumed to possess perfect foresight, the model is endowed with 120 periods (years). That way, a steady state is approached approximately when the simulation is terminated and results are no more dependent upon the chosen terminal time period. After the year 2110, steady state restrictions apply. Hence, all variables affecting the decisions of households due to forward-looking behavior are determined endogenously, even beyond the year 2110. For reasons of space results are reported for every 5 years only, although the model solves for each individual year. Since the simulated policies are all enforced as of 1999, instead of year 2000, year 1999 is reported.

Table 2 below shows the base case solution. Two facts deserve special attention in the present context. First, emissions of CO_2 rise from 60.8 million metric tons in 1990 to 84.3 million tons in 2020 (see Fig. 3). This projection corresponds to the upper third of emission estimates for Austria when no policy aiming at reducing carbon emissions is introduced. A look at emissions on a sectoral level shows that they mainly stem from three sources: EMEXP industries, electricity, as well as final demand. Second, the increase of the social security tax rate influences household decisions. The internal rate of return of the pay-as-you-go pension system is positive whenever retirement benefits exceed a cohort's contributions when working. Thus, it depends on the natural rate of growth. The simulation results (as well as empirical data) show that it is in no year equal to or higher than the real interest rate — the rate of return of "voluntary" saving. For this reason, lifetime income changes compared with a situation with a constant age structure of the population (and therefore a constant rate of contribution). Lifetime income declines because the interest rate exceeds the internal rate of return of the pension system and thus private saving declines, too. Additionally, there is another effect at work. The increase of the social security tax rate is associated with a redistribution away from younger generations towards older cohorts. Since older generations are seen (from Eq. (3)) to

[12] See Wendner (1997, 1999) for a detailed discussion of the issues involved in the process of calibration of perfect foresight CGE models.

Table 2
Base case

Aggregate variables[a]

	GDP	Consumer demand	Investment demand	Net exports	Capital stock	Capital services	Wage	Social security tax rate	CO_2 [10^6 tons]
Year									
1990	1789.4	997.2	397.0	10.3	8437.3	611.2	1.00	0.166	60.8
1995	2003.5	1126.6	462.2	8.2	9432.7	683.3	1.12	0.170	64.6
1999	2185.9	1236.4	500.8	6.9	10321.4	747.7	1.24	0.173	67.7
2005	2476.9	1420.9	553.4	5.6	11786.0	853.8	1.48	0.179	72.4
2010	2733.9	1579.5	604.0	5.8	13123.9	950.7	1.72	0.183	76.4
2015	3004.9	1752.2	652.9	6.3	14607.6	1058.2	2.04	0.189	80.4
2020	3288.2	1937.6	700.1	7.5	16250.3	1177.2	2.45	0.196	84.3
Av. %[b]	2.05	2.24	1.91	– 1.05	2.21	2.21	3.03	0.56	1.09

Sectorial variables[a]

Sectors	Production		Average growth [%]	Net exports		Average growth [%]	CO_2 [10^6 tons]		Average growth [%]
	1990	2020		1990	2020		1990	2020	
EMEXP	231.3	394.4	1.80	42.2	55.1	0.89	14.2	20.8	1.29
EMISS	112.9	243.1	2.59	– 33.6	– 39.9	0.58	2.4	4.9	2.38
EXPO	659.8	1291.0	2.26	– 46.9	– 44.3	– 0.19	2.8	3.4	0.63
LABIN	1477.8	2552.1	1.84	105.8	135.1	0.82	7.1	7.2	0.05
OTHER	760.8	1462.8	2.20	– 3.6	– 2.2	– 1.61	2.1	2.2	0.18
ELEC	46.3	67.2	1.25				15.9	14.7	– 0.25
FOSS	34.8	34.8	0.00	– 53.7	– 96.3	1.97	0.3	0.2	– 0.99
FINAL DEMAND							16.1	30.8	2.19

[a] In 10^9 Austrian Schillings (at 1990 prices).
[b] Av. % = average (yearly) growth rate.

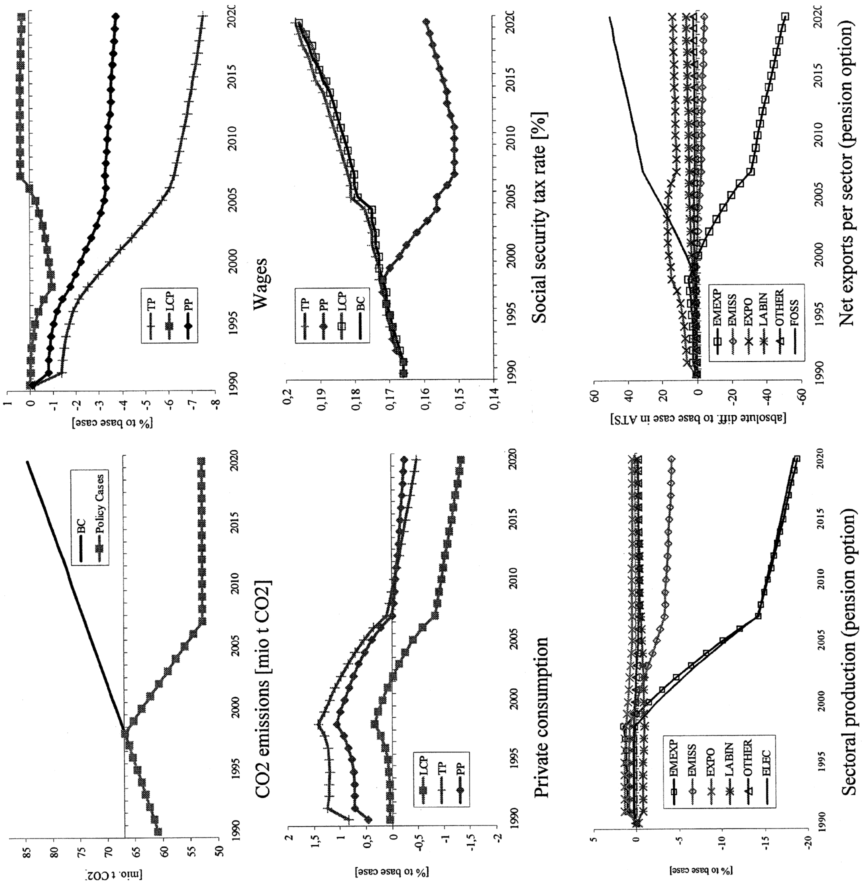

Fig. 3. CO_2 taxation: pension policy vs. transfer policy and labor.

have larger marginal propensities to consume than younger cohorts, aggregate saving further decreases. Therefore, capital formation is curbed leading to lower wages. Hence, not only is the return on saving lowered but so is the pre-tax wage. Both developments adversely influence lifetime income and subsequent consumption demand and household saving.

5. Implementing a tax on CO_2 emissions

The price of the fossil energy composite is the same for all sectors as long as the tax on emissions is zero. However, in the case where a carbon tax is charged, the individual sectors are affected differently.

$$PF_{s,c} = MCF_s + \tau_s^{CO_2} f_c \kappa_{s,c} \tag{18}$$

Since the fossil fuel good is a composite, its composition differs across sectors and so do its emission properties. Therefore, the emission tax — based on quantitative CO_2 emissions per unit of the fossil fuel composite — differs across sectors as well. Exemptions are often seen as politically desirable. The parameter κ allows for these and can be adjusted according to sector (i.e., it may take values lower than 1). Parameter f denotes the sector-specific emission coefficients (Eq. (18)). Total CO_2 emissions in year s are given by Eq. (19).

$$\mathrm{CO}_{2s} = \sum_c F^{\mathrm{int}}_{s,c} f_c + (C_{s,F} + F^{pub}_s + I_{s,F}) f_{fin} \tag{19}$$

Taxing tons of CO_2 emitted with tax rate $\tau_s^{\mathrm{CO_2}}$ and allowing for sectorally differentiated exemptions yields total revenues given by Eq. (20).

$$T^{\mathrm{CO_2}}_s = \tau^{\mathrm{CO_2}}_s \left[\sum_c \mathrm{CO}_{2s}, c\kappa_{s,c} + \mathrm{CO}_{2s},_{fin} \right] \tag{20}$$

A simplified version of the "Kyoto Objective" is simulated below. The primary goal of the Kyoto Agreement consists of a reduction of greenhouse gases and (or) an increase of CO_2 sinks. By the period between 2008 and 2012, greenhouse gas emissions will have to be reduced by an average of -8% (European Union), -6% (Japan) and -7% (United States) compared with the year 1990. In the course of burden sharing within the European Union, Austria committed itself to a reduction of 67% in addition to the average reduction objective. This objective amounts to a 13% reduction of Austria's CO_2 emissions.

The policy introduced below is much simpler than integrated instrument-mixes based on the Kyoto Agreement because it neither takes into account greenhouse gases other than carbon dioxide, nor does it consider carbon sinks or international emission trading. An exogenous path of allowed maximum emissions of carbon dioxide as of 1999, $\overline{\mathrm{CO}_{2s}}$, is introduced in the policy simulations. Emissions are not regulated before 1999. As of the year 1999, maximum emissions are reduced linearly from the base case levels until they reach the Kyoto Objective in the year 2008. This emission path corresponds to a decline of carbon dioxide emissions from 65.3 million tons in 1999 to 52.75 million tons in the year 2008 (i.e., 60.8 million tons CO_2 in 1990 minus 13.3%). Afterwards, the allowed maximum level of CO_2 emissions is held constant at this level, i.e., there is a permanent policy change. The path of the tax rate is determined endogenously. It can be interpreted as the (emission market) equilibrating price of emission permits and is calculated as shown in the following equation (Eq. (21)).

$$\mathrm{CO}_2 - \overline{\mathrm{CO}_{2s}} \leq 0, \qquad \tau^{\mathrm{CO_2}}_s \geq 0, \qquad (\mathrm{CO}_{2s} - \overline{\mathrm{CO}_{2s}}, \tau^{\mathrm{CO_2}}_s) = 0 \tag{21}$$

6. CO_2 taxation and the old-age pension system

Specifying the emission charge goes only halfway towards formulating a full policy experiment. The second half consists of specifying the usage of the emission tax revenues. Prominent suggestions to be found in the literature include the use of the revenues for labor cost subsidization, as well as for household transfers.[13] Both are simulated and analyzed in the intertemporal context of the present model. Firstly, revenues are paid out fully to households (which will be referred to as transfer option), i.e., transfers to households increase by exactly the amount of the new tax revenue: $T_s' = T_s + T_s^{CO_2}$. Secondly, revenues are employed to subsidize labor costs (labor cost option). Labor costs are refunded (equally across sectors) by a portion $\phi_s = \gamma_s^{wage} T_s^{CO_2} / (w_s L_s)$. The parameter γ^{wage} denotes the share of total revenues (of the CO_2 tax), which is refunded to firms. It is set equal to one for this policy option. Working households earn the same wage as before, but employees pay $w_s' = w_s(1 - \phi_s)$. Those two policies clearly point to the perils of implementing a carbon tax (see below) and therefore provide insights for the design of an improved option. These are considered in the development of the final option, which links CO_2 reduction policy with old-age pension policy (pension option). The revenues of CO_2 taxation are used to increase public contributions $S_s = \bar{S} + \gamma_s^{pens} T_s^{CO_2}$ to the old-age pension system. The parameter γ_s^{pens} indicates the share of the revenue used for contribution to the pension system and is set equal to 0.6 for this simulation. The remaining 40% is used to subsidize labor costs.

The main results of the policy simulations are described below (see also Table 4). Emphasis, however, is not given here to static general equilibrium or welfare effects but rather to intertemporal feedback processes, as well as the interplay between these effects and the (development of) key variables of the old-age pension system.

6.1. Announcement effects

The simulations show that the introduction of an emission tax as of the year 1999 affects (at least for some cohorts) lifetime income. Due to forward-looking behavior (perfect foresight) consumption, as well as saving decisions change even before the tax is actually put into effect, i.e., households respond right after announcement and before income is actually changed. Thus, as a consequence of announcement, consumption, saving and investment demand are altered. For example, if lifetime income is expected to rise upon introducing the tax

[13] Papers addressing these issues in the non-dynamic context of applied modeling include, e.g., Bergman (1988, 1991); Breuss and Steininger (1995); Glomsrod Vennemo, Johnsen (1992) and Schröder (1991) and, in a dynamic context, Burniaux, Martin Nicoletti, Martins (1992); Hazilla and Kopp (1990); Jorgenson and Wilcoxen (1990); Vennemo (1997).

consumption demand increases. Since actual income remains about the same between 1990 and 1999 savings must decrease according to Eq. (6). Assuming government debt, as well as the net foreign position, are unaffected by announcement, it follows from the financial capital market clearing condition that investment demand declines as well. The policy simulations reveal that lifetime income (slightly) increases. As a consequence, consumption is higher and investment demand is lower compared with the base case. With a (slightly) lower stock of capital both GDP and wages fall short of their respective base cases levels too.[14]

6.2. Response to the policy shock as of the year 1999

6.2.1. Transfer option and labor cost option

6.2.1.1. CO_2 emissions and tax rates. The simulations disclose that the Kyoto Objective (as defined above) can be met under either policy option though the associated tax rates, as well as the respective impacts on the economy differ quite substantially depending on the different uses to which the tax revenues are put. Fig. 3 shows that total CO_2 emissions fall from 67 million tons to 53 million tons by the year 2008. The endogenously calculated tax rates amount to 0.09 ATS per kilogram of CO_2 in 1999 rising up to 1.40 ATS in 2008 for the labor cost option (and nearly coincide with those of the other policies). The tax rate increases because as time goes on a higher rate of tax is required to restrain CO_2 emissions to the given, declining target levels.

Table 3 shows to which tax rates on various energy sources the CO_2 tax rate corresponds in 2008, the year of achievement of the final emission objective. Although the level of CO_2 emissions is held constant after 2008 tax rates still have to continue to rise. On a sectoral level, those sectors responsible for most emissions in the base case (EMEXP, ELEC, as well as the final demand) contribute most to the decline of CO_2 emissions in absolute terms. When pursuing the transfer option, emissions in final demand show less of a decrease since the transfers stimulate private consumption.

6.2.1.2. Impact on economic development. The simulations of the transfer and labor cost options show lower average growth rates of the GDP as a consequence of implementing an emission tax. In the year 2008 (2020), the level of the GDP is about 1.1% (1.3%) lower compared with the base case. The development of the

[14] As is shown in Wendner (1997), depending on the specific features of a carbon tax, different announcement effects can occur. If the carbon tax revenues are used to curb the budget deficit only, lifetime income (of the younger cohorts) will be strongly reduced, since the tax revenues do not flow directly back into the budgets of the households. This leads to a reduction of consumption expenditures and — as long as actual income before the implementation of the tax remains unchanged — to an increase of investment demand. It is therefore the respective specification of tax recycling, which determines the nature of the announcement effects.

Table 3
Tax rates per unit energy source in 2008[a]

US$ (ATS) per unit energy source[b]	Transfer policy	Labor cost policy	Pension policy
Gasoline [l]	0.27 (3.36)	0.26 (3.30)	0.27 (3.33)
Diesel [l]	0.30 (3.76)	0.30 (3.70)	0.30 (3.73)
Brown coal [kg]	0.12 (1.50)	0.12 (1.48)	0.12 (1.49)
Hard coal [kg]	0.30 (3.74)	0.29 (3.68)	0.30 (3.71)
Natural gas [m^3]	0.21 (2.66)	0.21 (2.62)	0.21 (2.64)

[a] ATS = Austrian Schillings, US\$1 ≈ 12.5 ATS.

wage rate plays a key role in explaining this impact. Two opposing forces influence its development, a substitution effect, as well as a capital-lessening effect. Because of the carbon tax, fossil fuel resources become more expensive, and firms react by substituting capital services and labor for fossil fuels. On the other hand, since the emission tax represents an additional indirect tax, optimal (real) saving and capital accumulation are reduced. Since the rate of capital accumulation influences the rate of growth of the economy (except within a steady state), the growth rate of the GDP is lessened as well. As a consequence of this latter effect, firms demand less of each factor (capital-lessening effect). Which of these effects is dominant depends on the specific policy pursued as well as on the relevant elasticities of substitution. The simulations show that in general, the capital-lessening effect exceeds the substitution effect by far, resulting in a lower demand for labor services. Consequently, the transfer option results in a strong decline of wages. However, substitution can be further stimulated by subsidizing labor costs (see Fig. 3). The development of the wage for the labor cost option therefore resembles that of the base case, i.e., the substitution effect compensates for the capital-lessening effect with respect to labor demand.

The low wages associated with the transfer option directly decrease lifetime income. On the other hand, increased transfers compensate households for this. The total impact on lifetime income cannot therefore be determined theoretically; simulation results reveal that it is slightly higher compared with the base case income. This also means that consumption expenses are rising a bit. At the same time (some) prices become higher due to the additional indirect tax. In total, this results in a decrease of real consumption demand according to Eq. (5). As there is a moderate increase in lifetime income, savings grow as well. Nonetheless, for two reasons, this does not entail a rise in real investment. For one thing, public debt accumulates more strongly compared with the base case. The reason for this is a decline in both revenues from wage taxes as well as revenues from indirect taxes.[15] The public sector thus induces more government bond sales. According to the capital market clearing condition households hold more government bonds

[15] As the emission tax enters the government budget constraint on both sides, it does not influence directly the yearly deficits.

and capital accumulation goes down. In the second place, the price increases directly reduce real investment.

Since labor demand is subject to a greater stimulus when the labor cost option is pursued the rate of growth of the wage is higher here than in the case of the transfer option. Lifetime income nevertheless is lower because no transfers are paid to households (actually households get fewer transfers as transfer payments are proportional to the now lower GDP). Wage growth parallels that of the benchmark equilibrium. Therefore, consumption demand is lower compared with the transfer option. Once again, for the reason already given above, investment demand decreases (see Table 4).[16]

Aggregate foreign trade is not adversely affected by either policy. Implementation of an emission tax does not worsen the balance of trade for two reasons. First, imports of fossil fuels strongly decline. Between 1999 and 2008, import demand for fossil fuels diminishes from 63 to 47 billion ATS (labor cost option). In the second place, sectoral prices are not only blown up by the emission tax they are deflated as well by lower wages (and by lower demand). In total, the prices of the emission-intensive sectors (EMEXP, EMISS and ELEC) increase, whereas the other more labor-intensive sectors face slightly lower prices at a sectoral level. Therefore, emission-intensive industries face decreasing exports and increasing imports and labor-intensive industries face increasing exports and decreasing imports.[17] The change in the trade pattern also affects total production of these sectors. Table 4 shows that the growth rates of emission-intensive sectors are heavily curbed. In the period from 2002 to 2008 growth of EMEXP and ELEC industries becomes negative. Nonetheless, even in 2008, both sectoral products exceed their respective levels of production from 1990 (base year). After 2008, both sectors start again to expand. Thus, in spite of the introduction of an emission tax, the aggregate foreign trade balance is not adversely affected. On a sectoral level, even the most exposed and emission-intensive sectors do not shrink below their base year's production levels (though, as is shown in Table 4, their growth rates strongly diminish).

Two important points can be recognized based on these policy simulations. First, labor demand generally diminishes because the (negative) capital-lessening effect exceeds the (positive) substitution effect.[18] This is most clearly seen for the transfer option (see wage developments in Fig. 3). This impact can only be

[16] Revenues from direct taxes are higher for this option. At the same time, due to the endogenous determination of the government consumption quota according to Eq. (10a) public expenditures are higher compared with the transfer option. As a result, public debt accumulation resembles that of the transfer option.

[17] As can be seen in Table 4, net exports of EMISS industries increase. Since these industries import more than they export, higher growth rates of net exports correspond to even higher trade deficits. The opposite holds for the LABIN industries. Since these industries are net exporters, the higher growth rates correspond to an increasing share of exports to imports.

[18] If wages were sticky, this would amount to an increase in unemployment. Since wages are modeled as flexible in this model, the lower demand for labor services manifests itself in lower real wages.

Table 4
Policy simulations

Aggregate variables[a]

Policies[c]	GDP	Consumption demand	Investment demand	Net exports	Capital stock	Wage	Social security tax rate	CO_2 [10^6 t]	CO_2 tax rate[b]
BC	3288.2	1937.6	700.1	7.5	16250.3	2.45	19.6	84.3	0.00
TP	3245.7	1928.0	680.0	44.2	15777.5	2.26	19.7	52.6	1.41
LCP	3243.2	1911.2	675.5	13.6	15832.0	2.46	19.6	52.6	1.40
PP	3247.7	1932.5	680.0	21.0	15846.4	2.36	15.9	52.6	1.41

Sectoral variables[d]

	Production[c]				Net exports				CO_2 emissions			
Sectors	BC	TP	LCP	PP	BC	TP	LCP	PP	BC	TP	LCP	PP
EMEXP	1.80	1.14	1.07	1.09	0.89	– 5.43	– 8.94	– 7.99	1.29	– 0.56	– 0.63	– 0.62
EMISS	2.59	2.44	2.40	2.44	0.58	0.92	0.97	0.96	2.38	1.01	0.97	1.00
EXPO	2.26	2.34	2.24	2.28	– 0.19	– 3.35	– 0.88	– 1.33	0.63	– 1.07	– 1.14	– 1.11
LABIN	1.84	1.80	1.85	1.83	0.82	1.00	0.93	0.95	0.05	– 1.11	– 1.05	– 1.08
OTHER	2.20	2.17	2.17	2.18	– 1.61	– 10.67	– 2.89	– 3.72	0.18	– 1.39	– 1.38	– 1.38
ELEC	1.25	0.55	0.55	0.56					– 0.25	– 0.93	– 0.94	– 0.93
FOSS	0.00	0.00	0.00	0.00	1.97	– 0.53	– 0.48	– 0.49	– 0.99	– 0.99	– 0.99	– 0.99
FINAL DEMAND									2.19	0.14	0.19	0.17

[a] 10^9 ATS in 2020.
[b] Austrian Schillings/[kg] CO_2 in 2008.
[c] BC = base case; TP = transfer policy; LCP = labor cost policy; PP = pension policy.
[d] Average (yearly) growth rates 1990–2020.

mitigated by further stimulating labor demand. Second, adverse impact of the implementation of a carbon tax also includes the lowering of real private consumption and investment demand. This effect is additionally reinforced by the increase of the social security tax rate. Fig. 3 clearly shows an increase of the social security tax rate from 16% in 1990 to 20% in 2020 (and an even stronger increase beyond the year 2020). Since disposable income increases by less than prices (or, depending on the specification of tax recycling, actually decreases), real consumption demand is lowered as is clearly demonstrated for the labor cost option. If our objectives are the non-discouragement of labor demand, of private consumption and of saving upon implementation of a carbon tax, an option is needed, which takes the following points into consideration: First, it must be able to account for wage subsidization. Second, it must allow for household compensation, e.g., by means of lower social security tax rates.[19]

6.2.2. Pension option

The above arguments are tackled when the pension option is pursued. From total carbon tax revenues, 60% is used for partially financing the old-age pension system and another 40% is employed for subsidizing labor costs. As can be seen in Table 4, this pension policy is capable of achieving the emission target as well. In Table 3, the tax rates on various energy sources under the pension policy are displayed. With 1.48 ATS per kilogram CO_2 in 2008, the tax rate is similar (slightly lower) to that necessary under the transfer policy. The simulation results show that the GDP is moderately higher than GDP under the other options. Labor demand and wages grow at a higher rate compared with the transfer option because substitution of labor services for fossil fuels is further stimulated by wage subsidization. The gross wage therefore resembles that of the labor cost option. At the same time, active cohorts face lower social security tax rates (i.e., higher net wages), as can be seen in Fig. 3. Since part of the carbon tax revenues is used for financing social security retirement benefits, the social security tax rate decreases compared with all other simulations including the base case. Between 1999 and 2008, the tax rate decreases from 17% to 15%, and it only grows slightly up to 16% by 2020 (compared with 20% for the base case). As a consequence, net wages are higher and private consumption, as well as investment demand, is fostered, these latter two being higher here than under the other policy options.

The intuition behind these results can be gained from an awareness of the cohort structure. Under the pension policy, the social security tax rate is lower

[19] A third problem, of course, is posed by the adverse foreign trade impact on a sectoral level. A way to cope with this problem may be to impose part exemptions on emission intensive sectors. For reasons of comparability of the simulations presented in this paper, no such exemptions are imposed. But as is shown elsewhere (Wendner 1997), exemptions result in a higher trade surplus, a higher growth rate of the GDP and in higher tax rates on carbon dioxide emissions.

than under the other alternatives. In the period of interest (1990 to 2020), young people have higher incomes under the pension policy than they do under the transfer policy. The opposite is true for old people. Compared with the transfer policy, the pension policy increases lifetime incomes of young people relative to old people because everybody receives the transfer under the transfer policy, but only wage-earners benefit from the lower social security tax rates under the pension policy. In effect, under the pension policy, old people partially fund their own social security benefits by paying the CO_2 tax embodied in their consumption. As can be seen from the consumption function, young households possess a lower propensity to consume than old households do. Therefore, the adoption of the pension policy rather than the transfer policy increases (at least temporally) the proportion of GDP saved. Greater national savings under the pension policy increase ownership of assets by Austrians. This increases the rate of growth.

Thus, the pension option neither results in a sharp decline of the demand for labor services nor in a lowering of consumption and investment demand, both of which were seen to result from the other policy simulations. Table 4 above and Fig. 3 below summarize these main results.

7. Conclusions

Commonly suggested CO_2 tax recycling options such as utilization of the revenues for transfers or for labor cost subsidization are revealed to be associated with unintended side effects: i.e., a strong decline in labor demand and consumption demand, plus a weakening in savings. The simulations demonstrate that when pursuing the pension policy (where part of the carbon tax revenues is used for financing social security retirement benefits and the remaining portion is employed to subsidize labor costs), these adverse impacts can be avoided. The simulation of the pension policy shows two effects: First, labor demand is further stimulated, resulting in a higher demand for labor services compared with the transfer option. Second, the social security tax rate is lower than for any other option and so directly increases net labor income. Both effects work in favor of an increase of lifetime income, thus affecting consumption and saving positively. Where the growth rate of GDP and private consumption are close to the base case values, not only is it possible to meet the Kyoto Objective (as defined above), but the financing of the old-age pension system can be facilitated. In spite of a rising share of retired households as a percentage of total population, social security retirement benefits can be financed without lowering the replacement rate and even by lowering the social security tax rate compared to the base case. Furthermore, an improvement in aggregate foreign trade is shown to result from a lessening of imports of fossil fuels.

Acknowledgments

I am grateful to Karl Farmer for many discussions concerning this research. I also wish to thank Charles Ballard, Peter Dixon, Larry Goulder, Christian Keuschnigg and Karl Steininger for substantial and very helpful comments on a previous draft. Finally, I am indebted to Channing Arndt, Nick Baigent, Laurie Conway, Ken Pearson and Tom Rutherford for important guidance in the process of this research.

Appendix A. List of variables

Indices

c (E, F)	commodity, sector (sector E, sector F)	*gov*	public sector (governmental)
cons	consumption	*im*	imports
CO_2	carbon dioxide	*ind*	indirect (taxes)
dir	direct (taxes)	*inv*	investment
ex	exports	*s*	actual year
f	foreign	*t*	age of a cohort
fin	final demand		

Variables and parameters

A	aggregate net wealth (summed over cohorts)	S	subsidy (contribution) from the public sector to the social security system
A^{gov}	government net worth (debt)	T	transfer payments (summed over cohorts)
a	assets (net worth) per cohort	T^{dir}	revenues from wage tax
b	pension benefits per cohort	t	transfer payments per cohort
C	aggregate consumption	U	utility
c	consumption per cohort	w	wage (per capita)
ER	nominal exchange rate	$\tilde{w}$	weighted average of labor income
F	fossil fuels sector	X	good, industry, sector
f	CO_2 emission factor	Y	composite energy-factor intermediate
GDP	gross domestic product	β	subjective discount factor
H	composite energy-capital intermediate	Γ	ratio of government consumption to the GDP
I	investment demand	γ	share
K	capital	δ	production function share parameters
$\tilde{K}$	capital services	ζ	ratio of government bonds issued at home to total government bonds
l	labor supply per cohort	Θ	weights for the calculation of the average index of earnings

H	composite energy-capital intermediate	Γ	ratio of government consumption to the GDP
I	investment demand	γ	share
K	capital	δ	production function share parameters
$\tilde{K}$	capital services	ζ	ratio of government bonds issued at home to total government bonds
l	labor supply per cohort	Θ	weights for the calculation of the average index of earnings
MC	marginal costs of X (F, E, ...)	κ	exemption coefficient
P	price of a commodity X (of Y, $\tilde{K}$, ...)	ν	strength of the bequests motive
p	number of years taken into account for the calculation of the average index of earnings	τ	tax rate
Q	composite energy (intermediate) good	ϕ	ratio of labor cost subsidization
r	rate of interest	Ω	replacement rate

References

Allais, M. (1947). *Economie et intérêt*. Paris: Imprimerie Nationale.

Armington, P. S. (1969). A theory of demand for products distinguished by place of production. *International Monetary Fund Staff Papers*, *16*, 159–177.

Auebach, A. J., & Kotlikoff, L. J. (1987). *Dynamic fiscal policy*. Cambridge: Cambridge Univ. Press.

Ballard, C. J., & Goulder, L. H. (1985). Consumption taxes, foresight, and welfare: a computable general equilibrium analysis. In: J. Piggott, & J. Whalley (Eds.), *New developments in applied general equilibrium analysis* (pp. 253–282). Cambridge: Cambridge Univ. Press.

Bergman, L. (1988). Energy policy modeling: a survey of general equilibrium approaches. *Journal of Policy Modeling*, *10*, 377–399.

Bergman, L. (1991). General equilibrium effects of environmental policy: a CGE-modeling approach. *Environmental and Resource Economics*, *1*, 43–61.

Blinder, A. S. (1974). *Toward an economic theory of income distribution*. Cambridge: MIT Press.

Breuss, F., & Steininger, K. (1995). *Reducing the Greenhouse Effect in Austria: A General Equilibrium Evaluation of CO_2-Policy-Options*. Research Institute for European Affairs Working Paper No. 7, Vienna.

Burniaux, J. M., Martin, J. P., Nicoletti, G., & Martins, J. O. (1992). GREEN — *A Multi-Sector, Multi-Region Dynamic General Equilibrium Model for Quantifying the Costs of Curbing CO_2 Emissions: A Technical Manual*. OECD Economics Department Working Paper No. 116, Paris.

Diamond, P. (1965). National debt in a neoclassical growth model. *American Economic Review*, *55*, 1126–1150.

Farmer, K., & Steininger, K. (1998). Reducing CO_2-emissions under fiscal retrenchment: a multi-cohort CGE-model for Austria. *Environmental and Resource Economics*, *12*, 255–288.

Farmer, K., & Wendner, R. (1999). The Use of Multi Sector OLG-CGE Models for Policy Analysis. Economics Department Research Memorandum No. 9903, 1999. Graz: University of Graz.

Feldstein, M. (1974). Social security, induced retirement and aggregate capital accumulation. *Journal of Political Economy*, *82*, 905–926.

Glomsrod, S., Vennemo, H., & Johnsen, T. (1992). Stabilization of emissions of CO_2: a CGE assesment. *Scandinavian Journal of Economics*, *94*, 53–69.

Harrison, W. J., & Pearson, K. R. (1996). Computing solutions for large general equilibrium models using GEMPACK. *Computational Economics*, *9*, 83–127.

Harrison, W. J., Pearson, K. R., & Powell, A. A. (1996). Features of multiregional and intertemporal AGE modelling with GEMPACK. *Computational Economics*, *9*, 331–353.

Hazilla, M., & Kopp, R. J. (1990). Social cost of environmental quality regulations: a general equilibrium analysis. *Journal of Political Economy*, *98*, 853–873.

Holzmann, R. (1988). Zu ökonomischen Efekten der österreichischen Pensionsversicherung: Einkommensersatz, Ruhestandsentscheidung und interne Ertragsrate. In: R. Holzmann (Ed.), *Ökonomische Analyse der Sozialversicherung* (pp. 152–205). Vienna: Manz.

Jorgenson, D. W., & Wilcoxen, P. J. (1990). Intertemporal Equilibrium Modeling of U.S. Environmental Regulation. *Journal of Policy Modeling*, *12*, 715–744.

Keuschnigg, C., & Kohler, W. (1994). Modelling intertemporal general equilibrium: an application to Austrian commercial policy. *Empirical Economics*, *19*, 131–164.

Neusser, K. (1993). Savings, social security, and bequests in an OLG Model. A simulation exercise for Austria. *Journal of Economics*, *7*, 133–155.

OECD (Ed.) (1992). *Global warming. The benefits of emission abatement*, Paris.

ÖSTAT (Ed.) (1996). *ISIS Datenbank* Wien.

Rutherford, T. (1998). Carbon Abatement, Revenue Recycling and Intergenerational Burden Sharing. Paper presented at the International Conference on Using Dynamic CGE Models for Policy Analysis, Assens, Denmark June 14th to 17th.

Samuelson, P. A. (1958). An exact consumption loan model of interest with or without the social contrivance of money. *Journal of Political Economy*, *66*, 467–482.

Schröder, M. (1991). *Die Volkswirtschaftlichen Kosten von Umweltpolitik. Kosten-Wirksamkeitsanalyse mit einem Angewandten Gleichgewichtsmodell*. Heidelberg: Physica.

Vennemo, H. (1997). A dynamic applied general equilibrium model with environmental feedbacks. *Economic Modelling*, *14*, 99–154.

Wendner, R. (1997). *CO_2 — Reduktionspolitik und Pensionssicherung*. Heidelberg: Physica.

Wendner, R. (1999). A calibration procedure of dynamic CGE Models for non-steady-state situations using GEMPACK. *Computational Economics, 13,* 265–287.

World Resources Institute, e.a., (Ed.) (1998). World resources 1998–99. *A guide to the global environment.* Oxford Univ. Press, New York.