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Public investments and debt policy

In view of the different pattern of costs and benefits, public investment might affect the welfare of the current and future generations differently. In this memo, we develop and apply a simple framework to explore the effects of public investment on the intergenerational welfare distribution. We consider three types of public investment: investment in public capital (or infrastructure); investment in education and investment in the environment (the latter is restricted to climate change policies). For each of the investment types we address three questions. First, what are the economic and distributional effects when the investment is financed by an uniform increase in taxes? Second, what are the consequences of debt financing for the intergenerational distribution? Third, how is the intergenerational distribution affected if government transfers are linked to the wage growth arising from higher public investments?

[1] Thanks are due to the members of the ageing team: Nick Draper, Casper van Ewijk, Albert van der Horst, Ruud de Mooij, André Nibbelink, Harry ter Rele and Richard Rosenbrand.

Contents

1 Introduction

This memo explores the effects of public investment on the intergenerational welfare distribution. We have briefly discussed simulation outcomes in Chapter 7 of Van der Horst et al. (2010). In this memo, we explain in detail the modelling choices and results.

The generational accounting approach attributes the benefits and costs of the public sector to different generations. These calculations treat public investment expenditures differently than public consumption. The costs and benefits of public consumption normally fall within the same year. In contrast, investment expenditures go ahead of the benefits which are only gradually generated. When the benefit principle is applied, the costs and the benefits are levelled for each generation. However, this principle is difficult to implement in practice since it requires a complex mix of tax and debt financing. This study focuses therefore on the distributional consequences of simple financing modes. In the standard Gamma model the relation between public investment and income gains is not modelled explicitly (i.e. the exogenous rate of productivity growth does not depend on investment outlays). In a stylized version of the model we incorporate endogenous income effects of public investment.

We consider three types of public investment: investment in public capital (or infrastructure); investment in education and investment in the environment (the latter is restricted to climate change policies). These three investment types differ in the time pattern of benefits and costs. We have modelled that infrastructure investment results in the shortest period in higher wages for the whole active population. Educational investment only increases the wages of the generations that go to school after the reform is implemented. Finally, the adjustment speed of income is the lowest for policies that reduce emissions of greenhouse gasses.

For each of the investment types we address three questions. First, what are the economic and distributional effects when the investment is financed by an uniform increase in taxes? As a benchmark, we start with lump-sum taxes, before we consider distortionary taxes. Second, can the intergenerational distribution be altered by relying more on debt financing? In this scenario we simulate a more gradual introduction of higher taxes. Third, how is the intergenerational distribution affected if government transfers are linked to the wage growth arising from higher public investments?

We isolate distribution effects from efficiency gains by assuming that optimal efficiency holds for the starting level of investment expenditures. Optimal efficiency is achieved when a change in government expenditures would reduce social welfare (defined as the sum of the discounted compensating variations over all current and future generations). By excluding efficiency gains, an expansion of investment will harm at least some generations.

The memo is structured as follows. A stylized version of Gamma is developed to simulate public investment. The main differences between the two versions are listed in the next section. In the following sections, we discuss the effects of an expansion of investment in public capital, education and environment, respectively. We end with the main conclusions.

2 The stylized version of Gamma

The ageing study by Van der Horst et al. (2010) is based on simulation outcomes of the Gamma-model, except for chapter 7 on public investment and debt financing.[1] Public investment is incorporated in a stylized version of Gamma. We explain the main differences between Gamma and the small Gamma-model.

- Gamma considers one-year periods and 100 generations coexist in every year. Small Gamma uses 5-year periods, implying that a lifetime spans maximal 20 periods. Life can divided in 3 parts. Persons are modelled as children in their first 4 periods. Working life is between period 5 and 13. Persons retire from the labour market in period 14.
- The population structure in Gamma is calculated from observed and projected fertility, mortality and net-immigration rates. As a consequence, Gamma captures the ageing of the population. In contrast, we prefer a stationary population in small Gamma to simplify the analysis. In combination with a constant productivity growth, a balanced growth path results for the basecase (except for the last case with environmental policy).
- Small Gamma simplifies the taxation system of Gamma. Small Gamma only includes indirect taxes and incomes taxes on labour income and transfers. It excludes capital income and corporate income taxes.
- Small Gamma abstracts from funded pensions and pension funds. Private savings are equivalent to a defined contributions pension system when premiums and pension income remain untaxed.
- Calibration of small Gamma is based on 2006-data, whereas Gamma reproduces the 2008-accounts.

3 Public capital

This section discusses the incorporation of public capital in small-GAMMA and presents some simulation results. We start with a brief overview of the literature on the effect of public capital on GDP. After we have explained how we have modelled public capital, changes in public investment are simulated.

[1] The Gamma model is discussed in detail in Draper and Armstrong (2007).

3.1 Literature survey

The standard approach to analyze public investment is by extending the production function in the private inputs (K and L) with the stock of public capital (K_G):

$$Y = A\ F(K,L)\ K_G^{\vartheta} \tag{3.1}$$

where A denotes TFP and F is normally a Cobb-Douglas specification with constant returns to scale.[2] The debate in the literature centers on the value of the elasticity ϑ.

The *econometric* literature in this field was launched by Aschauer (1989). He found with time series for the US that the production elasticity was significantly positive, ranging from 0.38 to 0.56. These estimates imply implausible values for the marginal product of public capital exceeding 100% per year. Moreover, subsequent research showed that the estimate was not robust to improvements of the econometric methodology. First, Aschauer (1989) has estimated (3.1) in log-levels. Cointegration tests indicate that the equation should be estimated in first differences. When the variables are expressed as growth rates, a significant relationship between productivity and public capital is no longer found (see Sturm and de Haan (1995) with time-series data and Garcia-Mila et al. (1996) with a panel set of US-states). Second, the identification of a positive relationship in Aschauer (1989) hinges on a few observations. When the relation is estimated with a larger panel with state-level data (including state-specific fixed effects), the public capital variable is again not significant (see Holtz-Eakin (1994) and Garcia-Mila et al. (1996)). For the Netherlands two estimates are available. The WRR (1999, Table 10.3) reports a significant, but implausible large elasticity (0.4 for infrastructure capital), while Sturm and de Haan (1995) obtain peculiar results that are impossible to interpret as production elasticities.[3] Holtz-Eakin (1994) nicely summarizes the findings as "It would be wrong to conclude from this analysis that the large stock of public capital provides no benefits. ... Instead, the main message is that the use of aggregate data does not reveal sufficiently large linkages between public sector capital and private production activities ...".

Alternatively, the choice of the value for ϑ can be based on a survey of *simulation* studies. Baxter and King (1993) choose a central value of $\vartheta = 0.05$. Heijdra et al. (2002) and Turnovsky (2004) simulate with a larger elasticity of 0.2. In setting the values of the production elasticities, the sum of the elasticity wrt private capital and the elasticity wrt public capital should be smaller

[2] We treat public capital as a pure public good. Irmen and Kuehnel (2009) discuss cases in which public goods are partially rival.

[3] Next to the production function approach, Sturm (1997) applies other methods to estimate the effects of public capital. The estimation of a cost function suggests that a 10% expansion of the stock of public infrastructure reduces the cost of the private economy on average by 3%. Sturm (1997) concludes that "public capital probably stimulates economic growth, but that we are still unsure about the size of this effect".

than one to avoid increasing returns to the capital composite.[4]

Finally, the total effect of public capital on GDP (including channels running via private inputs) can be assessed from VAR models, estimated for the Netherlands. Kamps (2004) reports that a one % long-run change in public capital leads to a change in private capital, employment and GDP by 0.24%, −0.24% and 0.52%, respectively. None of these elasticities are estimated significantly. From the impulse-response functions in van der Horst (2003, p. 230) we derive elasticities of 0.4, 0.1 and 0.2 (confidence intervals are not given).

3.2 Model extensions

In Gamma the production function F has a CES-specification. This function is extended with public capital as follows:[5]

$$Y(t) = CES(K(t), L(t))\ K_G(t)^{\vartheta} \tag{3.2}$$

The simulations are performed without productivity growth ($g = 0\%$); without population growth ($n = 0\%$) and a real interest rate of 3%. K_G is taken to represent the infrastructure capital stock. Figure 3.1 shows the declining trend in public expenditures on infrastructure. The share of 1.61% in 2006 fits well in the range of observed shares in the last 25 years. When a depreciation rate of 4% is used, this corresponds to a steady state capital stock K_G of 28.2% of GDP (compare with the CBS-estimate of 38.8%). The substitution elasticity equals $\sigma = 0.5$.

We focus on the intergenerational distributional consequences of a change in public investment in the social optimum. In the basic Ramsey model, all costs and benefits of public investment accrue to the single infinitely lived representative agent. As a consequence, the optimal level of public investment should simply yield a rate of return that equals the real interest rate (Heijdra et al., 2002). However, the determination of optimal policy becomes more complicated in a model with overlapping (disconnected) generations of finitely-lived agents. When Ricardian equivalence does not hold, the timing of costs and benefits does matter.

[4] We restrict attention to models in which public investment has no effect on the long-run growth rate. Irmen and Kuehnel (2009) survey the role of productive government expenditures in endogenous growth models.

[5] In the case of a CES-specification ($\sigma \neq 1$) with population (n) and/or productivity growth (g), public capital should be rescaled to ensure a balanced growth path:

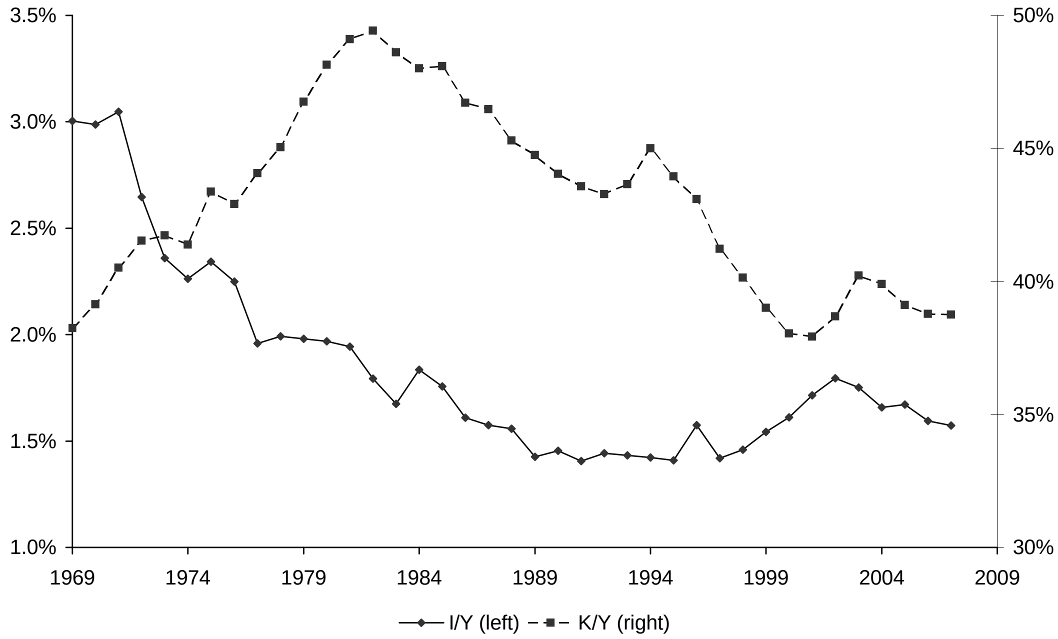
$$Y(t) = CES(K(t), A(t)L(t))\ \left[\frac{K_G(t)}{((1+n)(1+g))^t}\right]^{\vartheta}$$

The marginal productivity of capital should be constant on a balanced growth path. The growth rate of marginal productivity of capital can be derived as:

$$\tilde{Y}_K \backsimeq \frac{1}{\sigma}\left(\widetilde{CES} - \tilde{K}\right) - \vartheta\left(\tilde{K}_G - n - g\right)$$

Inspection shows that rescaling K_G is required to get a constant Y_K along a growth path (if $\vartheta > 0$ and $\sigma \neq 1$).

Figure 3.1 Infrastructure investment and capital stock (%GDP)



Moreover, when investment only expands the effective capital stock one period later, the productivity-enhancing effects lag behind the costs.

We calibrate the value of ϑ under the assumption that optimal efficiency is obtained for the observed share I_G/Y $(= 1.61\%)$. Optimal efficiency is achieved when a marginal change in I_G/Y does not affect total welfare. The total welfare change is defined as the sum of the present value of the compensation variations over all current and future generations (discounted at the rate of 3%).[6] The analysis of intergenerational distribution is based on this optimal scenario.[7]

[6] We have equalized the individual rate of time preference and the social discount rate to ensure a time-consistent welfare function (Calvo and Obstfeld, 1988).

[7] Ter Rele (1998) analyses infrastructure investment with a generational account approach. He focuses on the effects on net lifetime benefits of different generations, while this paper looks at total welfare effects. Furthermore, general equilibrium effects are not included in his analysis. In his baseline, the public capital stock to GDP ratio increases from 28% in 1995 to 56% in 2060. He analyses a reduction of investment by 0.6% (of GDP) after 2020, leading to a capital stock of 39%. On the unsustainable path, the tax level is unchanged, meaning that the debt falls. Ter Rele (1998, Table 9) reports that the net lifetime benefit of a 60-years-old, 30-years-old, newly borns and future generations changes with 0%, -0.9%, -6.8% and 6.7%, respectively. As a result of this, the generational imbalance between newly borns and fututre generations is reduced by about 20%.

3.3 Financing with lump-sum taxes

We simulate an increase in public investment in 2005 that expands the public capital stock in 2010 by 1% (0.08% of GDP). Thereafter, the investment increase compensates the extra depreciation such that the capital stock is held constant. In the reference case, changes in public investment are financed by uniform lump-sum taxes. Lump-sum taxes are linked to the wage growth. In the reference case, the expenditures on income transfers (including public pensions) and health care are linked to the constant steady state wage; i.e. these expenditures do not benefit from the extra wage growth caused by the expansion of public capital. When the change in public expenditures is financed by uniform lump-sum taxes, optimal efficiency is achieved for $\vartheta = 0.03$ (with given $I_G/Y = 1.61\%$). The return to public capital is 7.38% per year, which is comparable to the return to private capital of $r + \delta = 7\%$.

A permanent increase in public capital by 1% requires higher lump-sum taxes of 0.024% (of GDP) in every year. As the lump-sum taxes are a constant fraction of GDP over time (Figure 3.2), the expansion of public debt remains limited. After the additional public and private capital is installed (in 2010), output increases by 0.036% compared to the baseline (Notice that the contribution of the higher public capital stock equals $0.03 * 1\% = 0.03\%$).

Figure 3.3 shows that the current older generations suffer from the largest losses, as indicated by the negative equivalent variations (expressed as % of remaining lifetime income). As lump-sum taxes are independent of age and income, the financing cost falls disproportionately on current, retired generations. The more periods an individual can benefit from the permanent higher wage (starting in 2010), the larger is its welfare effect. Since we start from a Pareto optimal level, the increase in investment has to result in an aggregate welfare loss.

Figure 3.2 Increase in public capital by 1%, financed by lump-sum transfers

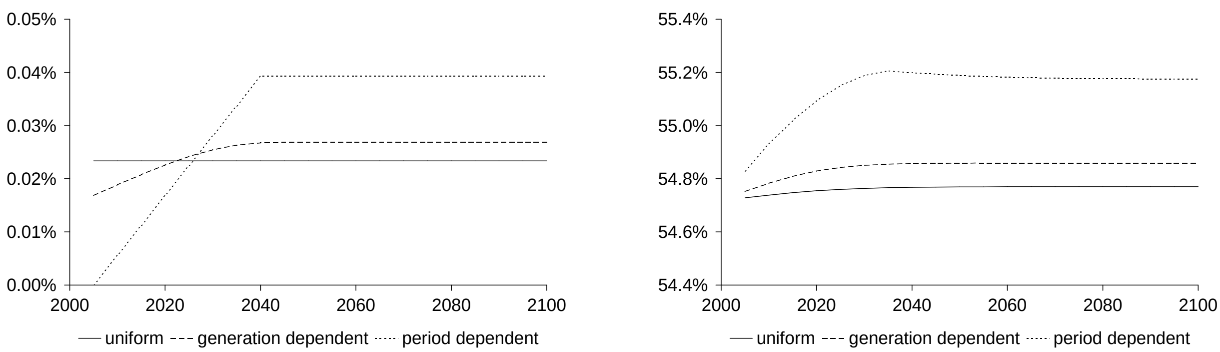
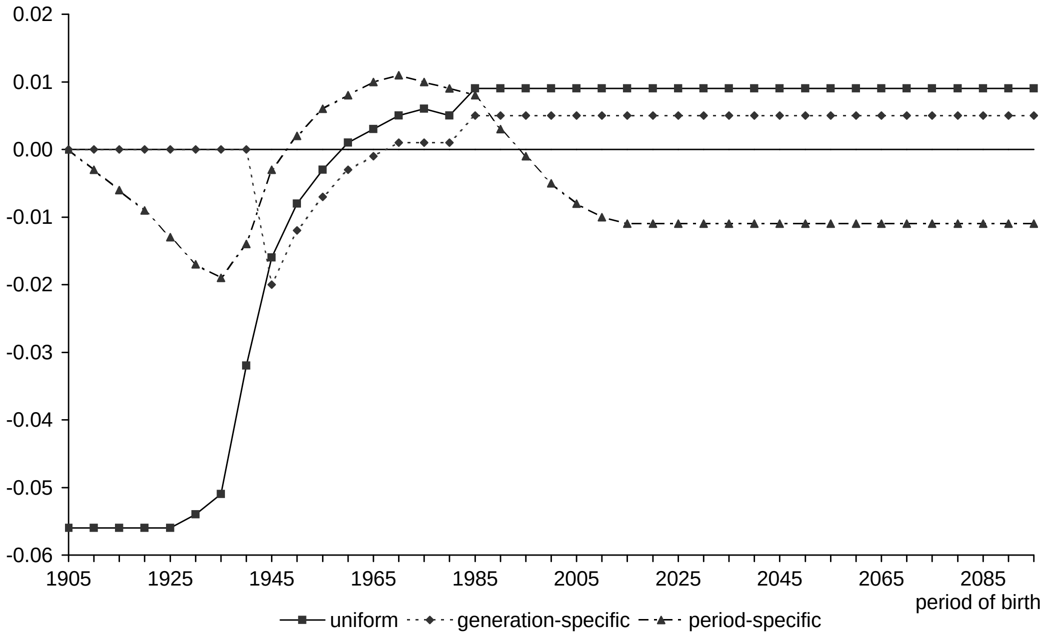


Figure 3.3 Equivalent variations (% of remaining lifetime income) from increase in public capital 1%, financed by lump-sum transfers



3.3.1 Generation-specific lump-sum taxes

Figure 3.3 clearly shows the unequal distribution of the costs and benefits of higher investments when financed by a uniform lump-sum tax. When the government is able to impose a generation-specific lump-sum tax equal to the equivalent variation, public investment is financed according to the benefit principle. We want to restrict the analysis to simple taxation schemes. In an alternative scheme, we first specify that the eight oldest existing generations are exempted from the extra tax, whereas the generations born in 1945 or later have to pay the full tax at every age. Since less taxes are received from current older generations, lump-sum taxes stabilize at a higher fraction of GDP and public debt increases faster to a higher level (Figure 3.2). By shifting the financing burden more to future generations, welfare losses of current retired generations and welfare gains of future generations both fall (Figure 3.3). Notice that for the oldest, existing generations net income does not change, meaning that its welfare remains unaffected.

3.3.2 Period-specific lump-sum taxes

Generation-specific taxes are less plausible in practice but large welfare losses can also be avoided by increasing the lump-sum tax gradually over time. The lump-sum tax is not imposed in the first period in order to leave utility of the oldest, existing generation unaffected. In the subsequent 7 periods, the lump-sum tax is increased to its final value in 7 equal steps. Since the tax revenues are lower in the first periods of this scenario, more debt is accumulated which requires a higher long-run level of the lump-sum tax (Figure 3.2). Figure 3.3 shows that this period-specific tax better approximates a benefit tax in yielding a more equal distribution of the welfare effects.

3.4 Distortive financing

3.4.1 Labour taxes

Labour taxes become distortive once we consider endogenous labour supply. When financed by the distortionary income tax, the optimal ϑ increases to 0.037 (i.e. the marginal productivity of public capital must be higher to compensate for the deadweight loss arising from the distortionary income tax).[8] When financed by an immediate, uniform increase in the income tax rate (+0.025%), higher public expenditures require extra income taxes of 0.034% in the long run (see Figure 3.4). Since the rise in the after-tax wage stimulates labour supply, output expands more than in the previous case (0.046% relative to the basecase).

Figure 3.5 shows that older, retired generations suffer from a larger (relative) welfare loss than younger retired generations. This can be explained by the feature that after retirement, in the absence of private pensions, untaxed capital income falls relative to the taxed public pensions. All future generations, which earn a constant wage (per efficiency unit) over their lifetime, end with a small welfare gain.

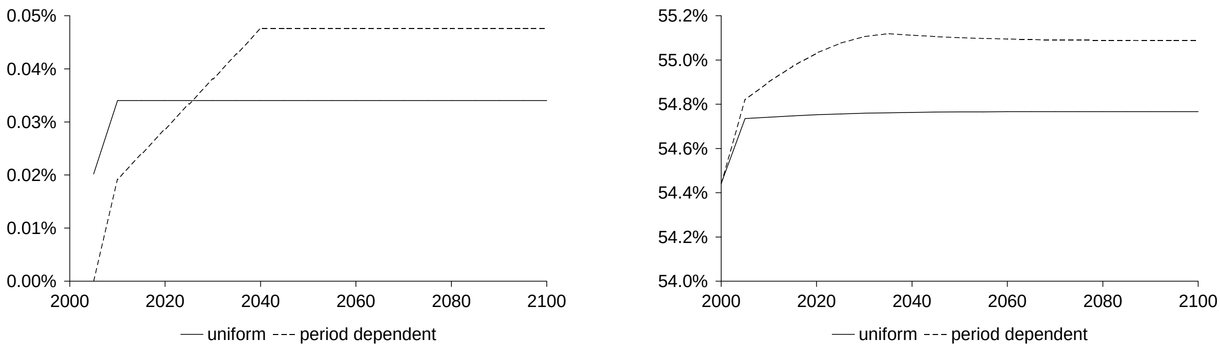
We aim at a more even distribution of the welfare effects by gradually increasing the income tax rate. A similar schedule is applied as in the previous case. The increase in the tax rate is postponed one period after the shock. The increment equals 1/7 of the final increase during the 7 following periods. After 8 periods, the tax rate has reached its final value. As a result, the welfare effects range between −0.014% and 0.011% in Figure 3.5.

3.4.2 Consumption taxes

When financed by consumption taxes, the same optimal ϑ is found as in the previous case (0.037). Consumption taxation is less distortionary than income taxation, as the intertemporal closure of the government budget requires a moderate increase in consumption taxes by 0.022% (of GDP) in the long run (Figure 3.6). In response to the higher consumption tax rate (+0.046%), the current, retired generations cannot change their remaining lifetime income (leisure is constant at the maximum level). Since they cannot avoid higher consumption taxes, these generations suffer from an identical (relative) utility loss that is the largest over all

[8] The income tax is imposed on labour income and transfers.

Figure 3.4 Increase in public capital by 1%, financed by income taxes



generations (Figure 3.7). The welfare effects increase monotonously in the year of birth.

The welfare losses of current generations can be reduced by shifting to more debt financing in the first periods. A period-specific introduction of a higher consumption tax rate is simulated following the time scheme discussed in the previous scenario. A more smoothed welfare distribution is obtained, turning the gain for future generations into a small loss.

3.5 Transfers with indexing

In the reference case, the expenditures on transfers (including public pensions) and health care are only linked to the exogenous wage growth; i.e. excluding the extra wage growth that arises from the expansion of public capital. In an alternative scenario, expenditures on transfers and health care are indexed at the total wage growth (including the extra, endogenous growth of 0.043% in 2010). The lifecycle profiles for the baseline in Figure 3.8 reveal that the transfers and health expenditures strongly increase with age.

In the model, utility is not dependent on health care expenditures, implying that it captures only the financing costs but not the benefits of higher health care consumption.[9] Since the standard welfare analysis cannot be applied for this policy, we present the change in lifetime income as an alternative measure. Lifetime income equals the sum of the present value of full incomes over the remaining lifetime, where full income in every period is defined as:

$$Y_i^f = \frac{(1-\tau_w)(w_i + T_i)}{(1+\tau_c)} + G_i \tag{3.3}$$

The value of the time endowment equals the net wage where w denotes the gross wage rate and τ_w the labour tax rate.[10] We have expressed full income in terms of the consumption good. In

[9] Since the transfers can be freely spent over the lifetime, this problem does not arise for this type of expenditures.

[10] Whereas the equivalent variation includes the utility value of leisure, full income captures the opportunity cost of leisure.

Figure 3.5 Equivalent variations (% of remaining lifetime income) from increase in public capital by 1% , financed by income taxes

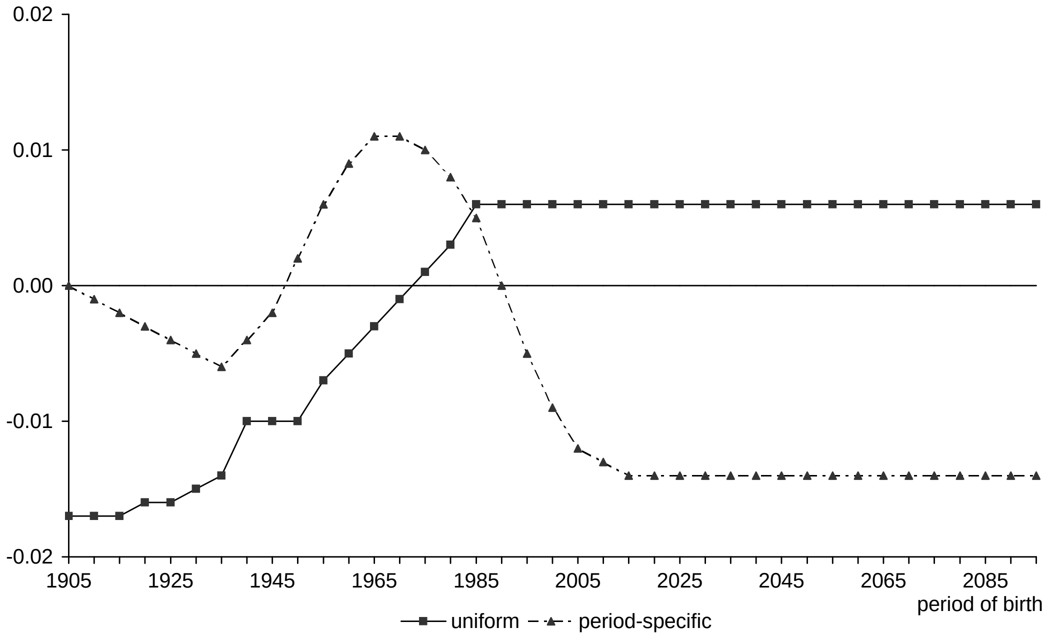
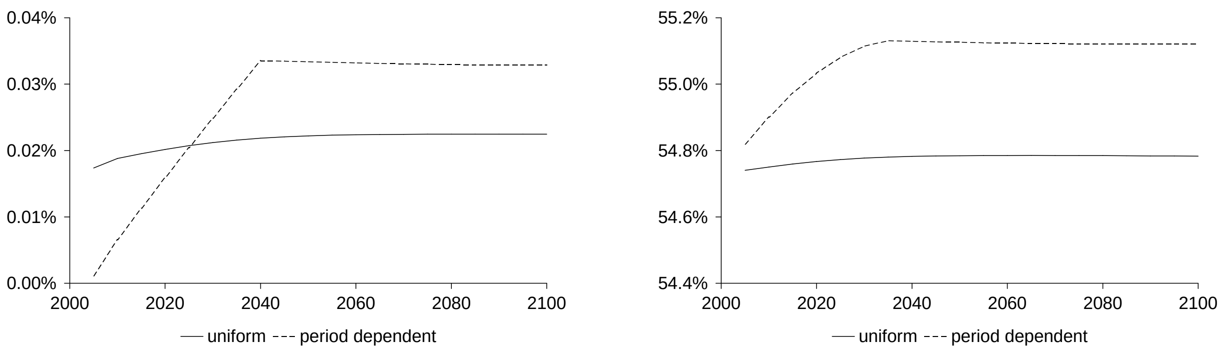


Figure 3.6 Increase in public capital by 1%, financed by consumption taxes

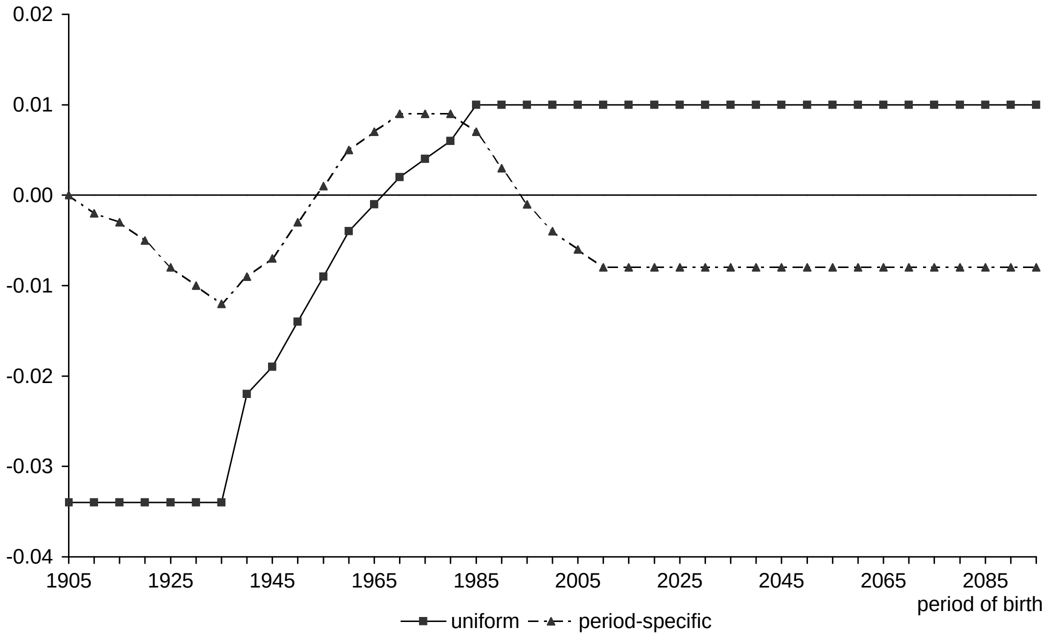


contrast to health care expenditures G, other transfers T are subject to income taxation (τ_w) and consumption taxation (τ_c). For existing generations, the value of financial wealth is added to lifetime income (Future generations are born without financial assets).

3.5.1 Lump-sum taxes

In the case with uniform lump-sum financing, the increase in indexed public expenditures raises lump-sum taxes to 0.032% (compare to 0.024% in the case without indexing). Since taxes are immediately increased to finance higher expenditures in the future, debt in Figure 3.9 is kept lower in every year than in the case without indexing (taken from Figure 3.2).

Figure 3.7 Equivalent variations (% of remaining lifetime income) from increase in public capital by 1%, financed by consumption taxes

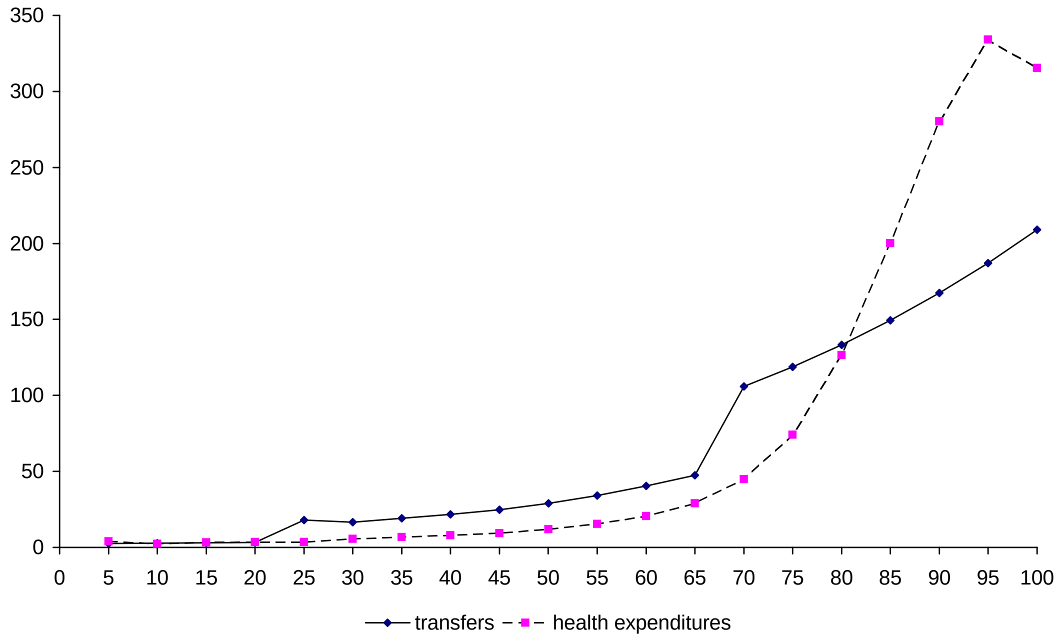


The changes in lifetime income are presented in Figure 3.10. In line with the welfare measure of Figure 3.3, (remaining) lifetime income of current generations falls after the increase in public investment, while it improves for the future generations in the case without indexing. When indexing is included, the income position of the two oldest current generations further worsens since they have to contribute to the finance of the higher future outlays. The income of most of the current generations relatively improves with the indexing option since they receive more periods higher transfers and public health payments. The younger current generations and all future generations suffer from an income loss since they have to cofinance the higher expenditures to current generations.

3.5.2 Labour taxes

When financed by labour taxes, indexing has strong consequences on the intergenerational income distribution. Figure 3.11 confirms the finding of Figure 3.5 that current generations have to pay for the income gains of future generations in the case without indexing and uniform labour tax financing. After indexing is introduced, current retired generations benefit from higher public transfers (except the oldest cohort). The lifetime income of all remaining generations fall due to the financing costs of the larger public expenditures. The long-run income gain of 0.01% in the scenario without indexing turns into a loss of -0.003% with indexing.

Figure 3.8 Lifecycle profiles for the generation born in 2000



When indexing is combined with a gradual increase of the labour tax rate, Figure 3.12 shows that the income of current, retired generations further improves. In this case also the current, working generations benefit as they have to contribute less to the higher financing needs of the government. The tax burden of the reform is now completely shifted to the future generations.

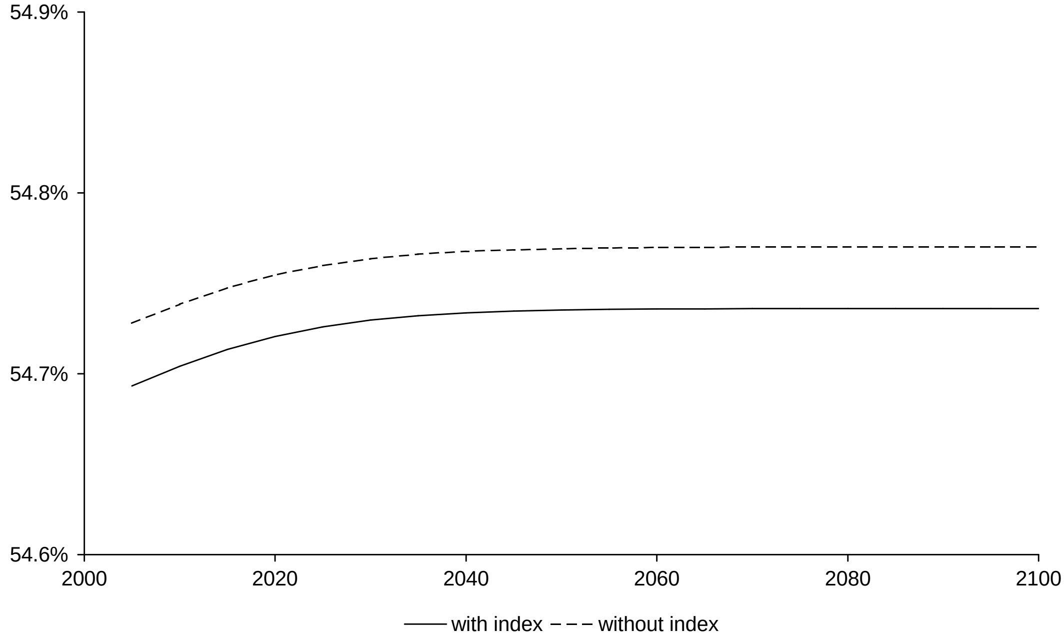
3.6 Simulations with higher ϑ

In the previous simulations, the calibrated value of the elasticity ϑ corresponds with optimal efficiency. In this subsection we consider public investment with a higher productivity by putting ϑ at a higher value. The value of 0.1 is in line with the value chosen in other simulation studies. However, when the initial investment share is socially sub-optimal, distributional effects can not be isolated from efficiency gains arising from an investment policy.

A policy that increases highly productive investments is almost self-financing when financed with uniform lump-sum taxes, as shown in Figure 3.13. When uniform income or consumption taxes are used as financing instruments, the corresponding tax rate can be reduced (by 0.006% and 0.012%, respectively). The lower income tax rate only leads to a fall in tax revenues in the first period. The expansion of the tax base explains the rise in tax revenues in other periods.

From Figure 3.14 follows that all policies are Pareto improving for all generations (except for the retired, current generations in the case with lump-sum taxes). The current generations are

Figure 3.9 Debt (% GDP) after increase in public capital by 1%, financed by uniform lump-sum transfers



better off with consumption taxes and the worst off with lump-sum taxes. The opposite ranking holds for future generations. Current generations benefit the most from the efficiency gains arising from the lower distortionary tax rate. The total social welfare gain equals 0.581%, 0.443% and 0.442% of base GDP in 2005 in the three scenarios, respectively (discounted at 3%).

Figure 3.10 The %-change in lifetime income after an increase in public capital by 1% (uniform lump-sum taxes)

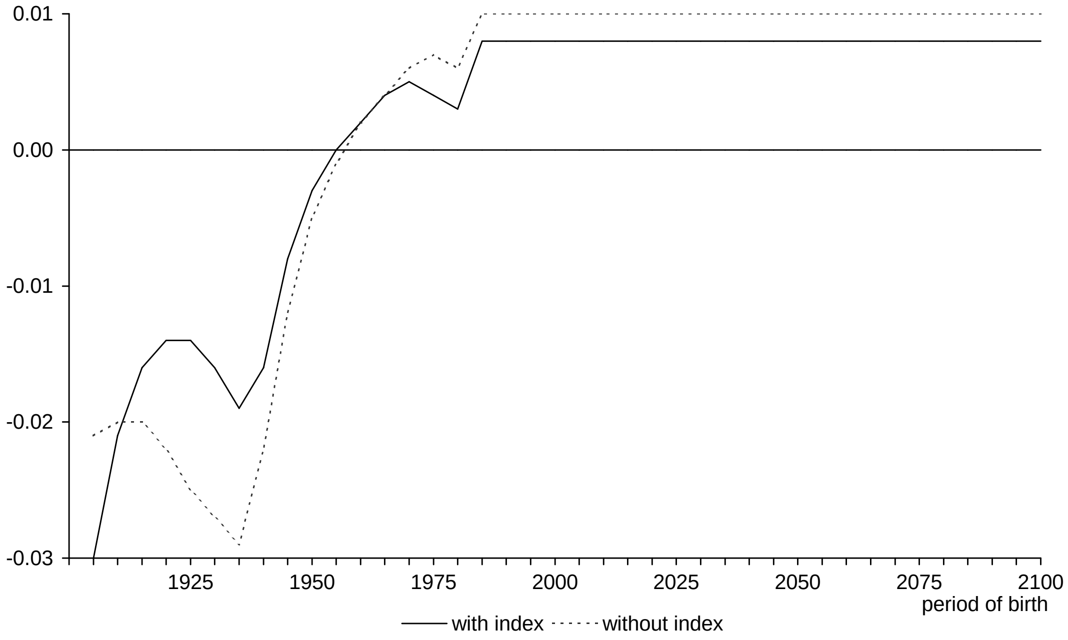


Figure 3.11 The %-change in lifetime income after an increase in public capital by 1% financed by uniform labour taxes

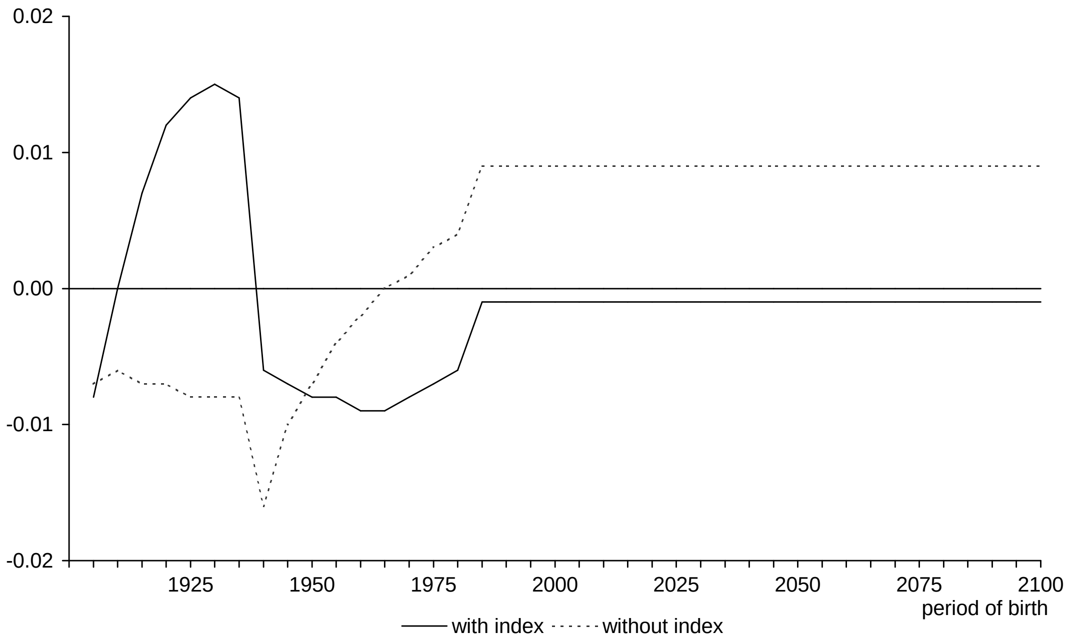


Figure 3.12 The %-change in lifetime income after an increase in public capital by 1%; with indexing; financed by labour taxes

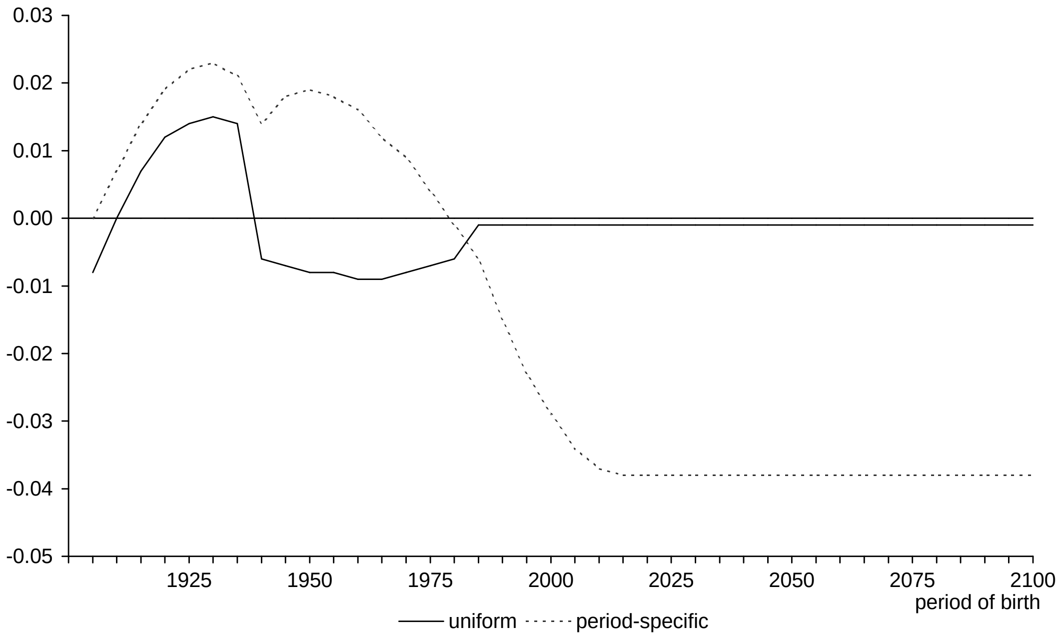


Figure 3.13 Extra taxes (%GDP) after increase in public capital by 1%, with $\vartheta = 0.1$

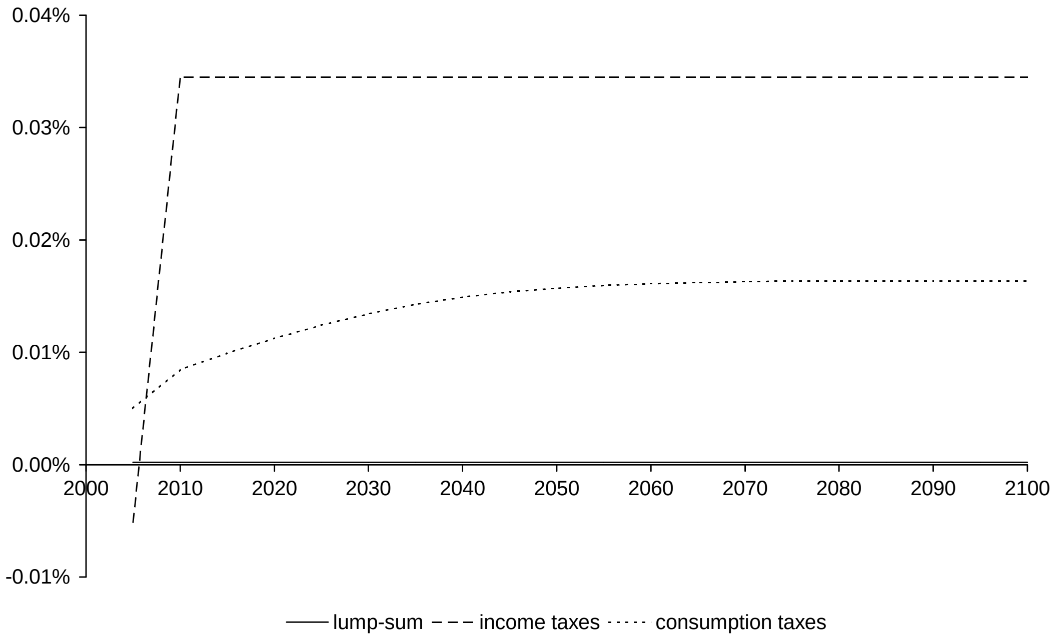
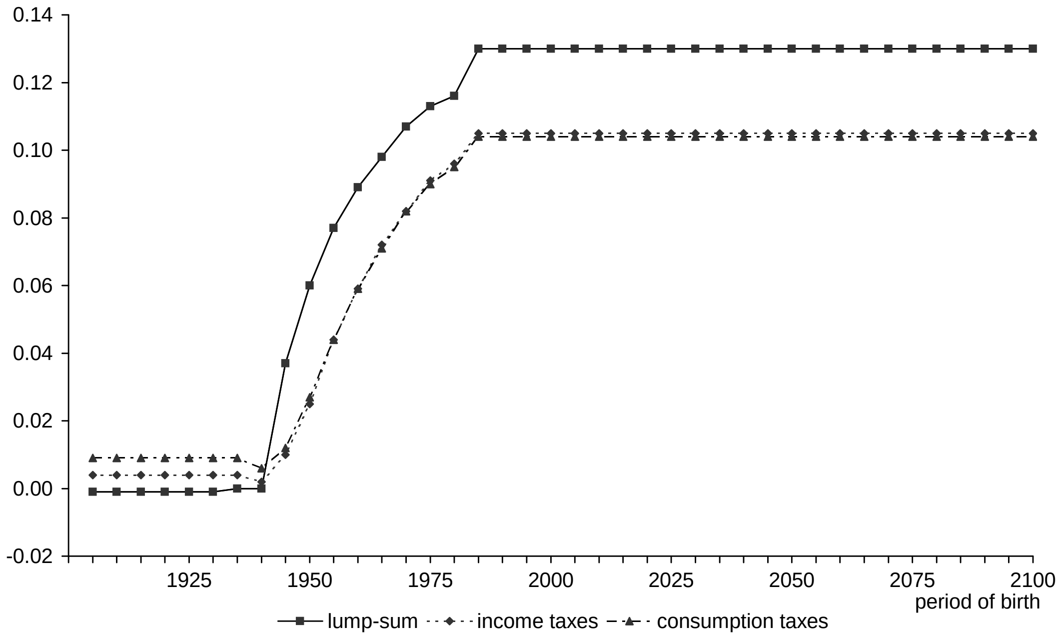


Figure 3.14 Equivalent variations (% of remaining lifetime income) from increase in public capital by 1% , with $\vartheta = 0.1$



4 Public investment in education

This section discusses the modelling approach and results of extending small-Gamma with public investment in education. We first sketch the determination of the optimal education level in the standard income-maximizing framework. This discussion provides the intuition for the calibrated values of our model.

4.1 The optimal years of schooling

Mincer has derived the optimal number of years of schooling in the basic human capital model (see Jacobs (2010) and Heckman et al. (2008)). We consider a social planner who chooses the education level that maximizes lifetime earnings of an individual, net of total education costs. Notice that a social planner considers gross incomes (including taxes) and that we abstract from externalities from human capital. The costs of one extra year of schooling consist of direct costs P and foregone earnings $Y(S)$:

$$MC = P + Y(S) \tag{4.1}$$

where $Y(S)$ denotes labour income at age S. The direct costs P might be interpreted broadly as including as well utility (or psychic) costs or benefits from schooling. Investing MC in extra education raises the present value of wage income by:

$$MB = \sum_{\tau=S+1}^{T} \Delta Y(\tau)\,(1+r)^{-(\tau-S)} \tag{4.2}$$

where ΔY denotes the increase in income due to extra schooling, r the social discount rate and T the last year of active life (We abstract from the small mortality rates during active life). The years of schooling S are optimal when the marginal costs MC are equal to the marginal benefits MB. The implications of this first-best condition are illustrated by some special cases.

First, suppose the wage income is age-independent ($Y(\tau) = \bar{Y}$ and $\Delta Y(\tau) = \beta\bar{Y}$); there are no direct costs ($P = 0$) and the horizon is infinite ($T \to \infty$). The condition reduces to $\beta = r$; i.e. the return on human capital equals the return on financial capital. Second, after the introduction of positive direct costs, the required increase in lifetime income should exceed the real interest rate:

$$\beta = \frac{P+\bar{Y}}{\bar{Y}} r \tag{4.3}$$

Direct costs are believed to be about 1/3 of foregone earnings ($P/\bar{Y} = 1/3$; see Jacobs (2010)). In this case, this implies that $\Delta Y/Y = 4/3r$. Third, the generalization to a finite lifetime gives:

$$\beta = \frac{P+\bar{Y}}{\bar{Y}} \frac{r}{1-(1+r)^{-(T-S)}} \tag{4.4}$$

Evaluating this condition for $r = 3\%$; $S = 20$ and $T = 65$ increases β to 5.4%.

Most of the empirical studies estimate the so-called Mincer return on education by regressing (log) wages on the years of schooling. Jacobs (2005) concludes from a literature survey that the EU-average rate of return equals 8% over all levels of education (each additional year of education lowers the Mincer rate of return by 1% on average). However, these studies seem to neglect that the Mincer specification only holds under strong conditions that are not met in practice. Jacobs (2010) stresses that the Mincer coefficient can only be interpreted as the rate of return on education in the absence of (i) direct costs; (ii) a risk premium on human capital; (iii) capital market imperfections; (iv) option values (positive or negative) and (v) utility costs or benefits. Jacobs (2010) concludes that an estimated Mincer coefficient of 8% cannot be directly used in policy analysis but that the evidence on the appropriate adjustment of this rate of return is unfortunately still inconclusive.[11]

4.2 Model extensions

In Gamma, human capital is captured by an exogenous age-profile of efficiency units. This profile is made dependent on education expenditures. By increasing the investment in education, the government can expand the productive capacity of the economy by stimulating the growth of the labour force in terms of efficiency units. We simulate general education policies, not limited to policies aiming at increasing the average school duration.

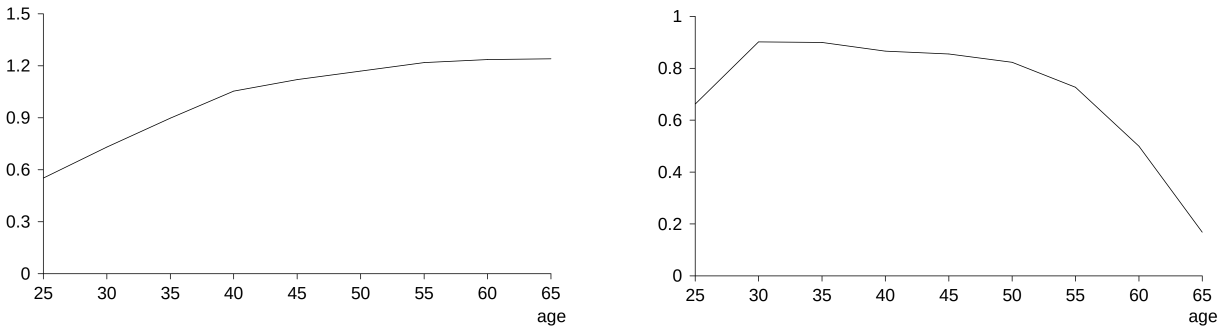
Figure 4.1 shows the number of efficiency units $e(\tau)$ of an individual of age τ. A worker receives the wage $p_l(t)e(\tau)$ per time unit he supplies, where p_l denotes the wage per efficiency unit. The resulting labour supply (% of the time endowment per year) is given in the right panel (Since the basepath is calibrated as a balanced growth path, this participation profile holds for all generations).

We model that each individual is educated from age 5 till age 24 (i.e. during 4 age groups of 5 years). Education of each age group requires public expenditures (P). Since we do not model decision making by individuals younger than 20 years old, we do not include private costs for these age groups. An individual starts working at the age of 20. Since we consider general education policies, we have not included that extra schooling time goes as the expense of labour supply of this generation. Instead, the opportunity costs of the age group 20-24 are captured by specifying private costs equal to three times the public costs ($\hat{P} = 3P$).[12] These private costs can be interpreted as a kind of transaction costs that lead to a direct utility loss.

[11] See the survey by Hanushek and Woessmann (2008) on the relation between earnings and other educational outcomes, like test scores.

[12] Notice that without borrowing constraints not the timing but only the present value of the costs matters.

Figure 4.1 Lifecycle profile of efficiency units (left) and labor supply in basecase (right)



Next, we have to specify the relation between (public and private) education expenditures and the number of efficiency units. After postulating the simple specification $e = \chi_0 \left(4P + \hat{P}\right)^{\chi_1}$, we derive the relation between the %-change in efficiency units $\tilde{e}$ (or wages) following a %-change in education expenditures as:

$$\tilde{e} = \chi_1 \widetilde{P} \tag{4.5}$$

We calibrate the value of χ_1 by assuming that the observed level of education expenditures maximizes total welfare. In other words, the marginal benefit of investment is assumed equal to the marginal cost for the society (in utility terms). For the calibrated value for χ_1, a marginal change in P does not affect total welfare (defined as the sum of the present value of the compensation variations over all current and future generations; discounted at the rate of 3%). By imposing optimal efficiency, we can focus on intergenerational distributional effects.

We use the framework developed in the previous subsection to explain what is a plausible value for the elasticity χ_1. In this framework the social planner does not maximize social welfare but the income of a representative generation. The corresponding first-order condition $MB = MC$ can be written as:

$$\sum_{\tau=5}^{13} \Delta Y(\tau)(1+r)^{-\tau} = \sum_{\tau=2}^{5} \Delta\left[P + \hat{P}(\tau)\right](1+r)^{-\tau} \tag{4.6}$$

with $\hat{P}(\tau) = 0$ if $\tau \neq 5$ and $\hat{P}(5) = 3P$. Under the assumption that the percentage increase in total education expenditures ($\widetilde{P}$) and in labour income ($\tilde{e}$) is age-independent, we obtain:[13]

$$\chi_1 = \frac{\sum_{\tau=2}^{5}\left[P + \hat{P}(\tau)\right](1+r)^{-\tau}}{\sum_{\tau=5}^{13} Y(\tau)(1+r)^{-\tau}} \tag{4.7}$$

The elasticity χ_1 in the income-maximizing framework equals the ratio between the present value of total education expenditures over the lifetime and the present value of labour earnings.

[13] We neglect here age-dependent responses of labour supply to wage changes.

Evaluating (4.7) at basecase values gives $\chi_1 = 0.32$. Next, we need to specify the costs of an extra year of schooling. According to OECD (2009) the average duration was 11 years for primary and secondary studies and 5 years for tertiary studies (in 2006). Under the assumption of linear costs, one extra year of tertiary education increases expenditures by $1/5 = 20\%$. Assigning this cost increase only to the last age group ($\tau = 5$) implies that total education expenditures rise by $20\% * 4/7 = 11\%$. Following (4.5), this would imply an income increase by $0.32 * 11\% = 3.5\%$. This figure is comparable to the real interest rate of 3%.

The calibrated value of χ_1 will differ from the value indicated by (4.7) for two reasons. First, the calibration is based on maximizing the sum of welfare over all existing and future generations. Second, the calibration includes the transition period during which not all working generations have enjoyed a better education.

4.3 Financing with lump-sum taxes

4.3.1 Uniform lump-sum taxes

In the case of uniform lump-sum taxes, the observed level of education expenditures is Pareto efficient when the calibrated value of χ_1 equals 0.252. We simulate an increase of education expenditures by 0.5% in 2005. For every period of schooling after 2005, the number of efficiency units is increased by $1/4 * 0.252 * 0.5\% = 0.031\%$. For generations who start schooling after 2005, human capital is improved by the full 0.126%.

The gradual increase in the supply of efficiency units does not change the wage per efficiency unit. In a small, open economy without adjustment costs, the capital stock is immediately adjusted to ensure a constant capital/labour ratio, except in the first period after an unexpected shock. In the first period, the capital stock is fixed and the capital/labour ratio falls. As a consequence, the marginal productivity of labour is temporarily lower while the opposite holds for the productivity of capital. Therefore, workers are paid a lower wage (per efficiency unit) and asset holders receive a capital gain in the first period. The gradual increase in the total efficiency units is reflected in the rise in production in Figure 4.2 (relative to basecase). Wages per hour increase by 0.13% for the better-educated workers. The induced increase in the labour supply in hours remains small due to the small substitution effect (leisure falls by 0.03% for all working ages of affected workers).[14]

The increase in public education expenditures (0.030% of GDP) requires higher lump-sum taxes of 0.026% (see Figure 4.3). In the explanation of the welfare effects in Figure 4.4, we distinguish 4 groups of generations. The current retired generations suffer from the largest

[14] We assume that there is no income effect on labour supply.

welfare losses since they do not benefit from higher wages while they have to pay higher lump-sum taxes. The current working generations lose less since lump-sum taxes are a smaller fraction of their lifetime income. The benefits for the transition generations of school age are increasing in the remaining years of schooling. Finally, the future generations enjoy the full impact of better education, while the costs are shared with older generations.

Figure 4.2 Output after an increase of education expenditures by 0.5%, financed by lump-sum taxes (relative to basecase)

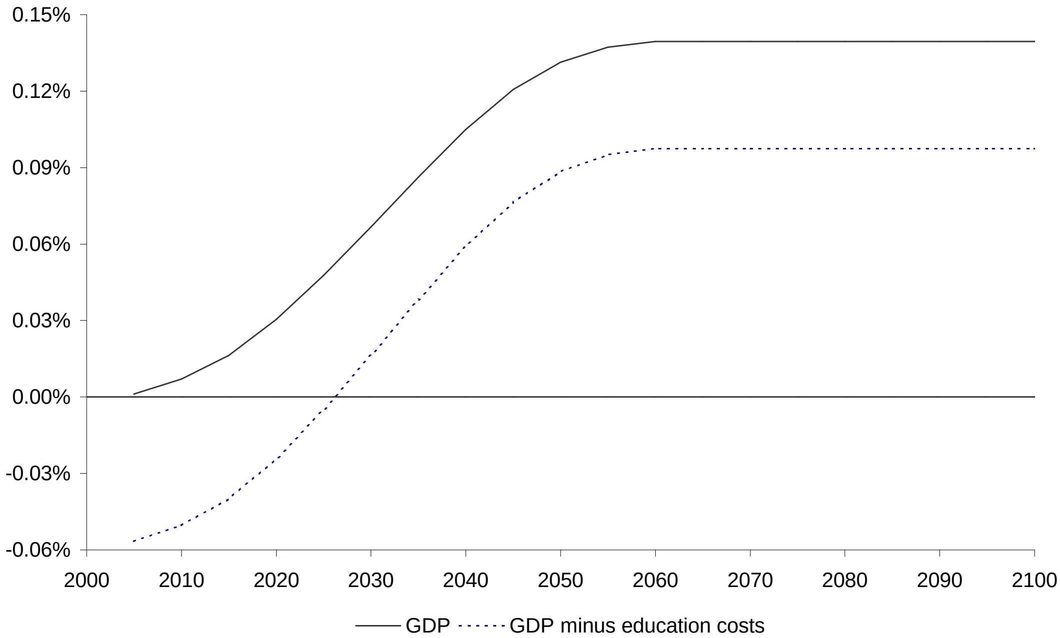


Figure 4.3 Taxes and debt after an increase in education expenditures by 0.5%, financed by lump-sum taxes

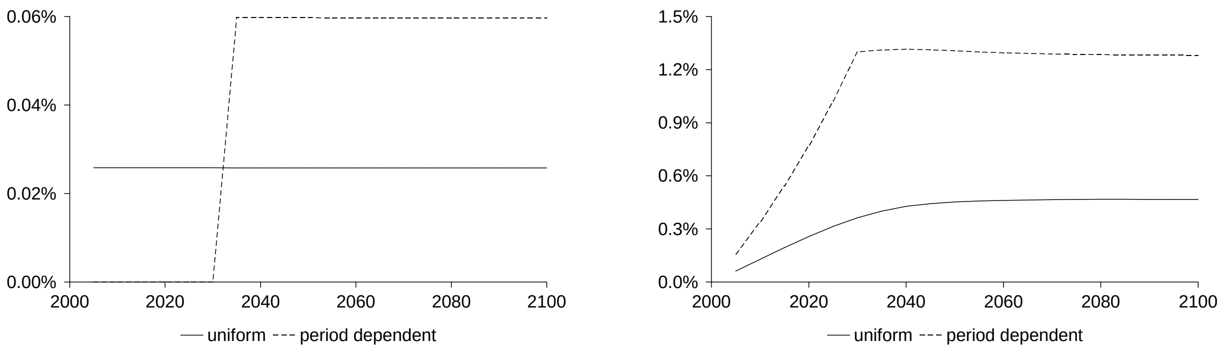
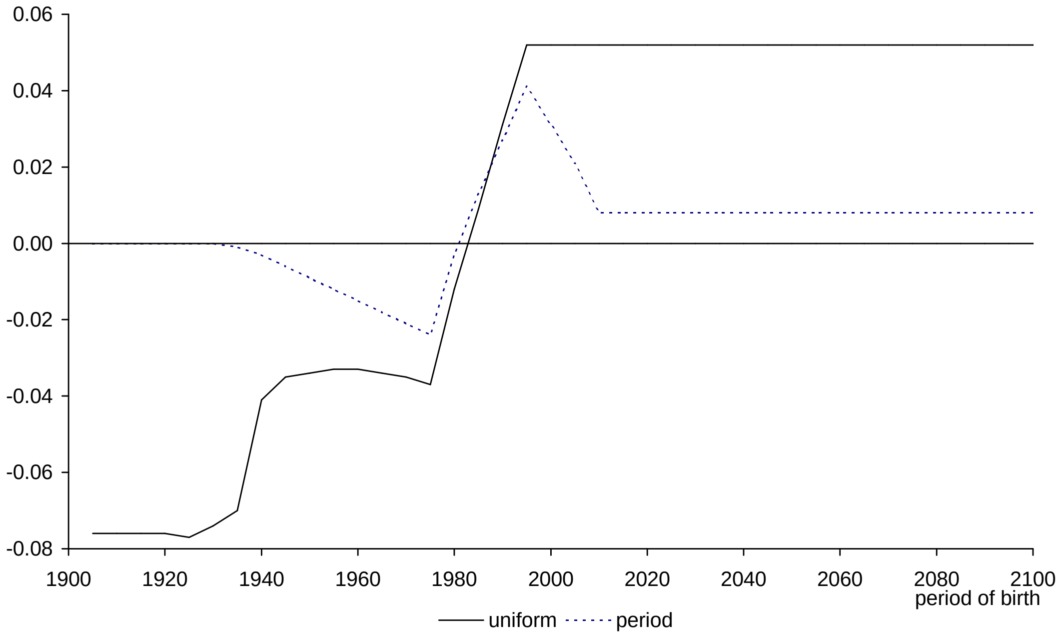


Figure 4.4 Equivalent variations (% of remaining lifetime income) from increase in education expenditures by 0.5%; financed by lump-sum taxes



4.3.2 Period-specific lump-sum taxes

Financing public investment by an immediate, uniform increase in taxes leads to an uneven welfare distribution over the generations. An even distribution is obtained when taxation follows the benefit principle: each generation should be taxed according to its equivalent variation. Since generation-specific taxes are considered unfeasible, we experiment with period-specific lump-sum taxes to generate a more smooth intergenerational welfare distribution. To relieve the current generations, we postpone the increase in lump-sum taxes till 2035. Starting in 2035, the tax is increased to its final value. Figure 4.3 reveals that the delayed collection of taxes leads to a permanent higher debt level. By relying more on debt financing, investment costs are shifted from current to future generations. Welfare of current older generations is not longer affected, while the other current generations gain from the more gradual increase in taxes in Figure 4.4. The welfare gains of current generations come at the expense of welfare losses for the future generations. As a consequence, the long-run welfare effect turns into a loss.

4.4 Financing with labour taxes

4.4.1 Uniform labour taxes

When financed by the distortionary labour tax, the optimal χ_1 increases to 0.259 (i.e. the marginal productivity of public investment is higher to compensate for the deadweight loss arising from the distortionary tax).[15] We first consider an uniform increase in the labour tax rate. The higher public education expenditures (0.03% of GDP) are balanced by higher labour taxes of 0.02% in the long run (Figure 4.6). The immediate increase in the tax rate induces a lower labour supply, resulting in a lower GDP in the first period (Figure 4.5). After the net-wage improves with the accumulation of human capital, GDP starts rising. In comparison with the case with lump-sum taxes, one main difference emerges in the welfare outcomes in Figure 4.7. The current working generations face the largest welfare losses since their lifetime utility depends the most on the income source that is more heavily taxed.

4.4.2 Period-specific labour taxes

The financing costs can be more imposed on the benefiting generations by implementing period-specific increases in the labour tax rate. We use the same time schedule as described in the case with lump-sum taxes. Since the tax rate is only increased after 2035, output expands in every period (The fall in the labour taxes/GDP ratio until 2030 is due to the larger denominator). However, the long-run tax rate has to increase more to compensate the tax losses in the first periods, and the resulting distortions lead to relative lower output in the long run (Figure 4.5). The resulting welfare distribution in Figure 4.7 resembles the pattern found in the case with lump-sum taxation, with one main difference: the higher distortive labour tax results in a long-run welfare loss.

4.5 Transfers with indexing

In the previous cases, the expenditures on transfers (including public pensions) and health care are kept constant over time, meaning that receivers of these transfers do not benefit from the increase in average labour productivity. In an alternative scenario, expenditures on transfers and health care are indexed at the total wage growth, presented in Figure 4.8. The extra growth of public expenditures due to indexing requires an additional increase in the budget-closing tax. For instance, the uniform lump-sum taxes have to increase by 0.04% of GDP (compared to 0.03% in the case without indexing).

[15] This tax is imposed on labour income and transfers.

Figure 4.5 Output after an increase of education expenditures by 0.5%, financed by labour taxes (relative to basecase)

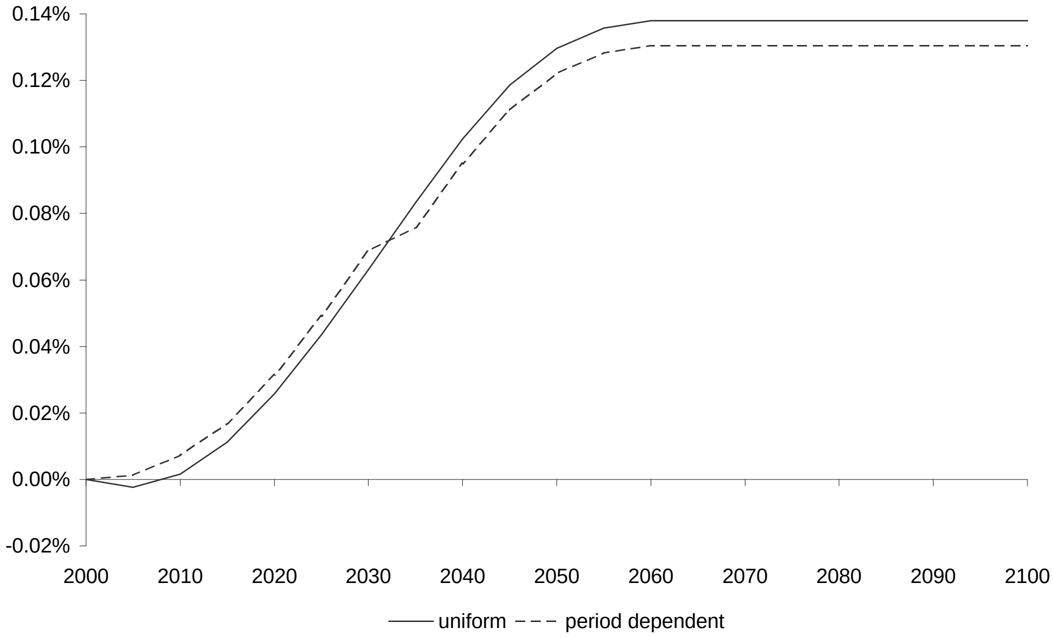
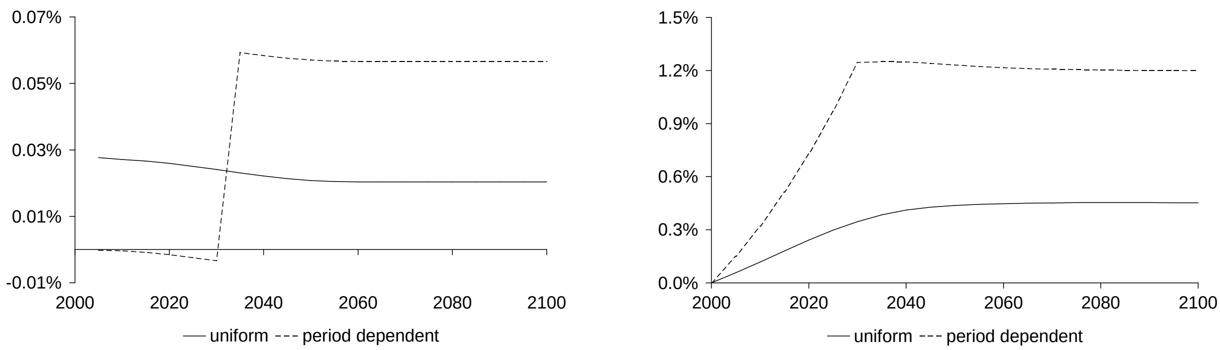
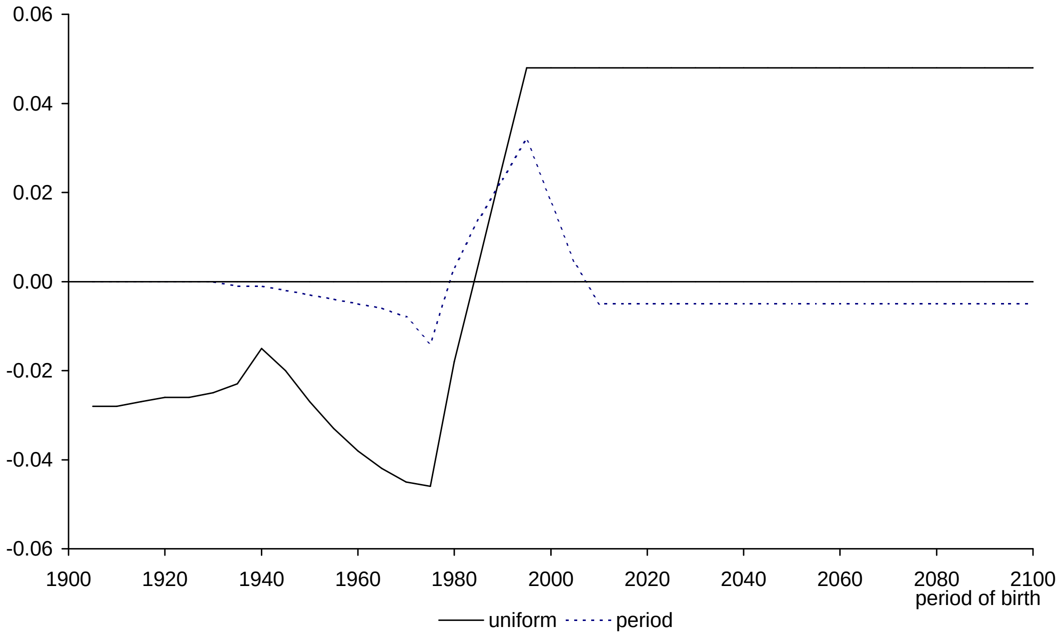


Figure 4.6 Changes in taxes and in debt after an increase in education expenditures by 0.5%, financed by labour taxes (%BBP)



The changes in lifetime income, calculated according to the definition (3.3), are presented in Figures 5.9-5.12. Figure 5.9 shows that indexing harms the remaining lifetime income of current generations in the case of uniform lump-sum financing. The gain from receiving higher transfers and public health payments is offset against their contributions to higher future outlays. This is mirrored by the income gain of future generations. The consequences for the income redistribution are reversed for the case with period-specific lump-sum taxes in Figure 5.10. Since current generations are exempted from higher taxes, future generations now have to incur the financing costs of the indexed expenditures. In the case of distortionary, uniform labour taxes,

Figure 4.7 Equivalent variations (% of remaining lifetime income) from increase in education expenditures by 0.5%**; financed by labour taxes**



income of retired, current generations relatively improves as they are less affected by a higher labour tax rate. In contrast, disposable income falls for all the other generations (when compared to the case without indexing). The distortionary effects of the labour taxation are most striking when the tax rate increase is postponed till 2035 (Figure 5.12). The income gains of current generations call for large income losses of future generations.

Figure 4.8 Wage per hour after an increase of education expenditures by 0.5%, financed by lump-sum taxes (relative to basecase)

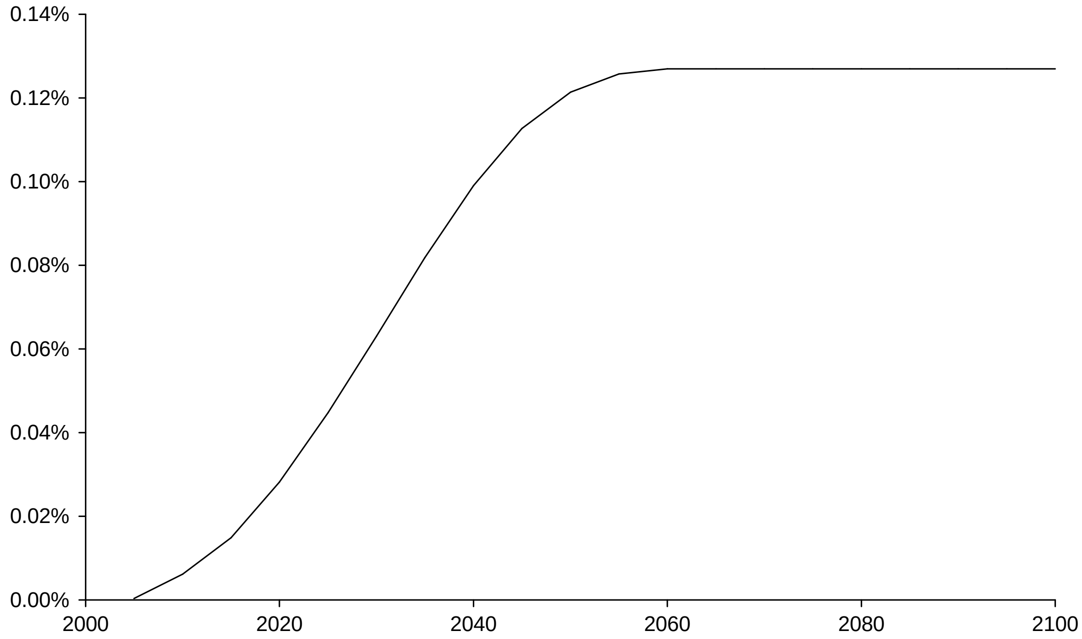


Figure 4.9 The $\%$-change in lifetime income after an increase in educational expenditures; uniform lump-sum taxes

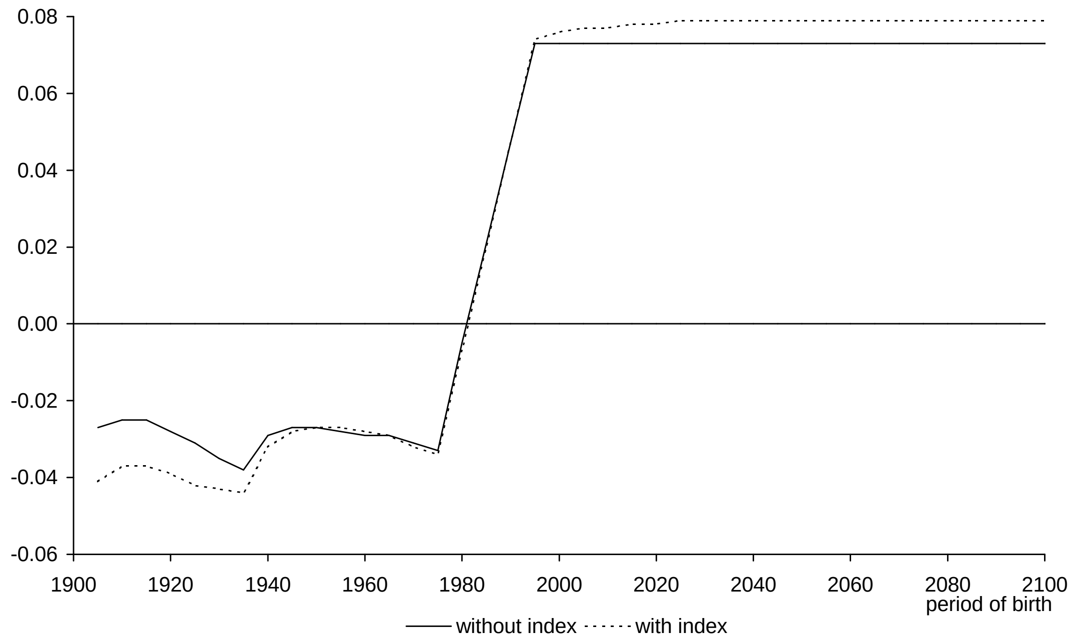


Figure 4.10 The %-change in lifetime income after an increase in educational expenditures; period-specific lump-sum taxes

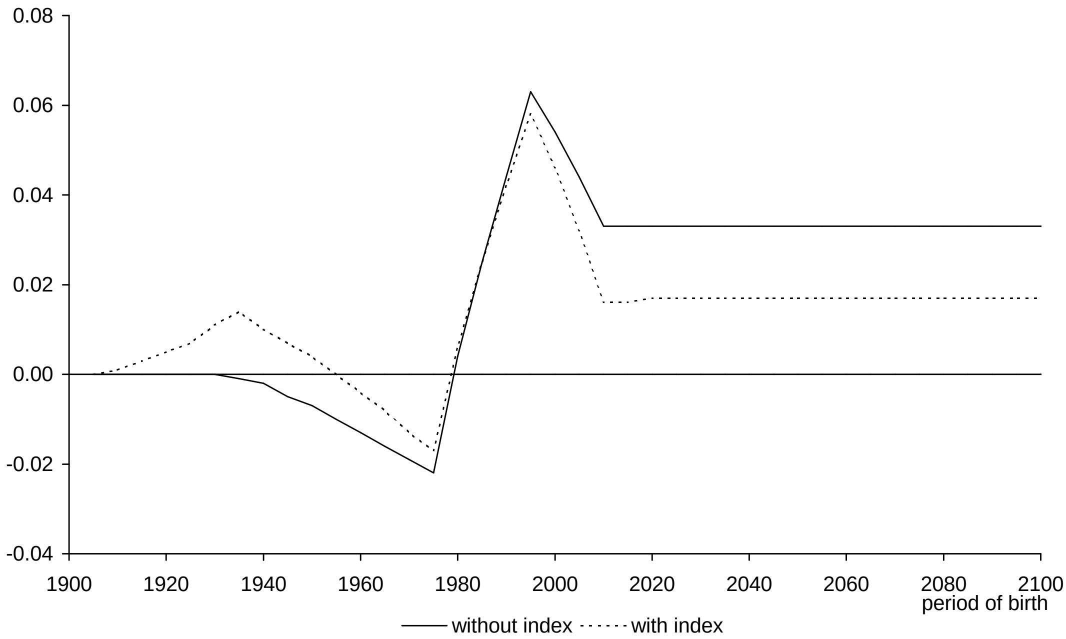


Figure 4.11 The %-change in lifetime income after an increase in educational expenditures; uniform labour taxes

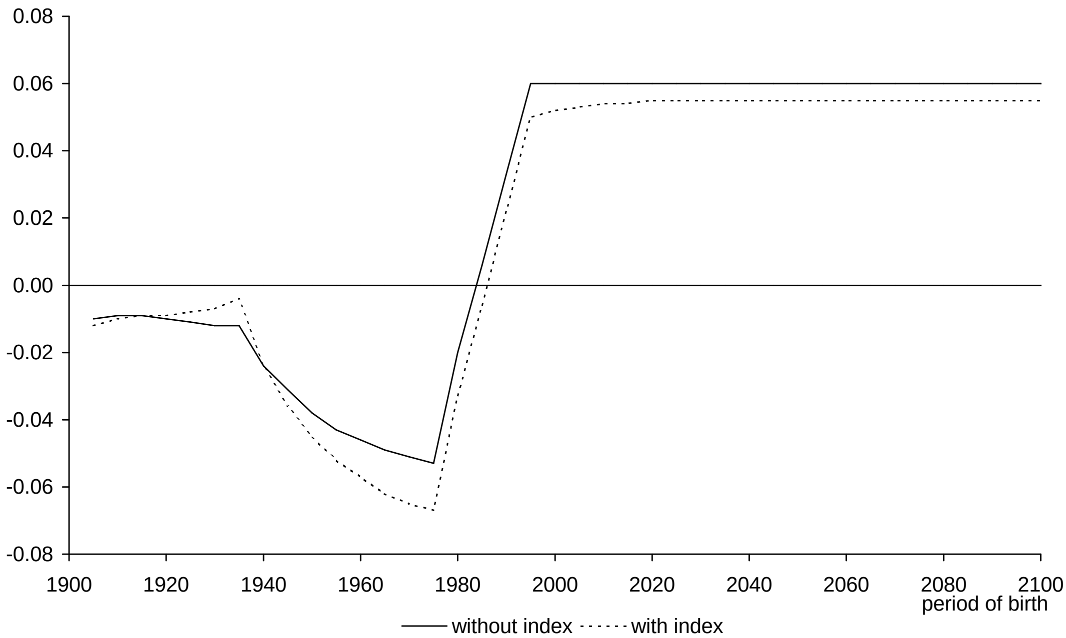
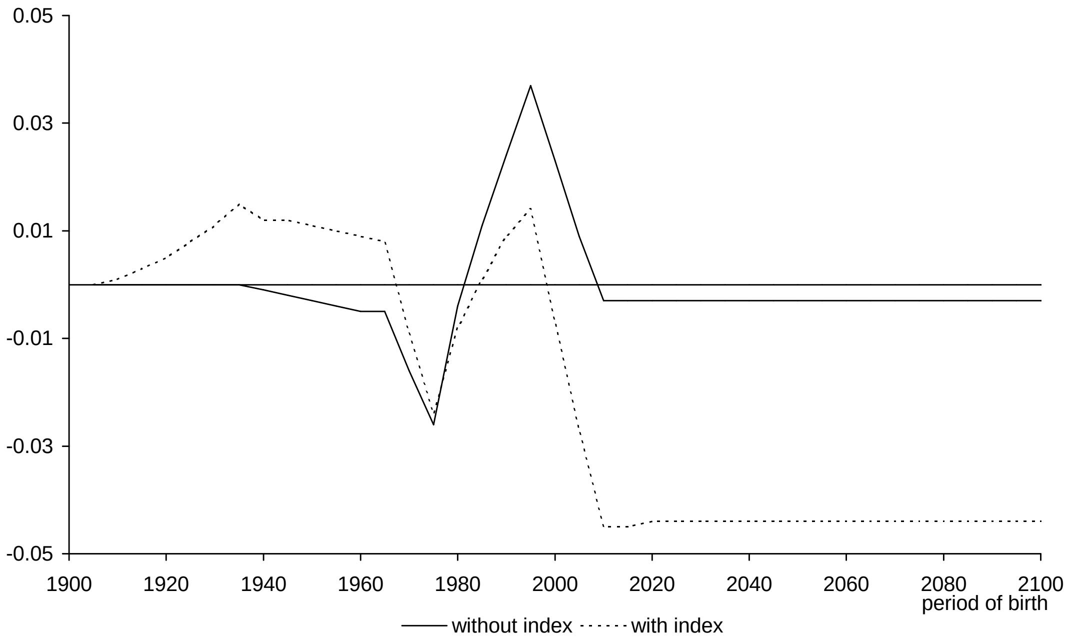


Figure 4.12 The %-change in lifetime income after an increase in educational expenditures; period-specific labour taxes



5 Public investment in environment

This section discusses intergenerational distributional effects of environmental policies as simulated with small GAMMA.[16] Environmental policies are here limited to policies that aim at reducing emissions of greenhouse gasses. Nordhaus (1994) has developed the standard economic model of global warning (updates are provided in Nordhaus and Boyer (2000) and Nordhaus (2008)). Howarth (1998) extends the model with overlapping generations. The climate equations in our model are taken from the latter model.

This section has the following outline. After the extension with the climate block is explained, its parametrization is discussed in comparison to standard climate-change models. We first simulate a base scenario with laissez-faire policies before we present the scenario with the social optimal reduction in emissions. This social optimum is used as a reference in the following simulations that focus on intergenerational welfare effects of emission reduction under different financing modes.

5.1 Model extensions

The extension with the climate block has a simple structure. The emission of greenhouse gasses increases with production. Emissions accumulate to a stock of greenhouse gasses, which affects global temperature. A temperature increase in its turn reduces the TFP-growth. Pollution abatement therefore affects output through two channels. First, public investment aimed at reducing emissions will reduce current net output. Second, lower emissions today reduce the future temperature and therefore increase future TFP-growth.

Emissions are modelled proportional to gross output:

$$E(t) = \omega_e \left[0.181 + 0.189(0.982)^t\right] Y(t) \tag{5.1}$$

In the absence of pollution abatement ($\omega_e = 1$), the emission rate E/Y falls exogenously. In the basecase, this rate starts at $E_0/Y_0 = 0.27$ and converges to 0.181 in the long run. This equation of the Howarth-model already points at a basic problem. In the Howarth-model all variables are assumed to converge to a constant level, whereas Gamma includes a rising balanced growth path. We tackle this problem by modelling emissions as a weighted average of two emissions levels:

$$E(t) = \lambda_e^t E_1(t) + \left(1 - \lambda_e^t\right) E_2(t) \tag{5.2}$$

[16] We thank Rob Aalbers for constructive comments on an earlier version of this section.

where E_1 is given by (5.1) and E_2 by

$$E_2(t) = \left[0.181 + 0.189(0.982)^{t^*}\right] Y(t)(1+g(t))^{t^*-t}$$

E_2 can be interpreted as the emission level at time t^* under the assumption that Y keeps growing at rate g. Notice that when the economy grows at the steady state rate in t^*, $Y(t)(1+g(t))^{t^*-t} = Y(t^*)$, implying that E_2 is constant as well (with $t \geq t^*$). As a consequence, E becomes constant for large values of t ($\lambda_e^t \approx 0$). Specification (5.2) will result in a concave time path for emissions. We have chosen a combination of λ_e^t and t^* that matches the emission rates E/Y of Howarth (1998) till 2100.

The atmospheric stock of carbon dioxide and chlorofluorocarbons Q is given by:

$$Q(t+1) - 590 = 0.64\omega_q E(t) + (1-0.008)(Q(t)-590) \tag{5.3}$$

The stock is taken in deviation from the preindustrial norm of 590 billions tons of carbon-equivalent. A fraction of 64% from the gasses emitted remains in the atmosphere. We postulate that the worldwide emissions develop similarly as the outcomes of the model's economy.[17] The constant ω_q rescales the model's emission level to a worldwide scale. The stock of emissions (in excess of the preindustrial level) 'depreciates' at a rate of 0.8% per year. We put the starting level of Q equal at the 2000-observation ($= 784$) and the worldwide level $\omega_q E(2000)$ at 8.6 billions of tons. For a given level of E, from (5.2), follows the constant ω_q.

The stock of greenhouse gasses is translated into temperature changes (relative to the preindustrial level) as follows:

$$T(t) = \frac{5.92 \ln(Q(t)/590) + F(t)}{1.41} \tag{5.4}$$

where F denotes the stock of other greenhouses gasses, which is exogenously determined as:

$$F(t) = 1.42 - 0.764(0.982)^t \tag{5.5}$$

According to (5.4), doubling Q relative to the preindustrial level raises the temperature by 2.91°C ($= 5.92 * ln(2)/1.41$). Note that the exogenous stock of other greenhouses gasses F contributes to a temperature increase by 1°C ($= 1.42/1.41$) in the long run.

[17] You should realize that the projected emissions of the Netherlands, and even Europe, do not represent well the worldwide developments. According to the regional model of Nordhaus and Boyer (2000), emissions of the high income countries (except US) fall by 19% in the period 2015-2105, whereas the worldwide emissions increase by 68%. This implies that the share of the high income countries in global emissions is almost halved from 19% to 10%. These outcomes are in line with the IPCC's fourth assessment report.

Production is a CES-function of the capital stock k and employment in efficiency units l:

$$y(t) = \Psi(t) \left[\kappa\, k(t-1)^{\frac{\sigma-1}{\sigma}} + \theta\, l(t)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{5.6}$$

Employment l grows at the exogenous rate of technological progress g. The feedback from the environmental quality on production is given by the adverse relation between the temperature change and TFP:

$$\Psi(t) = 1 - 0.0133 \left[\left(\frac{T(t)}{3} \right)^2 - \left(\frac{T_0(t)}{3} \right)^2 \right] \tag{5.7}$$

A temperature increase by $3^o C$ is assumed to reduce TFP by 1.33%. We normalize TFP on the base path at 1.

In deviation from Howarth (1998), we specify that a temperature increase might have a direct, negative utility effect. We add to the standard utility of full consumption the following utility loss from a temperature increase above the basecase level:[18]

$$\Phi(t) = 2 - \left(\frac{T(t)}{T_0(t)} \right)^2 \tag{5.8}$$

The government can implement a policy to reduce emissions. Howarth (1998) considers an emission tax. Its optimal value equals the discounted future benefits of lower emissions. We consider a policy of public mitigation measures. To reduce emissions by $(1-\omega_e)\%$, public expenditures should be equal to:

$$i_m(t) = 0.0686 * (1-\omega_e)^{2.89} Y(t) \tag{5.9}$$

A reduction by 50% requires public expenditures of 0.93% of current output, while a 100% abatement rate ($\omega_e = 0$) costs 6.86% of output.

The optimal policy is similarly determined as in the previous sections. Efficiency gains are maximized when a change in government environmental expenditures would reduce social welfare (defined as the sum of the discounted compensating variations over all current and future generations). For the exercises with optimal educational and infrastructure investments, we calibrated a particular elasticity under the assumption that the social optimum is obtained with the observed expenditures. In contrast, in the current case, we search for the optimal reduction in emissions (ω_e), and hence for the optimal level of public expenditures (i_m).

[18] Acemoglu et al. (2009) specify that environmental quality directly affects utility but they have not incorporated the adverse effect of temperature on TFP. They have calibrated the utility effects such that the welfare consequences of temperature increases are the same in their model as in Nordhaus model.

5.2 Parametrization

The parametrization is driven by the objective to reproduce the climate effects reported in Nordhaus (1994) and Howarth (1998). The exogenous growth rate of labour productivity g equals 1%. Nordhaus (1994) specifies that the growth rate of total factor productivity of a Cobb-Douglas production function falls from 1.4% in 1965 to 0% in the long run. This implies an average annual growth rate of 0.56% over the period 2005-2100. A similar specification in Howarth (1998) gives an average growth rate of 0.62%.

In the simulation exercises with investment in education and infrastructure we combined a real interest rate of 3% with a productivity growth of 0%. After increasing the productivity growth to 1%, we prefer a higher interest rate of 4% to keep the implicit discount rate $(r-g)$ constant. We put the rate of time preference equal to the real interest rate. In the closed economy models of Nordhaus (1994) and Howarth (1998) the real interest rate is endogenous. In the base run in Nordhaus (1994), the rate of return on capital declines from 6% to 3%, while the rate of time preference equals 3%. In the 1999-version, discussed in Nordhaus and Boyer (2000), the social rate of time preference is not constant but assumed to decline over time. It declines from 3% in 1995 to 2.3% in 2100 and 1.8% in 2200. The corresponding interest rate equals 4.5% in 1995; 2.8% in 2100 and 2.3% in 2200. In the latest DICE-model, Nordhaus (2008) fixes the rate of time preference at 1.5%. The path of the interest rate moves from 5.7% in 2005; 2.8% in 2105 to 3.9% in 2205.[19] Howarth (1998) reports an interest rate of 4.3% in the base year and a rate of time preference of 0.5%. The depreciation rate of the capital stock in Nordhaus (1994, 2008) and Howarth (1998) is 10%, while it is 4% in our model. We first exclude direct utility effects (5.8).

5.3 Basecase with lump-sum taxes

We start with a description of the laissez-faire basecase. The rise in emissions in Figure 5.1 is driven by the positive trend in output. The accumulation of the emissions causes an increase of the temperature from 1.7^{o}C in 2005 to 3.8^{o}C in 2100 (Figure 5.2; relative to preindustrial norm). Table 5.1 shows that the climate variables (in 2105) are very similar to the uncontrolled run of the DICE-1999 model of Nordhaus and Boyer (2000). However, the last column shows that

[19] An important difference between the older versions and the 2007-version of the DICE-model concerns the specification of the utility function. In the older versions, utility is logarithmic in consumption, implying a unitary elasticity of marginal utility. In the latest version, Nordhaus switches to a more concave utility with an elasticity of marginal utility of 2 (Notice that we apply the same elasticity for the consumption composite, including leisure, in Gamma). The revised utility function explains why the lowering of the rate of time preference is consistent with higher interest rates. Remember that in the steady state of a closed economy in a Ramsey setting holds that $r=\rho+\sigma g$ (where ρ is the rate of time preference; σ the elasticity of marginal utility and g the growth rate of output).

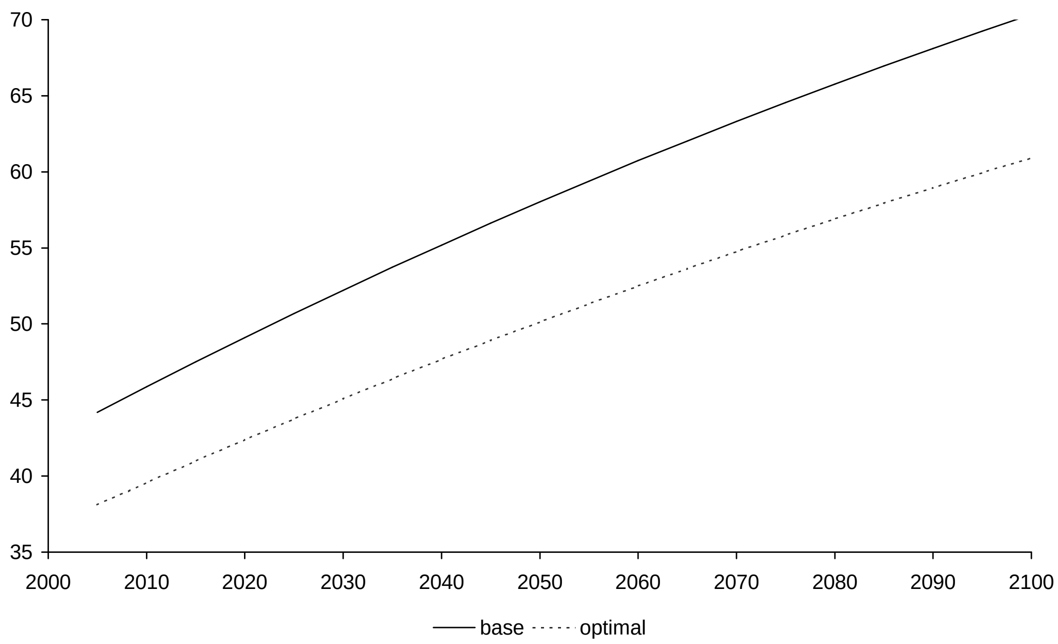
Table 5.1 Comparison basecase changes 2005-2105

	Gamma	DICE-1999[a]	DICE-2007[b]
emissions (%)	62	85	166
stock of CO_2 (%)	52	47	81
temperature (^{o}C)	2.1	2.0	2.3

[a] Nordhaus and Boyer (2000)
[b] Nordhaus (2008)

Nordhaus (2008) supports a more negative view on global warning in later work.[20]. Since our model is based on the climate block of Howarth (1998), outcomes are similar to the earlier DICE-versions.[21]

Figure 5.1 Emission levels (worldwide scale in billion tons per 5 year)



Starting with this basecase, we solve the model for the reduction in emissions that maximizes aggregate compensating variations. When financed with lump-sum transfers, the optimal emission reduction is 14% ($\omega_e = 0.86$), which mitigates the temperature increase (by 0.3^{o}C in 2100) and stimulates GDP (Figure 5.3). The emission reduction by 14% requires government expenditures of 0.02% of GDP every year.[22] This optimum is again highly comparable with the

[20] Nordhaus (2008, p. 46) describes the main revisions since DICE-1999. van Vuuren et al. (2009) find that the outcomes of DICE-1999 and DICE-2007 are within the range of the outcomes of more complex models.

[21] Unfortunately, Howarth (1998) does not report a laissez-faire basecase.

[22] DNB (2007) reports that the costs of the main dikes in the Netherlands range from 0.17% of GDP in 2007 to 0.02% in

Figure 5.2 Temperature increase (^oC, relative to preindustrial level)

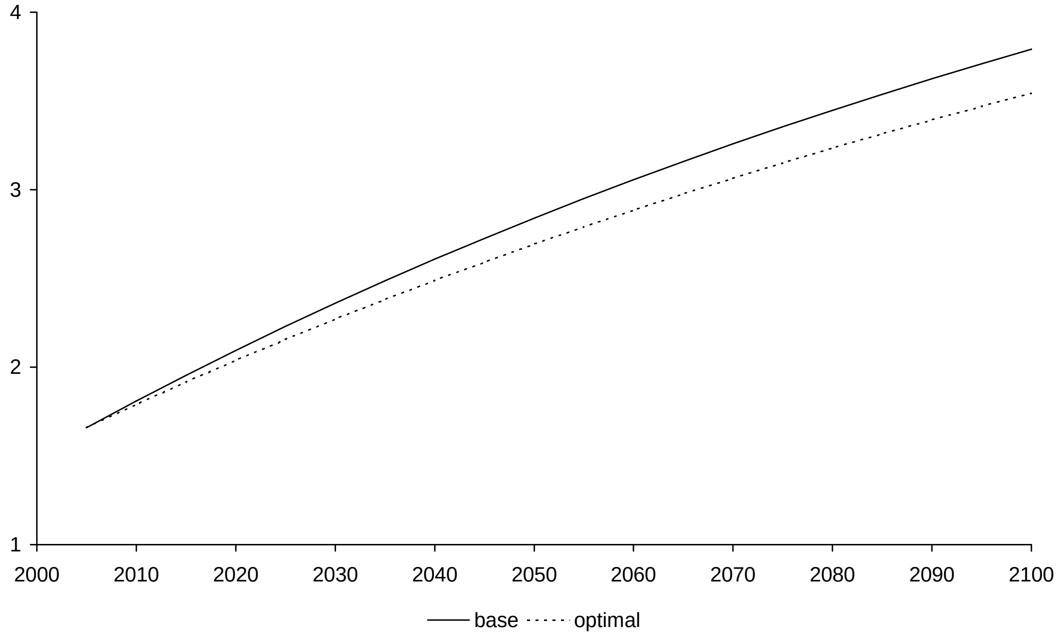


Table 5.2 Comparison optimum relative to basecase in 2105

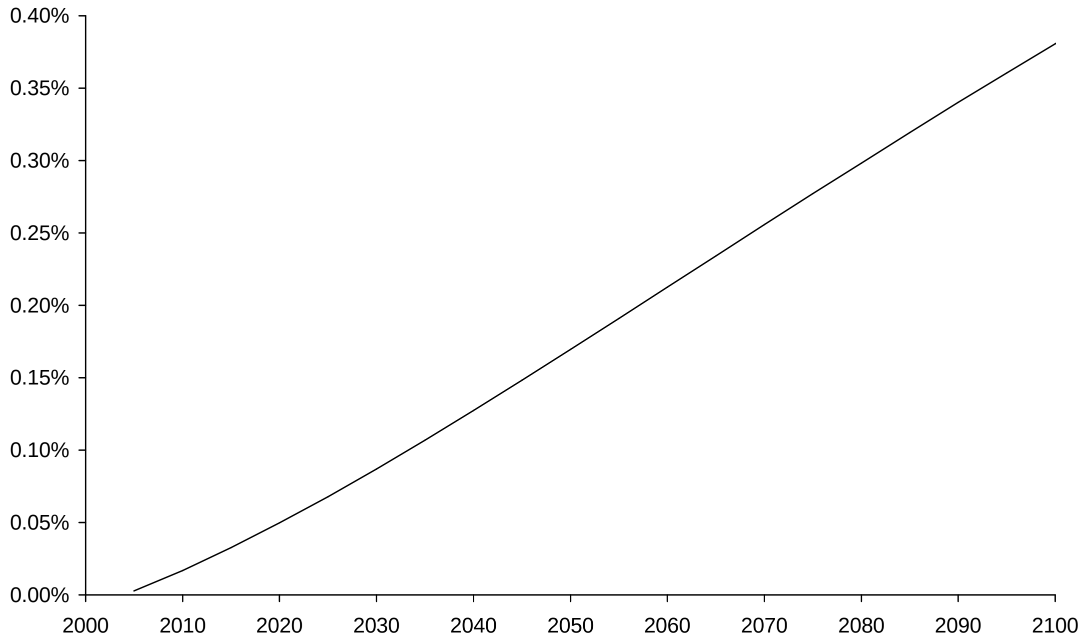
	Gamma	DICE-1999[a]	DICE-2007[b]
emissions (%)	– 14	– 11	– 43
stock of CO_2 (%)	– 6	– 4	– 15
temperature (^{o}C)	– 0.3	– 0.1	– 0.5

[a] Nordhaus and Boyer (2000)
[b] Nordhaus (2008)

optimal scenario (with non-constant emission control rates) of Nordhaus and Boyer (2000), whereas the 2007-revisions result in a more ambitious climate policy (see Table 5.2). The finding that optimal climate policy only has a small impact on global warming is typical for Nordhaus-type of models. Nordhaus (1994, p. 87) provides three reasons for this result. First, whereas the impact of global warning on output is relatively small, the costs of temperature reduction rise sharply with the emission control rates. Second, emission flows (8.6 billions tons in 2000) are small relative to the existing, persistent stocks of greenhouse gasses (784). Third, the relation between temperature and the stock of greenhouse gasses is logarithmic, implying that the first reductions in CO_2 concentrations only have a minor impact upon temperature. Critical reviewers of Nordhaus add another reason. The use of a relative large discount rate by Nordhaus gives a relative small weight to future benefits of an improved environment. The Stern

2100 (under the assumption of real economic growth of 2% per year).

Figure 5.3 Optimal GDP relative to basecase



review favours a near-zero discount rate, which justifies a more ambitious climate-change policy. Nordhaus (2008, Chapter IX) reacts to these discount issues. He argues that the combination of a 0.1% discount rate with a unitary-elastic utility function results in implausible low interest rates of 2%.[23] This low return to capital justifies a sharp, immediate emissions reduction. However, when the elasticity of marginal utility is calibrated on realistic interest rates[24], the optimal rate of emissions reduction becomes very similar to the finding of the DICE-model.

Finally, Figure 5.4 shows the intergenerational welfare effects of the optimal policy (expressed as an % of remaining lifetime income). The welfare effects reflect the costs of higher lump-sum taxes and the benefits from a higher TFP growth. The equivalent variations are only negative for the current, old generations and rising in the year of birth. Current generations suffer from the financing burden while future generations benefit more from the gradual fall in temperature. The figure also presents a similar pattern for real lifetime income.

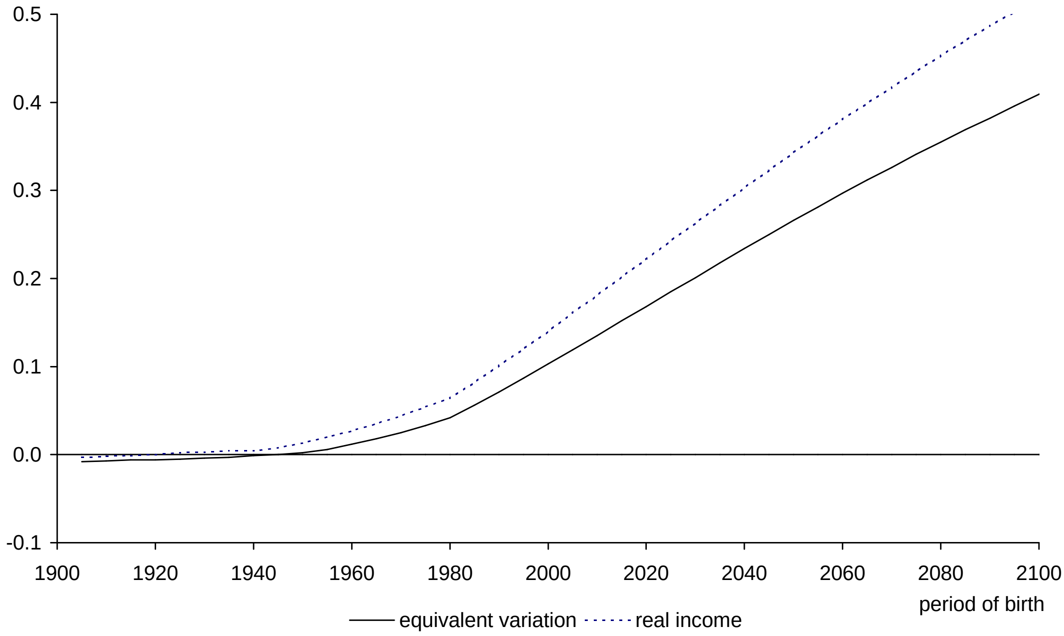
5.4 Financing with lump-sum taxes

In the following subsections we focus on the intergenerational distribution, starting in the social optimum. We simulate an extra reduction of emissions by 5%, starting in 2005 (i.e. ω_e is

[23] $r = \rho + \sigma g = 0.1 + 1 \times 1.8 = 1.9$; see the discussion in note 19.

[24] $\sigma = (r - \rho)/g = (5.2 - 0.1)/1.8 = 2.8$.

Figure 5.4 Effect on welfare (% of remaining lifetime income) and income (%-change from basecase) of optimal emission reduction with lump-sum transfers



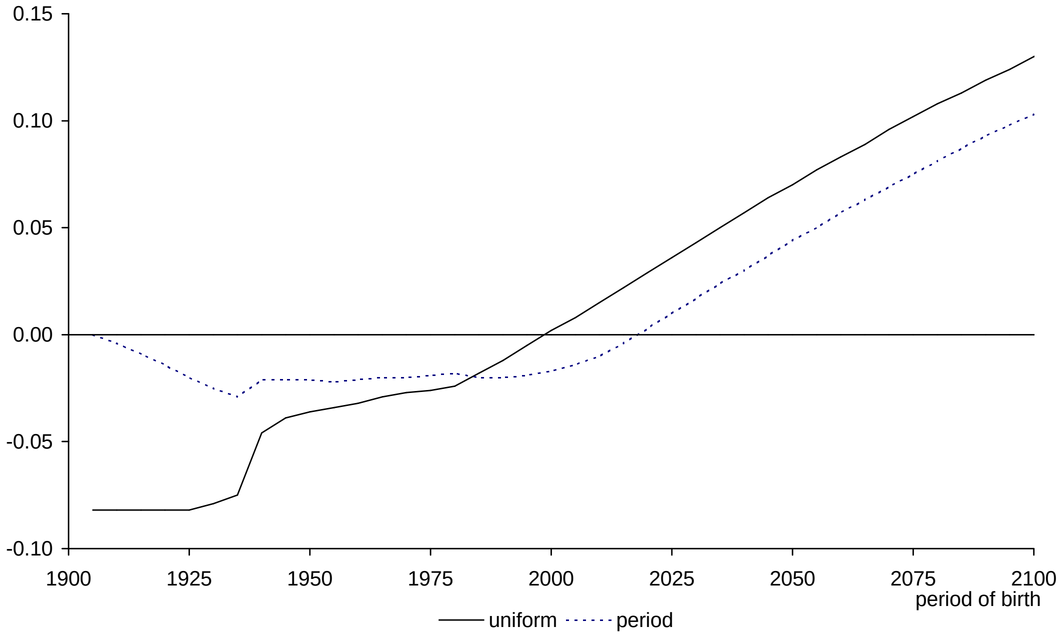
decreased from 0.86 to 0.81).

When financed by an *uniform* increase in lump-sum taxes, all generations born before 2000 suffer from a welfare loss (Figure 5.5). In particular, the current, retired generations lose due to the large weight of lump-sum taxes in remaining non-labour income. Slowing down the accumulation of greenhouse gasses and the resulting global warming generates welfare gains for future generations.

The combination of uniform financing and the gradual realization of benefits imposes a disproportional burden on current generations. Welfare losses of current generations can be reduced by shifting the financing costs more to future generations. We simulate a *period-specific* introduction of lump-sum taxes. The tax is not imposed in the first period, leaving utility of the oldest, existing generation unaffected. In the subsequent 7 periods, the lump-sum tax is raised to its final value in 7 equal steps. Figure 5.5 shows that this time schedule leads to a more even distribution of welfare losses over current generations. The postponed increase has to be compensated by higher lump-sum taxes in the future (+60% as from 2040). As a consequence, welfare gains are smaller for generations born after 1985.

At this stage, we have to stress the many uncertainties relating to climate change simulations. We are using a simple, deterministic model, for which the coefficients are set at mean values. In this way we might pay insufficient attention to extreme events that cause large damages. Since risk averse agents suffer large welfare losses of this type of events, optimal abatement policies might be based more on worst case scenarios, instead of central scenarios. A crucial parameter in this respect is the so-called climate sensitivity. It is defined as the equilibrium change in mean temperature that results from a doubling of the CO_2 concentration. Specification (5.4) implies a climate sensitivity of 2.9^{o}C. According to the IPCC's fourth assessment report, this sensitivity likely ranges between 2^{o}C and 4.5^{o}C (see van Vuuren et al. (2009)). We have re-simulated the scenario with uniform transfers using the upper bound of 4.5^{o}C. With this setting, emissions are optimally reduced by 21%, which reduces the temperature increase in 2100 from 5.4^{o}C to 4.8^{o}C. Deviation from the optimal policy in this case clearly has larger welfare consequences in Figure 5.6, but the pattern of losing and gaining generations remains very similar as before. Since this study focuses on small deviations from a social optimum, the parameter uncertainty plays a minor role in analyzing intergenerational distribution effects.

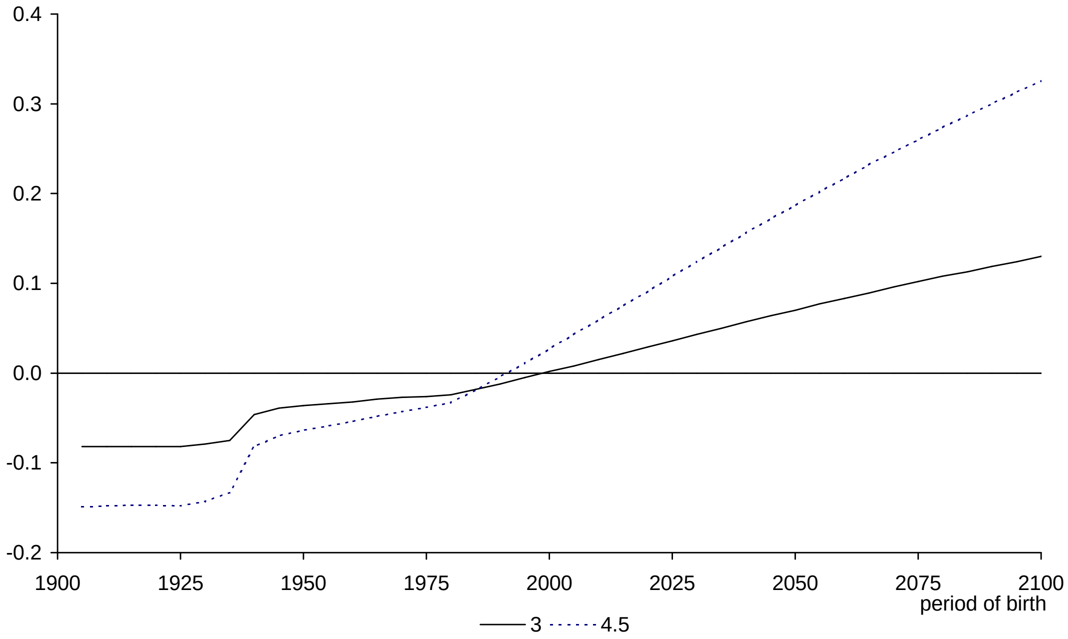
Figure 5.5 Equivalent variations (% of remaining lifetime income) from emission reduction by 5%, financed by lump-sum transfers



5.5 Financing with labour taxes

When the reform is alternatively financed by the distortionary, labour tax, the optimal cut in emissions is hardly affected ($\omega_e = 0.86$). Figure 5.7 presents the welfare effects following an additional emission reduction by 5%, financed by an immediate and permanent increase of the labour tax rate by 0.04%. The financing burden now mainly falls on generations featuring a large

Figure 5.6 Equivalent variations (% of remaining lifetime income) from emission reduction by 5%, for different values of the climate sensitivity, financed by uniform lump-sum transfers



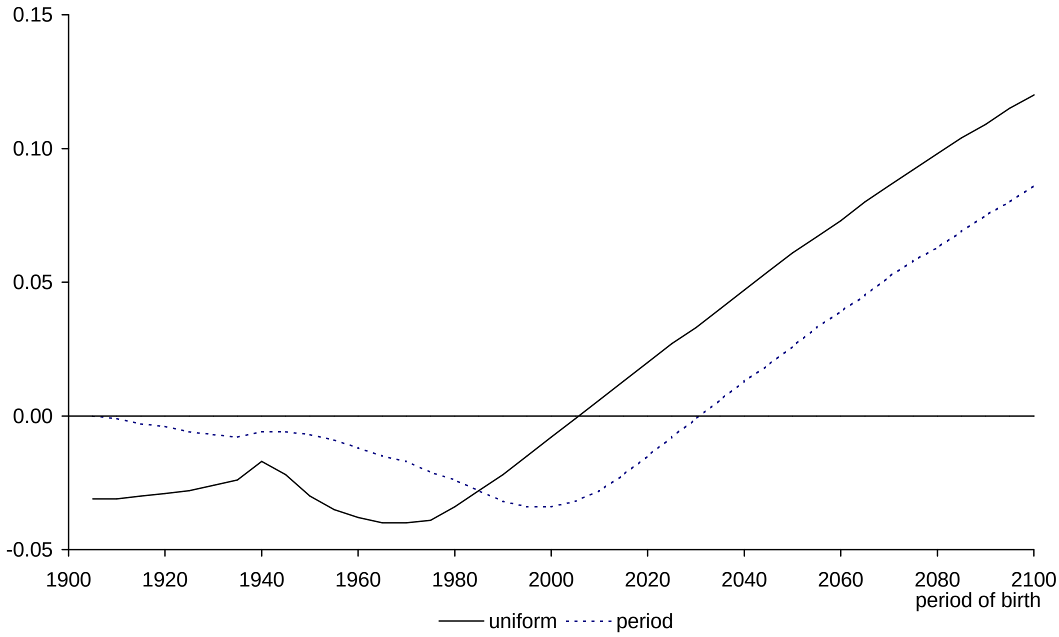
labour tax base, i.e. the current, working generations. Retired generations have to pay more taxes on public pensions. A more gradual implementation of the tax increase (as described before) shifts the welfare losses to future generations. In this case, the tax rate ultimately increases by 0.07%. In the uniform scenario the first generation that gains from the reform is born in 2010. With period-specific taxes, the critical year of birth shifts by 25 years.

5.6 Transfers with indexing

In the previous simulations, we specified that transfers, including public pensions and health care expenditures, grow at the exogenous rate of technological progress. In other words, the transfer recipients do not benefit from the wage growth caused by the endogenous improvement of TFP. In this subsection, the transfers are linked to the total wage growth (as presented in Figure 5.8).

The effect of the indexing option on real income identifies the generations who receive more (or less) than they pay for the higher indexed transfers. From Figure 5.9 follows that in the case with uniform transfers, indexing harms further the income position of current generations since they have to contribute to the growing future transfers. The benefit principle applies better in the case with period-specific transfers as the indexing costs are more incurred by the generations that receive them (see Figure 5.10). Figure 5.11 confirms for the case with uniform labour taxation the pattern that the same generations pay for the more generous transfers, next to the

Figure 5.7 Equivalent variations (% of remaining lifetime income) from emission reduction by 5%, financed by labour taxes



more ambitious abatement policy. When the rise in labour taxes is gradually implemented, the income of current, retired generations even improves in Figure 5.12 since they are exempted from higher taxes. The distortionary nature of the financing tax is reflected by the large deterioration in incomes of the other generations.

Figure 5.8 Increase in wage rate after reduction in emissions by 5% (uniform transfers

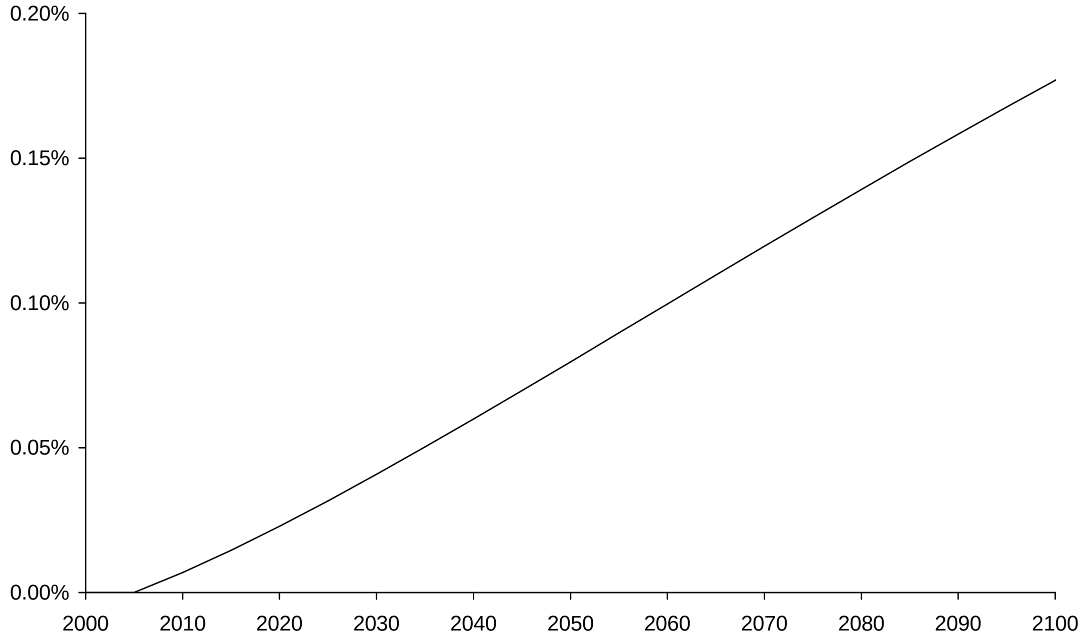


Figure 5.9 The %-change in lifetime income after emission reduction by 5%; uniform lump-sum taxes

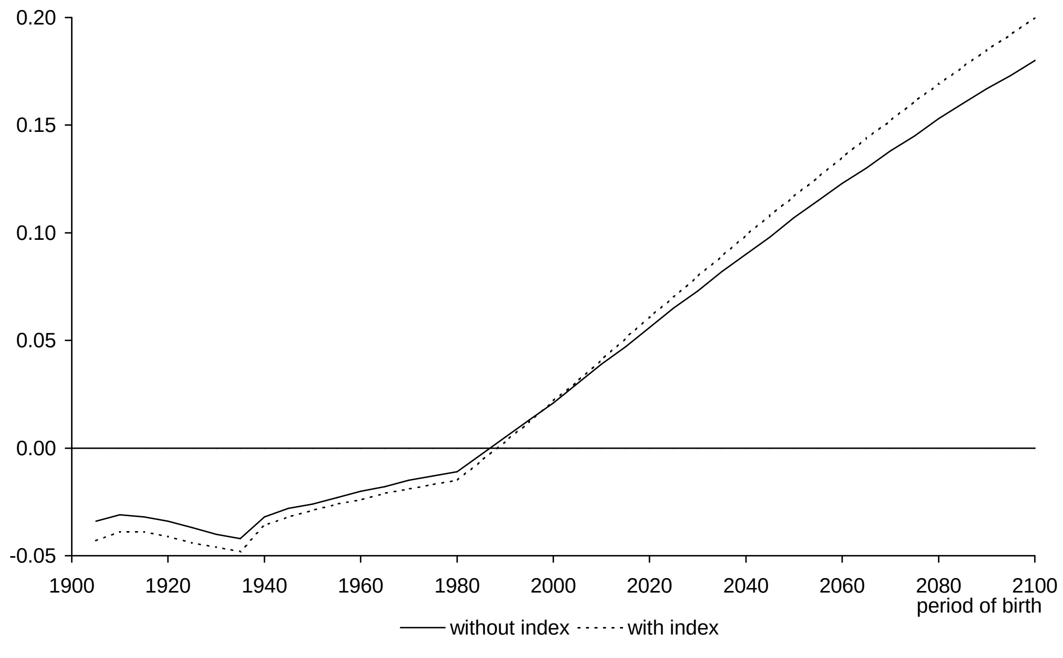


Figure 5.10 The %-change in lifetime income after emission reduction by 5%; period-specific lump-sum taxes

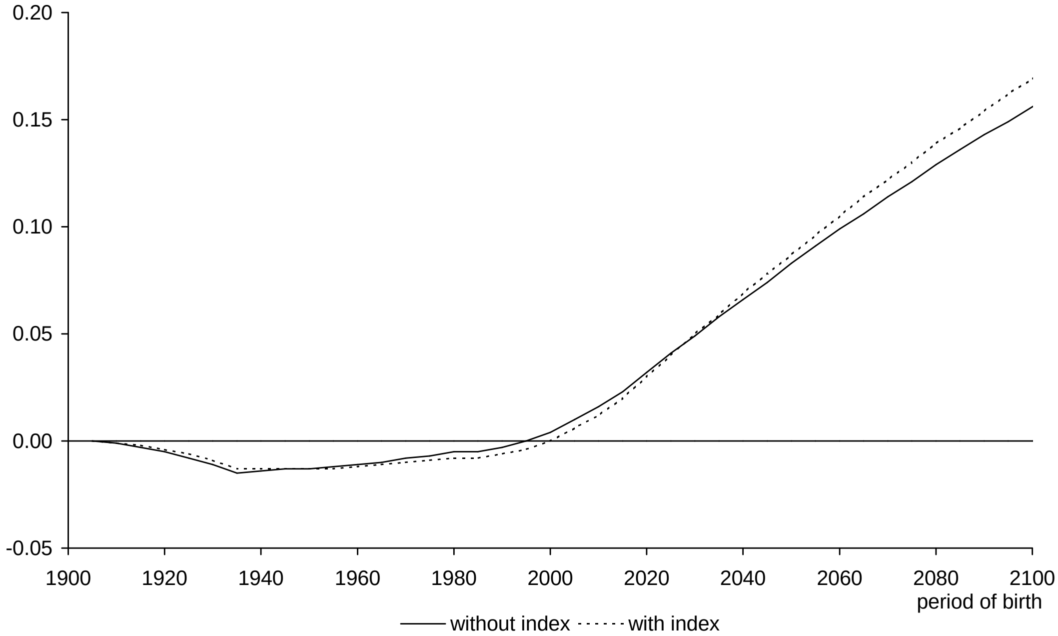


Figure 5.11 The %-change in lifetime income after emission reduction by 5%; uniform labour taxes

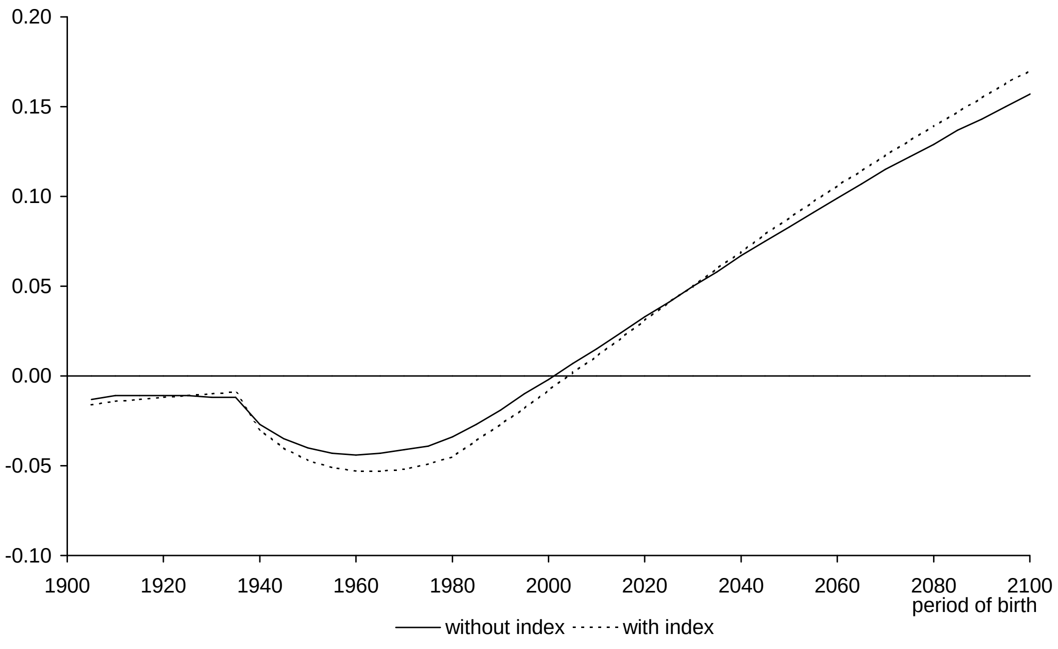
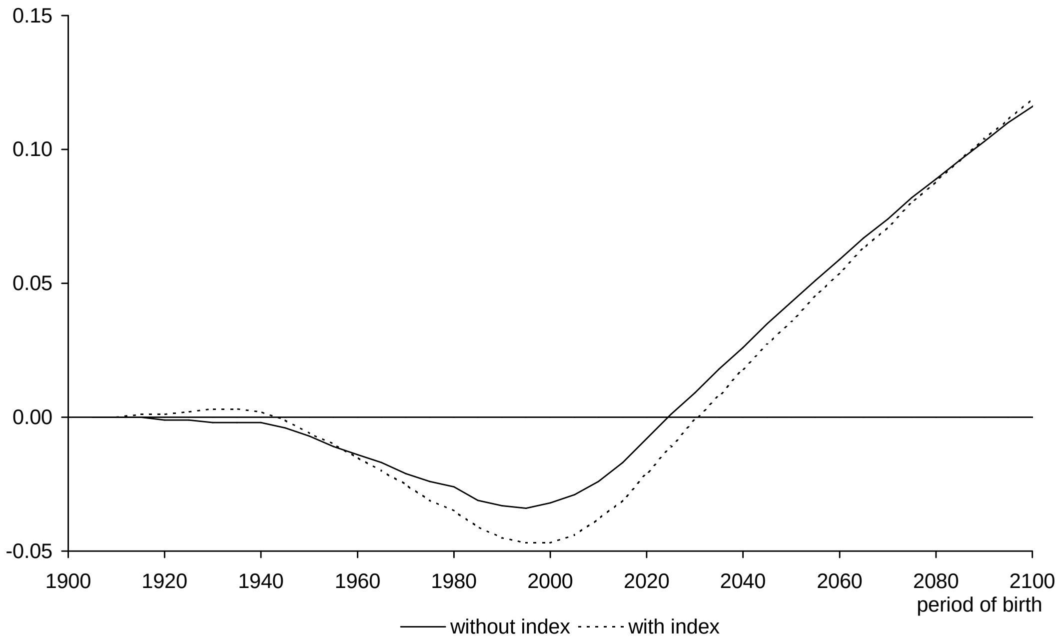


Figure 5.12 The %-change in lifetime income after emission reduction by 5%; period-specific labour taxes



6 Conclusions

We summarize our findings on the three distributional issues identified in the introduction. We focus on the relevant scenarios with labour tax financing.

First, when the investment is financed by an uniform increase in the labour tax, we find the expected pattern for the welfare effects: current generations bear the costs while the future generations benefit from the income gains.

Second, financing costs are shifted to future generations by using more debt financing. We experiment with simple schemes, in which the tax increase is postponed to spare current, older generations. When wages only improve gradually, benefitting generations can be better distinguished from losing generations by a simple taxation scheme. Therefore, in the case of educational and environmental investments, debt financing is effective in generating a more equal distribution over the generations.

Third, in the reference scenarios public transfers and health care expenditures are not linked with the wage growth caused by the expansion of public investment. In alternative scenarios we illustrate the impact of indexing on lifetime income. We find that in the case with uniform financing, current, older generations only benefit from indexing when the investment improves wages rapidly. When wages only increase gradually in the future, the income distribution is hardly affected by indexing.

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