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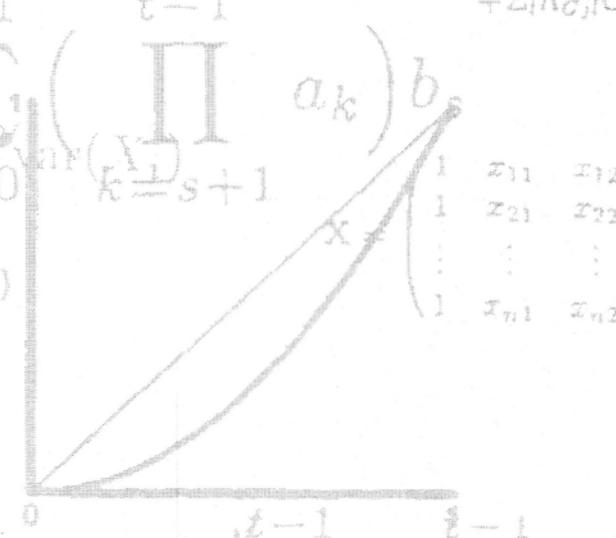
Discussion Papers

Environmental Tax Reform and Producer Foresight An Intertemporal Computable General Equilibrium Analysis

Brita Bye

$$+ 2 \sum_{i>j} \sum_{j=1} \text{cov}_0(X_i, X_j)$$

$$\text{var}\left(\sum_{i=1}^n a_i X_i\right) = \sum_{i=1}^n \sum_{s=0}^{t-1} a_i^2 \text{var}(X_i) + \sum_{i=1}^n \sum_{s=0}^{t-1} \left(\prod_{k=s+1}^{t-1} a_k\right) b_i$$



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Environmental Tax Reform and Producer Foresight: An Intertemporal Computable General Equilibrium Analysis

Abstract:

This paper analyses the non-environmental welfare costs of an environmental tax reform using a numerical intertemporal general equilibrium model for the Norwegian economy. The tax reform is revenue neutral such that an increase in the carbon tax rate is accompanied by a reduction in the payroll tax. By exploiting existing tax wedges in the labour market and between consumption and saving, the total non-environmental welfare effect of the tax reform is positive. The paper also analyses how imperfect price expectations for the investors in real capital influence the total welfare costs of the tax reform. The welfare effect is the same due to exploitation of initial distortions, but the transitional dynamics are quite different in the two paths.

Keywords: Dynamic general equilibrium analysis, Environmental tax reforms, Imperfect expectations.

JEL classification: C68, D58, D60, D90, H20, Q43.

Acknowledgements: I am grateful to Taran Fæhn, Erling Holmøy, Torbjørn Hægeland, Diderik Lund and Knut Moum for useful suggestions and comments on this or an earlier draft, and to Birger Strøm for excellent computer assistance. The Norwegian Research Council has provided financial support through the SAMMEN programme.

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1 Introduction

By increasing environmental taxes to curb pollution and using the revenues to cut distortionary taxes on income, it may be possible to obtain a “double dividend”, i.e. not only a better environmental standard, but also a less distortionary tax system, thereby improving economic welfare. Goulder (1994) and Christiansen (1996) discuss different interpretations and definitions of the term “double dividend”, and give an overview of the literature.

In recent years there has been increasing concern about the potential contributions of carbon dioxide (CO_2) emissions to the greenhouse effect and global climate change. A carbon tax, a tax on fossil fuels — coal, oil, crude oil and natural gas — in proportion to their carbon content, will internalise these externalities associated with fossil fuel combustion. It is clear that the introduction of a carbon tax combined with changes in other taxes, will through their effects on prices and costs, have long term welfare effects through changing the rate of capital accumulation and economic growth. Hence, the suitable model framework is intertemporal general equilibrium models which generate optimal consumption-savings paths. Intertemporal general equilibrium analyses of such environmental tax reforms for the U.S. are presented in Jorgenson and Wilcoxon (1993), Goulder (1995) and Bovenberg and Goulder (1995).

Recent Norwegian analyses of environmental tax reforms as Brendemoen and Vennemo (1994), Håkonsen and Mathiesen (1995) and Mathiesen (1996)¹, are all based on static general equilibrium models with exogenous stocks of real and financial capital. Hence, these analyses only consider reallocation effects of the tax reforms, given the resource constraints, and do not consider the effects of the tax reforms on the accumulation of real and financial capital. In addition the models allow for terms of trade gains from domestic tax increases, a property which is much criticised, see e.g. Norman (1990). There is a need for additional analyses which take into consideration the dynamic effects of environmental tax reforms and where the tax reforms do not give rise to terms of trade gains. The analyses by Jorgenson and Wilcoxon (1993), Goulder (1995) and Bovenberg and Goulder (1995) all use intertemporal models, but a small open economy as the Norwegian behaves and reacts differently under tax reforms, compared to a large economy as the U.S. This demands another model specification which implies that analyses on the Norwegian economy will give additional insight into measuring and interpreting the effects of environmental tax reforms. Compared to these U.S. analyses, the small open economy framework implies that the interest rate and prices on export are given in the world market. The assumption of internationally mobile capital implies that net savings in financial capital may be uncorrelated with net investment in real capital. In addition the tax rates in Norway are generally higher. Especially the marginal excess burden of labour taxation is high, see Brendemoen and Vennemo (1996). All these elements may contribute to give other welfare implications of environmental tax reforms than the above cited U.S. analyses. The analysis in this paper is also based on the tax

¹See also the Ministry of Finance (1996).

system of the 1992 tax reform², which especially implied approximate neutrality between the taxation of real and financial capital, and lower average marginal tax rate on wage income.

This paper analyses the total non-environmental welfare costs of an increase in the carbon tax combined with a reduction in the payroll tax by using an intertemporal disaggregated general equilibrium model for the Norwegian economy. The model pictures a small open economy since the domestic producers and consumers are assumed to be price takers in the world market, and the interest rate is exogenously given from international financial markets. But the producers are assumed to execute some market power in the domestic market.

The total welfare effect of the tax reform measured as the change in total discounted utility from a reference path, is positive, due to exploitation of existing tax wedges, especially in the labour market and between consumption and saving. The paper also examines whether the welfare effect is sensitive to expectation formation. The welfare gain is approximately the same with imperfect expectations equal to unchanged expectations from the reference path, but the transitional paths are quite different in the two simulations. The reason for these differences is the negative effect of the tax reform on the domestic producer prices, implying negative capital gains in the user cost of capital along the transitional path with perfect foresight, while the negative capital gains are absent with unchanged expectations. This initialises reallocation of saving from financial to real capital along the path, increasing net foreign debt, which induces a welfare loss. This negative effect is though outweighed by the positive welfare effect of higher employment, especially in the announcement period, but also in the stationary solution.

The paper is organised as follows: Section 2 gives some comments on the literature concerning the double dividend hypothesis and the possibilities for obtaining welfare gains through environmental tax reforms. Section 3 describes the model framework, data and important parameter values. In section 4 the simulations of the environmental tax reform are presented and interpreted, including the simulation with imperfect expectations. Section 5 concludes.

2 Tax reforms and the double dividend hypothesis

The recent literature on environmental taxation and the double dividend in a second best economy with other distortionary taxes and a revenue requirement, gives in general little support for the double dividend hypothesis, see e.g. Bovenberg and de Mooij (1994) and Bovenberg and van der Ploeg (1994a,b). However, an existing tax system is in general far from being in a second-best situation, such that there may be a potential for welfare improvements by introducing an environmental tax reform. Bovenberg and de Mooij (1996) extend these previous analyses by exploring how inefficiencies in the initial tax system affect

²See Holmøy and Vennemo (1995) for a CGE analysis of the tax reform.

the potential for a double dividend. It is possible to obtain a double dividend if the tax system is made more efficient from a non-environmental point of view, and the carbon tax does not erode such positive tax shifting effects between e.g. labour and capital used as input factors in the production in the economy. Hence, by extending the model framework to incorporate initial distortions, the possibilities for obtaining a double dividend of an environmental tax reform are larger.

The literature on the marginal costs of public funds (MCF) indicates that there are substantial efficiency costs of existing taxes. Brendemoen and Vennemo (1996) are using a static general equilibrium model for Norway and calculate the MCF for labour income taxation to 1.76, which implies that the marginal efficiency cost is 76 percent.³ According to Brendemoen and Vennemo (1996), the MCF of a carbon tax is 0.82 indicating that there should be a large potential for welfare gains of increasing the carbon tax and reducing the taxes on labour income. This is supported by Håkonsen and Mathiesen (1995) and Mathiesen (1996) who are using a static general equilibrium model for Norway to analyse the effects of a revenue neutral increase in the carbon tax.⁴ According to Håkonsen and Mathiesen (1995) there may be a small welfare gain from imposing a carbon tax of 25-100 \$ per ton CO_2 which reduces the CO_2 emissions by 5-15 percent, and rebating the tax revenue by reducing the payroll tax.

Neither Bovenberg and Goulder (1995) nor Goulder (1995) obtain a double dividend, independently of how the tax revenue is rebated, but the welfare loss is smallest by rebating through the payroll tax. Jorgenson and Wilcoxon (1993) obtain a double dividend by rebating the carbon tax revenue through lowering the capital income tax, but find it impossible to obtain the same by reducing the labour income tax. This reflects the higher marginal excess burden of capital taxation compared to labour income taxation in the U.S. As is also pointed out by Jorgenson and Wilcoxon (1993) and Bovenberg and Goulder (1995), fossil fuels are used as input in the capital producing industries, and the carbon tax implies higher capital costs, so that reducing the capital taxation may be more beneficial than reducing the labour taxation. Compared to Goulder (1995) and Bovenberg and Goulder (1995) the positive effect by Jorgenson and Wilcoxon (1993) of reducing the capital income tax, may be explained by differences in the mobility of capital in the two model frameworks. Jorgenson and Wilcoxon (1993) assume full capital mobility, while Goulder (1995) and Bovenberg and Goulder (1995) assume that capital is immobile between different sectors, which implies that the elasticity in capital demand is substantially larger in Jorgenson and Wilcoxon (1993).

³Ballard, Shoven and Whalley (1985) and Jorgenson and Yun (1990) calculate a MCF for labour income taxes in the range of 1.2 - 1.4 on U.S. data, which is substantial lower than the Norwegian analyses. Jorgenson and Yun (1990) using an intertemporal model get a higher MCF for capital income taxes than for labour income taxes.

⁴See also Ministry of Finance (1996).

3 The model

The model is a disaggregated intertemporal general equilibrium model for the Norwegian economy. Since the model gives a detailed description of the structure of production and consumption in the Norwegian economy, and has especially emphasised the modelling of demand and supply of energy commodities, it is well designed for analysing the effects of environmental tax reforms. The model of producer behaviour is designed to avoid two well known problems when building disaggregated general equilibrium models of open economies. If the domestic producers are assumed to be price takers in the world market, the long run equilibrium will be characterised by specialisation of the industries competing in the world market. The existence of a large number of heterogeneous industries implies that specialisation of the industries competing in the world market would be a bad approximation of the industry structure in the Norwegian economy. On the other hand to assume that the domestic producers in a small open economy as the Norwegian have market power in the world market, implies that there are possibilities for unrealistic terms of trade gains. This model incorporates both the small open economy assumption of given world market prices, and avoids specialisation by assuming that the producers are price takers in the export markets, while they have market power in the domestic market. Empirical analyses of Norwegian producer behaviour support the existence of some market power, see e.g. Klette (1994) and Bowitz and Cappelen (1994). The model has 41 private and 8 governmental production activities, which are listed in appendix A, and 17 consumer goods, see figure 3.2. This section briefly outlines some of the important features of the model.

3.1 Producer behaviour

The model of producer behaviour is described in detail by Holmøy (1996). Producer behaviour in an industry is generally specified at the firm level. All producers are considered as price takers in the world market, but have monopoly power in the home market. Each firm allocates the production, X , between the domestic market, X^H , and the world market, X^A , when maximising profit. Abstracting from net subsidies, profit, R , in each firm is given by

$$(1) \quad R = B^H X^H + P^W X^A - C(X),$$

which is maximised w.r.t. the domestic producer price, B^H , and the deliveries to the world market, X^A , given the following constraints

$$(2) \quad X = \left[(X^H)^{(1+1/\sigma^{HA})} + (X^A)^{(1+1/\sigma^{HA})} \right]^{\frac{1}{1+1/\sigma^{HA}}},$$

$$(3) \quad C(X) = P^S \left[\frac{X}{\gamma} \right]^{\frac{1}{\rho}} + C^F,$$

$$(4) \quad X^H = (B^H)^{-\sigma^{HH}} \beta.$$

For convenience the firm label i is suppressed. Equation (2) is the transformation frontier. P^W is the world market price and σ^{HA} is the elasticity of transformation between deliveries to the domestic and the world market. Equation (3) is the cost function. There are decreasing returns to scale in the variable costs, $P^S \left[\frac{X}{\gamma} \right]^{\frac{1}{\rho}}$. P^S is the price of the input aggregate, γ is the firm specific productivity parameter and ρ is the elasticity of scale, $0 < \rho < 1$. The average cost curve is downward sloping around producer equilibrium due to fixed costs, C^F . Each domestic firm produces a different variety of the composite industry product. Equation (4) is the subjective demand function for the firm, where σ^{HH} is the subjective demand elasticity and β is regarded as a constant by the producer but is endogenous in the model. The market structure is assumed to belong to the Chamberlanian large group case. According to Holmøy (1996) the following parameter restriction has been imposed

$$\sigma^{HA} = \frac{\rho}{1 - \rho}.$$

This restriction implies that the technology becomes additively separable in export- and domestic deliveries. In Holmøy (1996) it is shown that following the profit maximisation, the deliveries to the domestic market and the export markets are given by

$$(5) \quad X^H = \left[\frac{B^H \rho \gamma}{m^H P^S} \right]^{\sigma^{HA}} \gamma,$$

$$(6) \quad X^A = \left[P^W \frac{\rho \gamma}{P^S} \right]^{\sigma^{HA}} \gamma,$$

where m^H is the mark-up factor. X^H , X^A and B^H are determined by equations (5) and (6), and the true demand function (see Holmøy (1996)).

The ideal market price index of the composite of domestic varieties, P_D^H , is derived from a CES preference structure, often referred to as Spence-Dixit-Stiglitz (SDS) preferences.

$$(7) \quad P_D^H = (1 + t) \left[\sum_{i=1}^N (B_i^H)^{(1-\sigma^{HH})} \right]^{\frac{1}{1-\sigma^{HH}}}$$

The firm's subjective demand elasticity, σ^{HH} , is assumed to be equal to the elasticity of substitution between the different domestic varieties, Holmøy (1996). The indirect tax rate, t , is common to all domestic and imported varieties. The ideal price index of the composite of a fixed number of imported varieties P_D^I is also derived from a SDS preference structure. Since all the variety prices are exogenous because Norway is assumed to play a negligible role in the world market, the pre-tax c.i.f. price index B_D^I can be treated as exogenous. The exchange rate is the numeraire.

$$(8) \quad P_D^I = (1 + t) B_D^I$$

The ideal price index of the composite good which is used for domestic investment and consumer purposes, is given by the following CES-aggregate

$$(9) \quad P_D = (1 + t) \left[(B_D^H)^{(1-\sigma^{HI})} + (B_D^I)^{(1-\sigma^{HI})} \right]^{\frac{1}{1-\sigma^{HI}}},$$

where σ^{HI} is the elasticity of substitution between the domestic composite good and the composite import good. In (9) symmetric preferences are imposed for notational simplicity.

An industry consists of N heterogeneous firms which are ordered according to their productivity levels such that firm 1 is the most efficient one. The differences in the productivity levels are assumed to follow a simple exponential structure such that it is possible to derive exact closed form solutions for the industry aggregates as the price index given in equation (7), see Holmøy (1996). The entry-exit condition for the marginal firm N (the number of firms, N , is endogenous) requires that the after tax pure rents equal the fixed costs.

$$(10) \quad (1 - t^D) \left[B_N^H X_N^H + P^W X_N^A - PK^P K_N^P - C(X) \right] = C_N^F$$

where t^D is the effective profit tax rate, K_N^P is the stock of structures and C_N^F are other fixed costs. The dynamics due to intertemporal behaviour is captured by the user cost of structures (dwellings, non-residential buildings and other structures), PK^P . The user cost formulas are derived from a standard arbitrage condition, see Holmøy, Nordén and Strøm (1994) for a detailed description. Abstracting from several details in the tax code and the risk premium, the user cost of capital can be written as

$$(11) \quad PK^k = \left[\frac{r(1 - t^D) + d_{+1}^k}{1 - t^D} \right] \left[\frac{1}{1 + r(1 - t^D)} - \frac{t^D a^k}{a^k + r(1 - t^D)} \right] PJ^k,$$

where $k = M$ (Machinery), T (Transport equipment) or P (Structures). r is the world market interest rate, d_{+1}^k is the net rate of economic depreciation which includes perfectly foreseen capital gains on asset k , a^k is the rate of capital allowances of asset k and PJ^k is the purchaser price index for capital good k . d_{+1}^k is given by

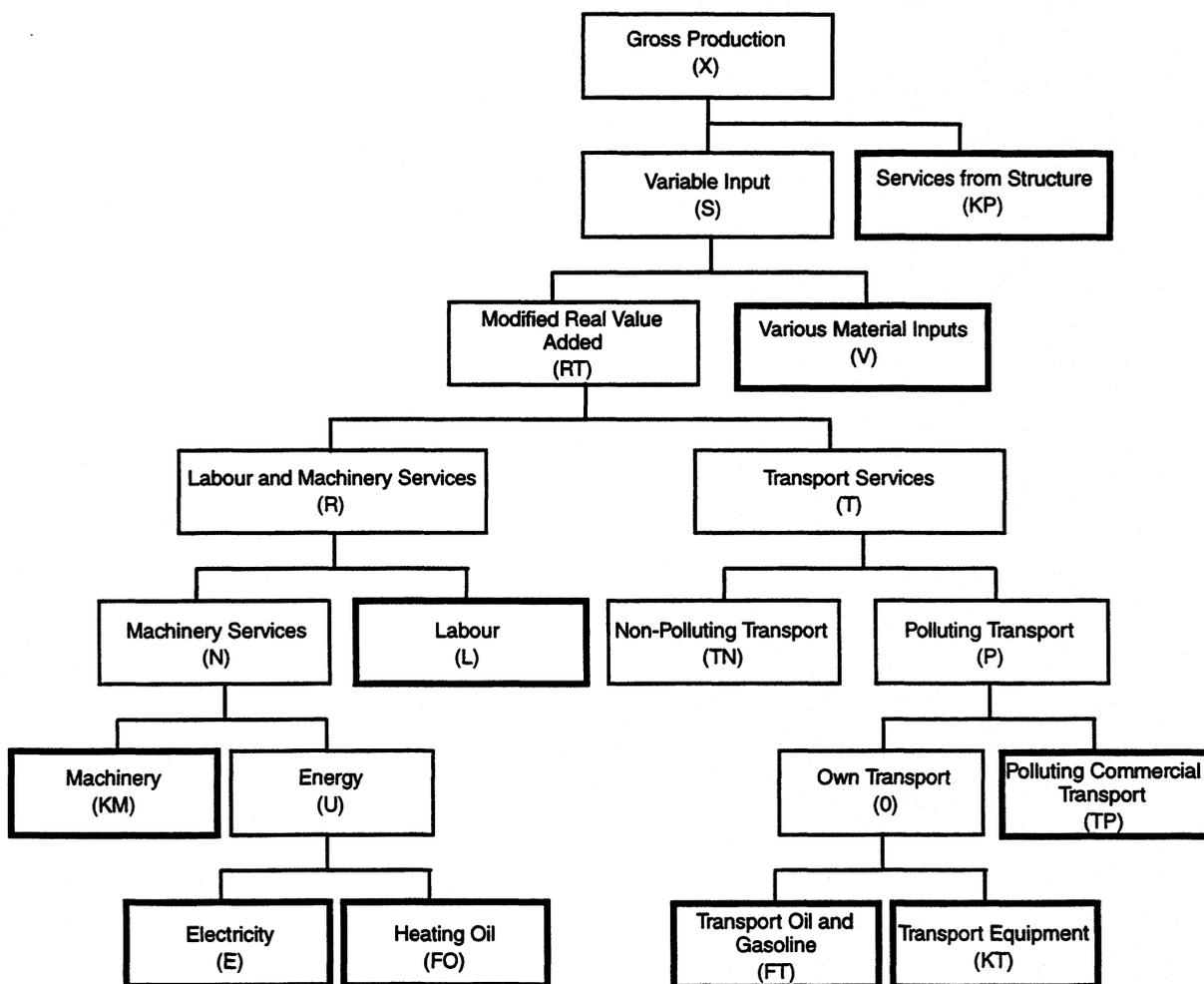
$$(12) \quad d_{+1}^k = \delta^k - (1 - \delta^k) \left(\frac{PJ_{+1}^k - PJ^k}{PJ^k} \right)$$

where δ is the rate of physical depreciation and PJ^k is the price of the capital good. The tax code in the model represents the system of the 1992 tax reform, whose intention was to give approximate neutrality between the effective tax rates of the different capital incomes. However, with significant positive or negative capital gains, the effective rate of capital taxation will deviate from the neutral rate.

3.2 Production structure

The structure of the production technology is represented by a nested tree-structure of CES-aggregates given in figure 3.1. The input structure has a detailed description of the use of energy commodities and the demand for polluting and non-polluting transport activities. All factors are completely mobile and malleable.⁵

Figure 3.1. The production structure



⁵Except in the production of electricity, see Holmøy, Nordén and Strøm (1994).

3.3 Household behaviour

Consumption, labour supply and saving result from the decisions of an infinitely lived representative consumer maximising intertemporal utility with perfect foresight. In year t the consumer chooses a path of “full consumption”, F , by maximising

$$(13) \quad U_t = \sum_{s=t}^{\infty} (1 + \rho)^{t-s} \frac{\sigma_F}{\sigma_F - 1} F_s^{\frac{\sigma_F - 1}{\sigma_F}}$$

where ρ is the subjective rate of time preference and σ_F is the intertemporal elasticity of substitution in full consumption. The consumer maximises intertemporal utility subject to an intertemporal budget constraint requiring that the present value of full consumption in all future periods does not exceed total wealth (current nonhuman wealth plus the present value of labour income and net transfers). The demand for full consumption following from the utility maximisation, is given by

$$(14) \quad F_s = \lambda^{-\sigma_F} \left[\frac{1 + r(1 - t^D)}{1 + \rho} \right]^{\sigma_F t} PF_s^{-\sigma_F},$$

where r is the world market interest rate on financial wealth, t^D is the tax rate on capital income, λ is the marginal utility of wealth and PF is the ideal price index of full consumption. Full consumption is a CES-composite of material consumption, C , and leisure, LE . The corresponding ideal price index is given by

$$(15) \quad PF_s = \left[\alpha_C PC_s^{(1-\sigma_C)} + (1 - \alpha_C) \left(\frac{PLE_s}{1 + g} \right)^{(1-\sigma_C)} \right]^{\frac{1}{1-\sigma_C}},$$

where PC is the price index of material consumption and PLE is the price of leisure measured in efficiency units such as labour, implying that the price of leisure must be adjusted with g , the factor augmenting technical change. σ_C is the elasticity of substitution between material consumption and leisure and α_C is the intensity parameter for material consumption. In each period full consumption is distributed between leisure and material consumption, and the demand functions follow from applying Shepard’s lemma to equation (15).

$$(16) \quad C_s = \alpha_C \left(\frac{PC_s}{PF_s} \right)^{-\sigma_C} F_s$$

$$(17) \quad LE_s = (1 - \alpha_C) \left(\frac{PLE_s / (1 + g)}{PF_s} \right)^{-\sigma_C} F_s$$

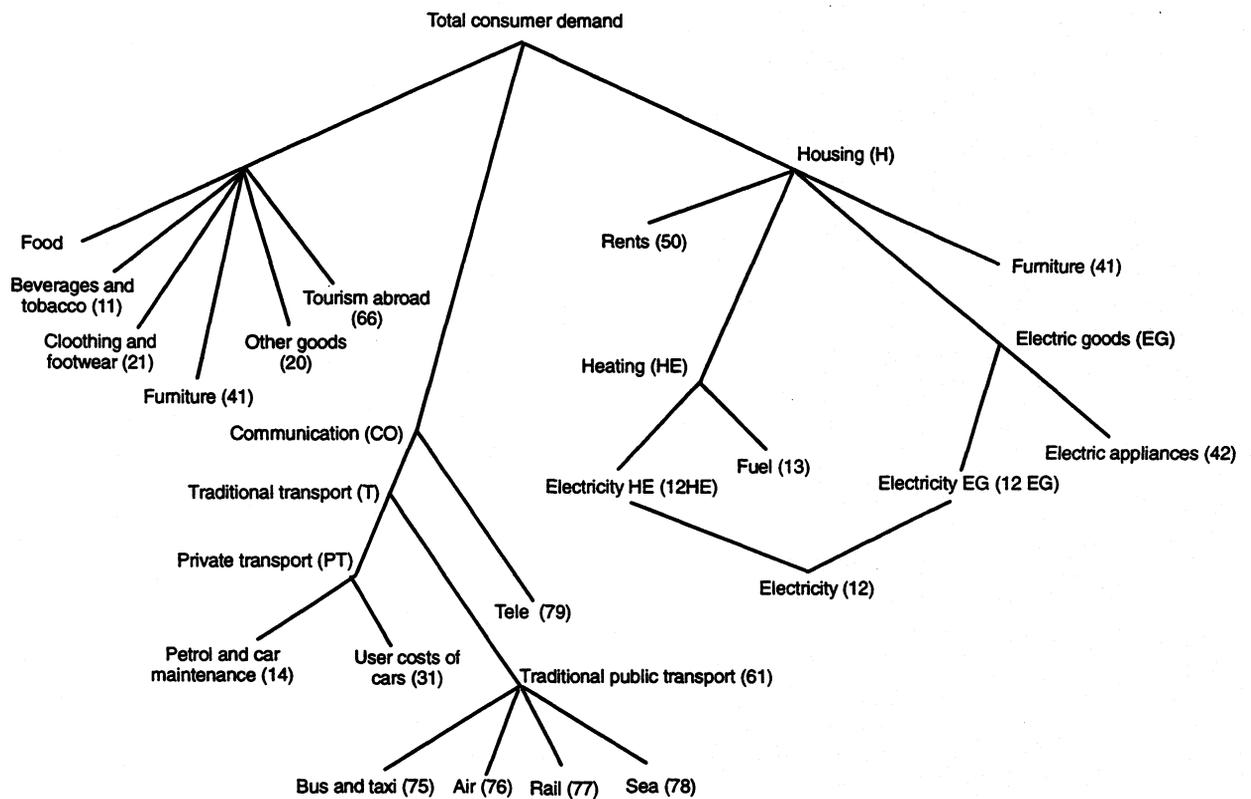
Then total labour supply L is determined by

$$(18) \quad L = T - \frac{LE}{1 + g}.$$

The aggregate endowment of total available time in each period, T , is exogenous and grows at the constant rate, g , which determines the long run (steady state) growth rate of the economy.

The total of material consumption is allocated across N different consumer goods according to a nested OCES (Origin Adjusted Constant Elasticity of Substitution) structure as shown in figure 3.2, Holtmark and Aasness (1995). The OCES demand system implies that the Engel elasticities are not equal to 1, and is designed for studying the effects of environmental tax reforms due to the detailed description of both the use of energy commodities for residential purposes, and the demand for public and private transport services.

Figure 3.2. The demand system



3.4 The government sector

The government collects taxes, distributes transfers, and purchases goods and services from the industries and abroad. Overall government expenditure is exogenous and increases at a constant rate $(1 + g)$, equal to the steady state growth rate of the model. The model incorporates a detailed account of the government's revenues and expenditures. In the policy experiments it is required that the nominal deficit and nominal government spending follow the same path as in the reference case. To meet its cash flow requirements, the government's nominal tax receipts under a policy change must be the same as in the reference case. The carbon tax increase is accompanied by a reduction in the payroll tax, to obtain revenue neutrality in each period.

3.5 Intertemporal equilibrium

Intratemporal equilibrium requires that demand equals supply in all commodity markets and the labour market in each period. Intertemporal equilibrium requires fulfillment of the two transversality conditions; total discounted value of net foreign debt and the value of real capital, respectively, must both be zero. The model is characterised by a path dependent steady state solution, see Sen and Turnovsky (1989) and Bye and Holmøy (1992) for theoretical expositions. A necessary condition for reaching a steady-state solution is

$$(19) \quad 1 + r(1 - t^D) = (1 + \rho)(1 + g)^{\frac{1}{\sigma_F}}$$

which is a “razor's edge” condition since r , t^D , ρ and g are all considered as exogenous. In the analyses, equation (19) is assumed to hold at all points in time. The firms determine their net investments by maximising total discounted value of each firm, given the transversality condition for the value of real capital. The other transversality condition regarding the net foreign debt, is fulfilled by adjusting the optimal level of full consumption for the representative consumer. Numerically, this transversality condition is taken into account in the same way as in Bye and Holmøy (1992); the marginal utility of wealth, λ , in equation (14), will be constant during a transitional path, and is adjusted to find the optimal path of full consumption which also satisfies this transversality condition. The endogeneity of the domestic prices in the model prevents steady state from occurring immediately.⁶

3.6 Data and parameters

The model is calibrated to the 1992 national accounts. For the production functions the elasticities of substitution between machinery and energy, the elasticity of substitution between the energy-machinery aggregate and labour and the elasticity of substitution between the modified real value added and various material inputs (see figure 3.1.), are adjusted to parameters of a Generalized Leontief (GL) cost function estimated on time-series data from

⁶The intertemporal model with perfect foresight expectations is solved by using a Stacked time algorithm developed by Intex Solution Inc., Massachusetts, USA.

the national accounts, see Alfsen, Bye and Holmøy (1996). The elasticities of substitution between electricity and fuel oil in the energy aggregate are based on CES-function estimates on time series data by Mysen (1991). Most elasticities of substitution are smaller than 1, indicating fairly low substitution possibilities at each step in the factor-tree. The elasticities of substitution between non-polluting and polluting transports, and the corresponding elasticities between the modified real value aggregate and various material inputs are set to 0.5, for all industries.

In the model of producer behaviour the elasticities of transformation between deliveries to the domestic and foreign market are set equal to 4. The elasticities of scale are then calibrated to 0.83, given the elasticities of transformation. The elasticities of substitution between domestic products and imported goods, are partly based on estimated parameters (see e.g. Svendsen (1990)), but adjusted upwards such that all are around 4. The elasticities of substitution between the different domestic varieties are calibrated by using the observed values of markups in the industries. For further details of the calibration of the model of producer behaviour, see Holmøy (1996).

For the household model the calibration of the parameters in the complete demand system is based on detailed econometric studies using both micro and macro data, see Holtmark and Aasness (1995). The elasticity of substitution between material consumption and leisure equals 0.25, which is based on estimates of labour supply for married women and men on micro-data by Aaberge, Dagsvik and Strøm (1995). Estimates of the wage elasticity of the labour supply will in general depend on the ratio of hours worked compared to total available time. Hence, the larger this ratio, the larger the wage elasticity of labour supply. The share of leisure in the full consumption aggregate is set equal to 0.51. The intertemporal elasticity of substitution, σ_F , equals 0.3, Steigum (1993). Econometric estimates of σ_F vary considerably between different sources, and 0.3 is in the lower end of the range of the estimated parameters.

4 Simulation results

4.1 Reference case

The effects of policy shocks are measured as deviations from a reference path. The reference path is simulated by keeping all tax rates and other policy variables constant at their benchmark (1992) values. All other exogenous variables as e.g. the world market prices, are also kept constant along the reference path. The benchmark year is not interpreted as a steady state solution. Instead, the model is simulated to obtain a steady state solution, given the assumption of constant exogenous variables. The economy adjusts along a saddle-point stable path, and in the long run the economy reaches a steady state with a constant growth rate and constant relative prices.⁷ The long run growth rate is set to zero. This

⁷The steady-state solution is reached after 40 periods.

simplifies the solution of the model without affecting significantly the marginal multipliers in the model.

4.2 The environmental tax reform

This section analyses to what extent the gross costs of CO_2 taxation measured by welfare changes of a *unilateral* CO_2 tax, are reduced when revenues are rebated through cuts in the payroll tax rate.

In Norway the existing CO_2 tax⁸ differs substantially between different kinds of fossil fuels and between industries. In 1995 the CO_2 tax on gasoline was 360 NOK (approximately 50 USD) per ton CO_2 , nearly twice as much as the CO_2 tax on other fuel-oils and coke and coal. Production and transport of petroleum products are taxed at the same level as gasoline. There is no tax on domestic use of natural gas and on the use of fossil fuels for processing purposes in the production of industrial chemicals, metals and refined oil products. For most of the fossil fuels, especially for gasoline, the CO_2 tax is levied on top of other commodity taxes,⁹ which is also the case in this analysis. The carbon tax implemented in the analysis is equal per ton of CO_2 emissions for every kind of fossil fuel and does not differ between industries or consumers.

In the policy simulation the carbon tax on gasoline is increased to 700 NOK (approximately 100 USD) per ton CO_2 , as for the other kinds of fossil fuels. A carbon tax of 700 NOK gives an increase in the price of heating oils, transport oils and gasoline of 50, 60 and 10 percent respectively. The carbon tax suggested in the Ministry of Finance (1996) is 50 NOK per ton CO_2 , but Mathiesen (1996) analyses the effects of a carbon tax of 650 NOK per ton CO_2 . The carbon tax is implemented in year 2000, and kept constant at this level for the rest of the simulation period. The carbon tax is announced in the first simulation period, which implies that the agents start adjusting to the new tax immediately.

4.2.1 Long run effects

Total welfare, measured as total discounted utility ignoring the environmental effect, increases by 0.12 percent. The emissions of CO_2 are reduced by 13.5 percent, hence, the tax reform supports the double dividend hypothesis. What are the effects present in this analysis of an environmental tax reform which make it possible to obtain a double dividend? In order to answer this question, I will first examine the main sources of possible welfare changes.

In an intertemporal general equilibrium model, first order welfare gains are obtained by intra- and intertemporal reallocations originating from existing tax wedges. I will here especially mention two initial tax wedges; *i*) the discrepancy between the marginal value of

⁸In the following the terms carbon tax and CO_2 tax are used interchangeably.

⁹In an analysis of the effects of optimal carbon taxes on the Norwegian economy by Brendemoen, Bye and Hoel (1995), it is argued that there are substantial arguments for keeping the existing taxes on gasoline since they can be justified by internalising other externalities as traffic congestion and emissions of local pollutants as NO_X and SO_2 .

labour and leisure due to the taxation of labour, influencing the labour-leisure choice, and *ii*) the taxation of income from net financial wealth implying that the social marginal value of net foreign wealth is larger than the private marginal value, influencing the consumption-saving decision. As the discussion of the results shows, there are also other initial tax wedges and distortions which contribute to the results. The long run effects on full consumption, employment, net foreign wealth and the stock of real capital are all positive, see table 4.1. It is the positive effects on employment, net foreign wealth and the real capital stock which make room for the positive effect on full consumption and then overall welfare. Let us start with the effects on full consumption and net foreign wealth to justify this conclusion.

Table 4.1. Long run effects

Percentage deviation from the reference path

GDP, purchaser prices	-0.02
GDP, producer prices	0.01
Employment	0.08
Real capital	0.05
Net foreign wealth	4.2
Full consumption	0.08
Material consumption	0.26
Leisure	-0.06
Wage costs per hour	-2.8
Price of leisure	0.8
Price index, material consumption	-0.5

Figure 4.1. Effects on full consumption
 Percentage deviation from the reference path

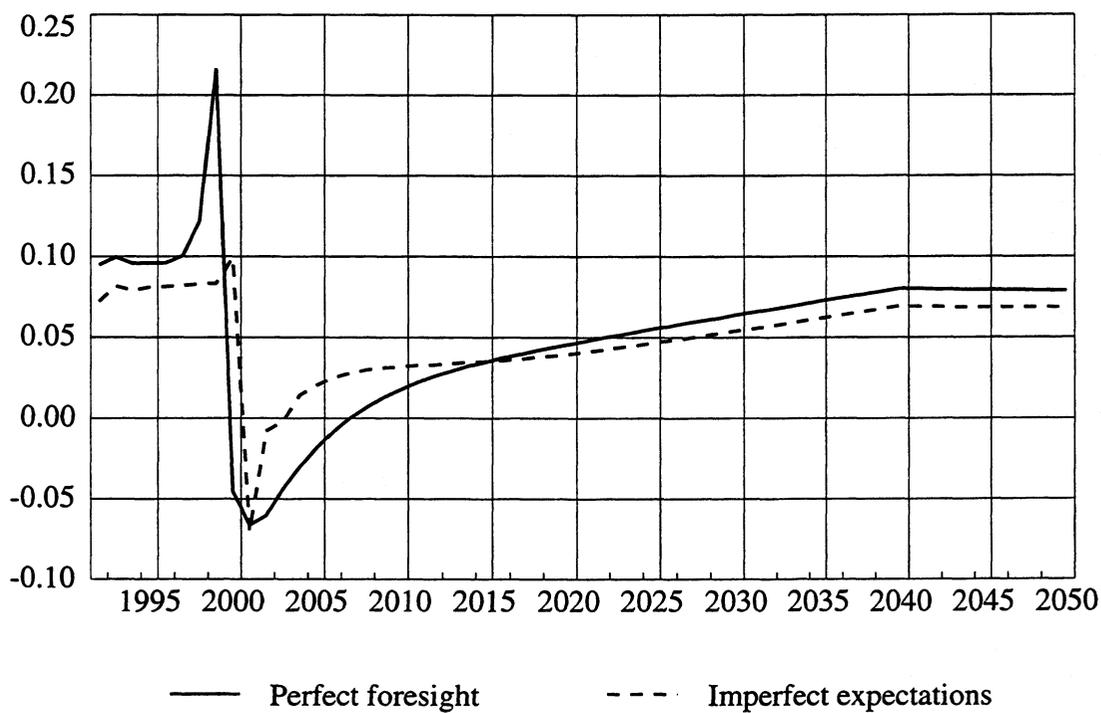
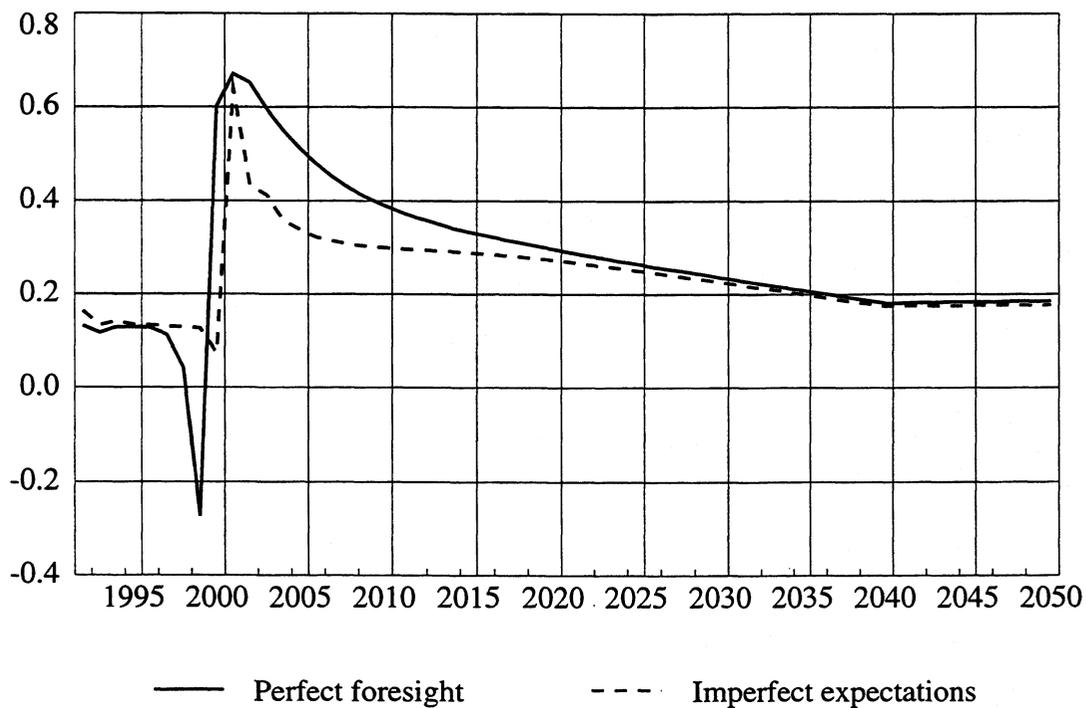


Figure 4.2. Effects on the price of full consumption
 Percentage deviation from the reference path



Full consumption is determined by (see equation (14) and the discussion of intertemporal equilibrium in section 3.5) the income effect which is constant during the whole simulation path through the constancy of the marginal utility of wealth, and the intertemporal substitution effect depending on the price of full consumption which varies along the path. The marginal utility of wealth is determined by the transversality condition. The marginal utility of wealth is lower under the tax reform, reflecting a positive income effect on full consumption along the whole path. Whether the total effect on full consumption is positive in each period, see figure 4.1, depends on whether the increase in the price of full consumption through the intertemporal substitution effect, see figure 4.2, outweighs the positive income effect from the marginal utility of wealth.

The long run level of net foreign debt is lower. This is mirrored by a reduction in the long run trade surplus. The society's cost of net foreign debt is higher than the private cost, due to the taxation of income from financial capital for the private investors. This tax adjusted interest rate is assumed to equal the intertemporal rate of time preference for the consumer, which determines the consumption-saving path. Reducing net foreign debt has a positive effect on full consumption and welfare, due to this discrepancy between the social and private cost of net foreign debt:

The increase in full consumption gives a positive income effect on both material consumption and leisure in the long run. The payroll tax is reduced by 20 percent which gives an average reduction in the payroll tax rate of approximately 4 percentage points, and hourly wage costs by 2.8 percent. Labour demand increases, having a positive effect on the wage rate paid to the employees. The increase in material consumption contributes to reallocate domestic demand to industries which produce consumer goods and services. These industries are more labour intensive. Accordingly, total labour demand increases both due to substitution within the industries over to labour since labour becomes relatively cheaper, but also due to inter-industry substitution over to more labour intensive industries. In the long run equilibrium the wage rate paid to the employees is 0.8 percent higher. Due to the reduction in the domestic producer prices the price on material consumption is reduced by 0.5 percent, see the discussion further down, implying that material consumption has become relatively cheaper than leisure. In the long run material consumption is 0.26 percent higher and consumption of leisure is 0.06 percent lower, so labour supply and employment measured in man hours increase by 0.08 percent under the environmental tax reform. Higher employment has a positive welfare effect since the marginal productivity of labour is higher than the marginal willingness to pay for leisure.

The tax reform's effects on the domestic costs and prices differ between the industries according to the intensity of fossil fuels in the production process. Implementation of the carbon tax gives a substantial increase in the price of fossil fuels, inducing a large increase in the production costs for the pollution intensive (w.r.t. CO_2 emissions) industries such as manufacturing of industrial chemicals, metals and refined oil-products. These industries have limited possibilities of substituting away from the CO_2 tax since the use of fossil fuels

such as coke and coal is directly connected to the production processes in the industries. Both the production and export from these industries are reduced by 20 to 30 percent in the long run, contributing to a reduction in total export.

Manufacturing of industrial chemicals and metals are also intensively using subsidised hydro power. Production of hydro power is the only industry in the model with no possibilities to run down the capacity due to irreversibility of the investments.¹⁰ The reduction in the demand for electricity from these industries induces a fall in the average electricity price of 17 percent. Reallocation of hydro power from the subsidised deliveries to the pollution intensive industries to ordinary consumption, has a positive welfare effect. On the other hand the reduction in the average price of hydro power implies that the value of the hydro power resources is reduced, contributing negatively to total welfare. Approximately all Norwegian electricity is produced by hydro power, which are not subject to the carbon tax. In the analysis there are no possibilities of exporting the excess capacity of hydro power. This may seem unrealistic in such a long run analysis, but the existing export capacity is small and it is assumed as a simplification that this capacity is unchanged during the analysis.

The reduction in the electricity price gives an additional substitution from fossil fuels to electricity and contributes to reduce total private energy costs. Together with the reduction in the hourly wage costs, this induces a negative shift in the cost curve for all industries except for the pollution intensive industries, from the year of implementation. Hence, the level of production and export from the non-polluting industries (including the primary industries) increases. On the domestic market where the producers are assumed to have market power, the negative cost effect is dominating the positive demand effects, such that the producer prices are reduced, except for the pollution intensive industries. The fall in the domestic producer prices gives a reduction in both the price of capital goods and material consumption. In addition the domestic price fall induces substitution over to domestic products, and total import is reduced in the long run.

The total stock of real capital has increased by 0.05 percent in the long run, due to an increase in structures, especially dwelling services, but also from higher consumer demand for housing. On the other hand, the stock of transport equipment and machinery declines due to lower demand and activity in the pollution intensive industries, such as land and air transport and the manufacturing of industrial chemicals and metals. The marginal utility of housing capital is lower than for other structures, since the effective tax rate on housing capital is small compared to other structures.¹¹ Hence, reallocations within the stock of structures in favour of housing contribute negatively to overall productivity.

Higher employment and stock of real capital should induce an increase in GDP, but as is shown in table 4.1 GDP is reduced. The measurement of GDP though deserves a comment: The value of GDP is measured in purchaser prices which include indirect taxes. When commodities with high indirect taxes are substituted with commodities with low indirect taxes, the total value of GDP measured in purchaser prices is reduced, due to these reallo-

¹⁰See Johnsen (1991) for a more detailed description of the model of the electricity producing sector.

¹¹The value of housing capital subject to taxation is only a fraction of its real value.

cations of demand. The substitution over to material consumption has a positive effect on the consumer demand for fossil fuels, but the substitution between the commodities within the aggregate material consumption gives an overall reduction in the consumer demand for gasoline, transport services, cars and fuel oil for heating purposes. These commodities initially have high indirect taxes, leading to a reduction in GDP in purchaser prices, but measured in producer prices GDP increases by 0.01 percent. Compared with the increase in the stock of real capital of 0.05 percent and total employment by 0.08 percent, the increase in GDP of 0.01 percent still implies a reduction in total factor productivity. As mentioned earlier, this is partly due to within capital substitution over to housing, but also increases in production in low-productivity industries as the primary industries. In addition decreasing returns to scale contribute to lowering total factor productivity.

To summarise the main long run effects of the tax reform, exploiting existing tax wedges gives positive welfare effects. From the simulations it seems to be clear that there are two main initial tax wedges which give rise to the positive welfare effect: Reducing the payroll tax has a positive effect on employment which contributes positively to total welfare since the social marginal value of labour is larger than the private marginal value of leisure. In addition the reduction in net foreign debt has a positive welfare effect since the social marginal costs of debt are higher than the private marginal costs. To compare with corresponding analyses by Goulder (1995) and Jorgenson and Wilcoxon (1993) which do not obtain a welfare gain by such tax a reform, the difference may be explained by the higher marginal excess burden of capital taxation than labour taxation in the U.S. Since the carbon tax in general has a positive effect on the costs of using capital equipment, it can be interpreted as an indirect tax on capital, reducing the capital stock and the possible welfare gains by reinforcing the existing tax wedge on real capital.

Figure 4.3. Effects on the stock of real capital

Percentage deviation from the reference path

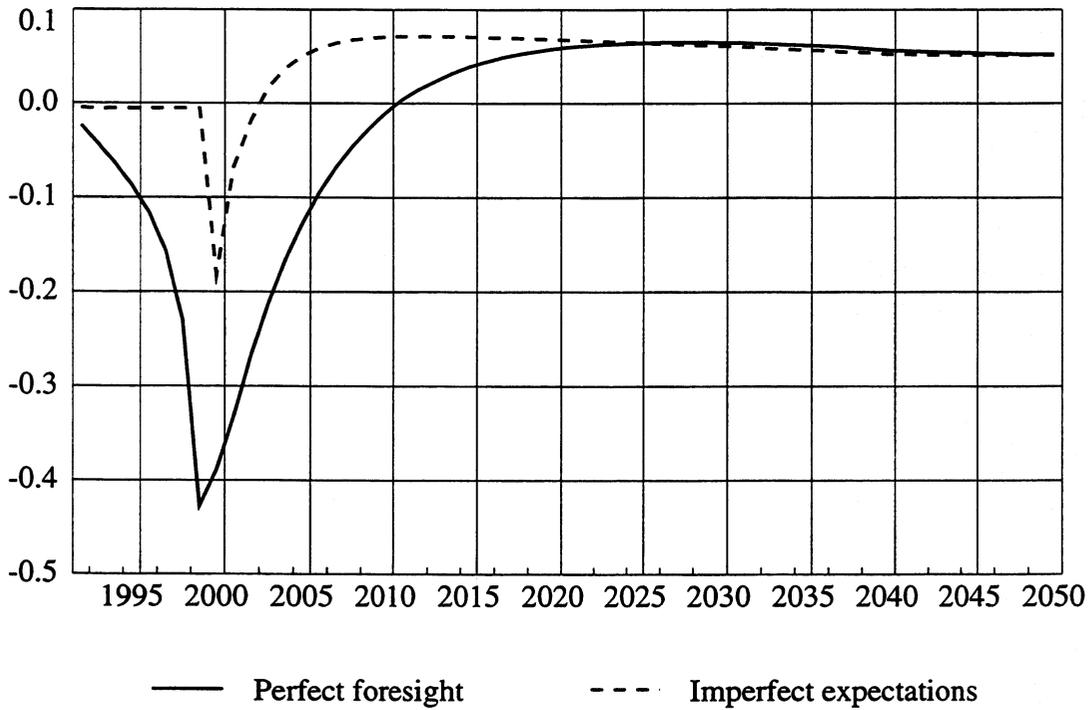
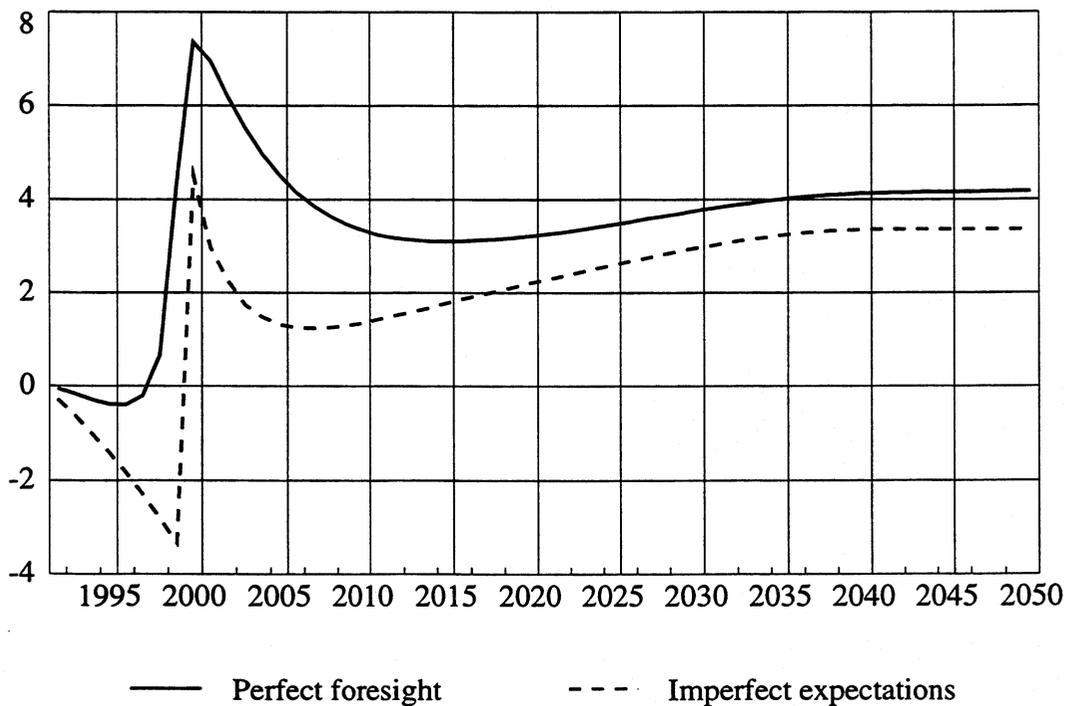


Figure 4.4. Effects on net foreign wealth

Percentage deviation from the reference path



4.2.2 Transitional dynamics

Total discounted utility is determined by the time path of full consumption, which is given in figure 4.1. The effects of the tax reform are different in the years between announcement and implementation (1992-1999), denoted the announcement period, compared to the period after implementation. We know from the discussion of the long term effects that the marginal utility of wealth is lower with the tax reform, implying a positive income effect on full consumption along the whole path. But as we can see from figures 4.1 and 4.2, the time path of the price of full consumption implies that there are some periods just after the tax reform is implemented where the negative intertemporal substitution effect outweighs the positive income effect, such that full consumption is reduced during these periods, compared to the reference path. Hence, there are some transitional effects which modify the positive long run effect on total welfare. The next question to ask is then; what are the effects creating this transitional path for the price of full consumption?

Let us start with the announcement period. Due to the investors' perfect foresight, the long run reduction in the domestic producer prices following the implementation of the tax reform, is reflected in negative capital gains affecting the user cost of capital in the announcement period. The equilibrium adjustments in 1999 induce endogenous price changes. Therefore announced price changes in future periods are spread backwards in time to the initial period. Both the increase in the user cost of capital and the wage rate, due to equilibrium adjustments in the labour market following the negative income effect on labour supply, contribute to increase the production costs and the domestic producer prices, implying an increase in the price of material consumption. Hence, the price of full consumption increases. This price increase does not outweigh the positive income effect, so full consumption is higher compared to the reference path in the announcement period.

After the implementation of the tax reform in year 2000, the equilibrium wage rate increases due to higher demand for labour following the reduction in the payroll tax, see figure 4.6. The increase in the price of leisure outweighs the reduction in the price of material consumption, contributing to an increase in the price of full consumption which is large enough to reduce full consumption in the first years after the implementation of the tax reform. As the economy adjusts towards the new stationary solution, the price of full consumption reaches its new higher long run level, but the increase does not outweigh the positive income effect on full consumption from the reduction in the marginal utility of wealth.

Figure 4.5. Effects on the price of leisure
 Percentage deviation from the reference path

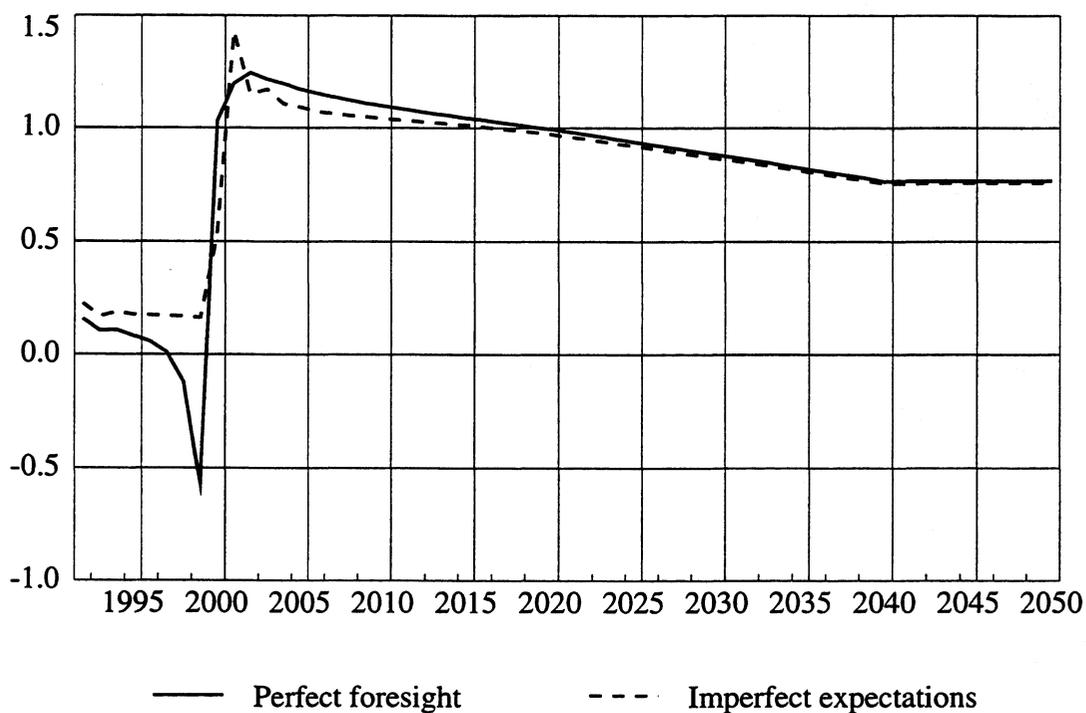
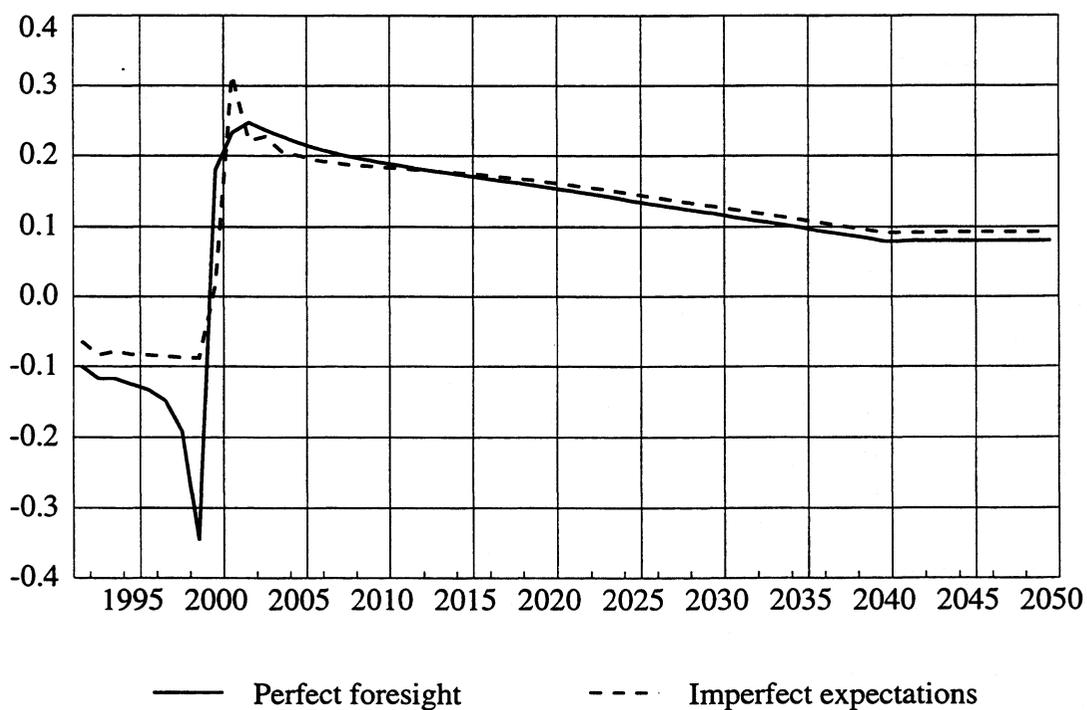


Figure 4.6. Effects on total numbers of man hours
 Percentage deviation from the reference path



The effects of the negative capital gains in the announcement period are common for both transport capital, machinery and structures. I will here concentrate on the effect of structures since it constitutes the largest part of the total stock of real capital, and is mainly domestically produced. The effects on the user cost of structures are illustrated in figure 4.7. The negative capital gains are largest in the year of implementation, reflecting that the fall in the price of structures is largest from 2000 to 2001, see figure 4.8. The negative capital gains induce an increase in the user cost of structures. The capital gains, relative to the reference path, are negative from the first period of simulation, and the user cost of structures is increasing towards the period of implementation. From the entry-exit condition this increase in the user cost of capital contributes to reduce total after tax profit, having a negative effect on the total capacity in an industry. The least efficient firms will exit, reducing the stock of structures in an industry. In addition, the consumer demand for housing is reduced due to substitution over to other commodities. The user cost of transport capital and machinery also follows this kind of path, reducing the demand for the corresponding capital equipment. All these effects contribute to reduce the stock of real capital in the announcement period, see figure 4.3. In the periods just after the implementation of the tax reform there are still negative capital gains due to reduction in the price of structures as it adjusts towards the new lower stationary equilibrium level. From 2003 the effect of the negative capital gains is neutralised by the effect of the lower price of structures.

Figure 4.7. Effects on the user cost of structures

Percentage deviation from the reference path

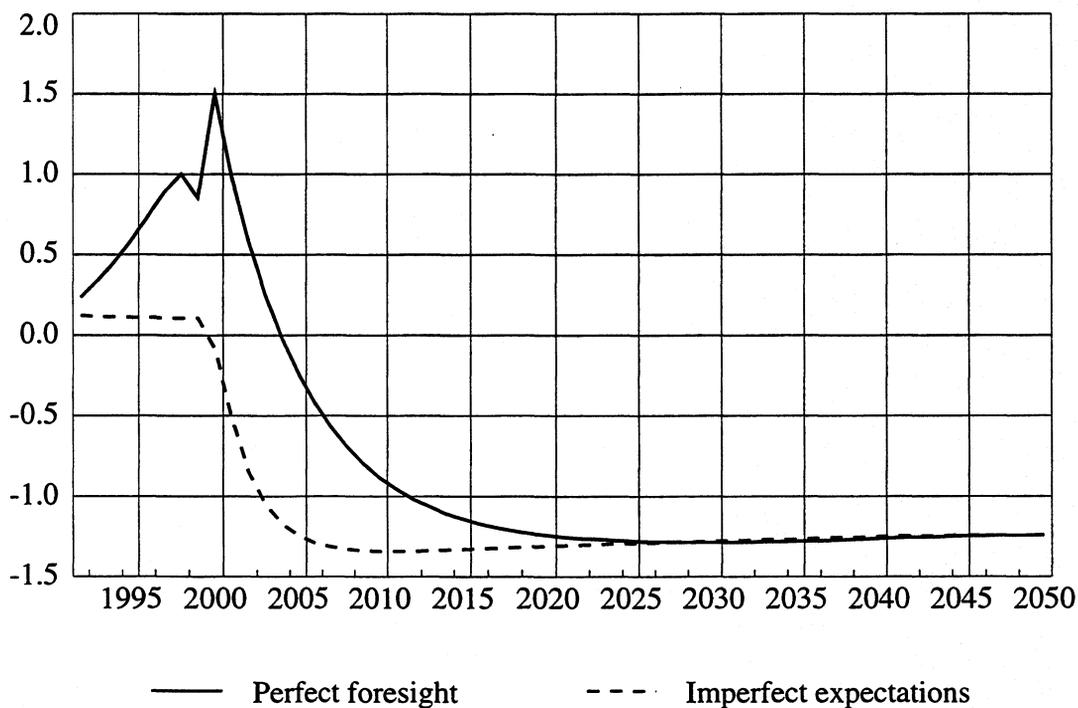
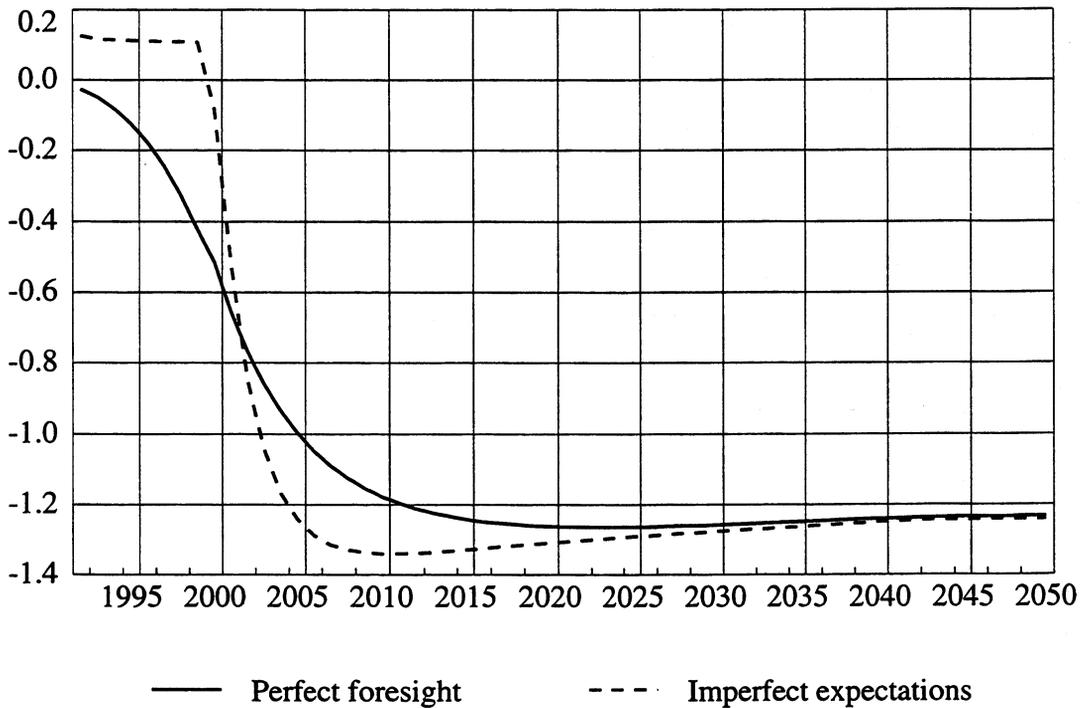


Figure 4.8. Effects on the price of structures

Percentage deviation from the reference path



Compared to the reference path, full consumption increases in the announcement period, reducing savings. Saving in financial capital increases in the period 1998 to 2000, due to lower domestic demand for both consumption and investment purposes, reducing net foreign debt. In the year of implementation, saving in both real and financial capital increases. The investments in total real capital are positive due to an increase in the demand for housing and dwelling services. From 2001 saving is reallocated to real capital.

To summarise the transitional effects due to intertemporal substitution effects and the implications for total welfare, the announcement of the tax reform implies that full consumption is put forward in time to the announcement period, due to future increase in the price of full consumption. After the implementation of the tax reform, full consumption is postponed as the price of full consumption following an initial jump just after the implementation, is reduced as the economy adjusts towards the new steady state solution. The higher level of employment and net foreign wealth from the year of implementation of the tax reform are the major contributors to the positive welfare effect.

A sensitivity analysis w.r.t. the year of implementation and the importance of the announcement period is also performed. In the sensitivity analysis the tax reform is implemented immediately, giving no announcement period. The total welfare gain is higher, confirming that the introduction of a tax reform which has a positive welfare effect, is more beneficial the earlier it is implemented.

4.3 Implications of imperfect expectations

In the reference path and in the simulation of the tax reform, it is assumed that the agents have perfect foresight. In this section it is analysed whether and to what extent imperfect expectations will influence the total welfare costs. It is assumed that the investors in real capital have imperfect expectations of future prices. To be able to single out the partial contribution of the investors making an expectation error, it is assumed that the investors do not change price expectations from the reference path. This assumption can be interpreted as if they do not recognize future price changes due to the tax reform. This seems to be the best way to design the experiment testing for partial implications of imperfect expectations. By choosing another process of expectation formation, the policy simulation and the reference path with perfect foresight would not have been comparable w.r.t. the partial implications of imperfect expectations, since both the assumption about expectations and the policy variables are altered, compared to the reference path. The consumers are still having perfect foresight, and they are optimising their consumption-saving path, given the restriction from the transversality condition.

Bye and Holmøy (1992) discuss the effects of an anticipated versus an unanticipated price change in an aggregate intertemporal model with perfect foresight and no distortive taxes. It is shown that the economy will experience a welfare loss with an unanticipated change in an exogenous world market price compared to an anticipated change, since the price expectations in some periods are wrong compared to the prices that actually occur, i.e. perceived prices deviate from shadow prices. In my experiment the investors have imperfect expectations during the whole transition period.¹² In a first best economy that would certainly lead to a welfare loss. But, in an initially distorted economy as in the analysis presented here, the welfare implications of imperfect expectations may be different from a first best situation. Imperfect expectations may contribute to reduce the distortion between the social and private marginal valuation of savings, and generate reallocations between distorted markets which may be welfare improving. Such gains from imperfect expectations are found and discussed in Ballard and Goulder (1985) and Ballard (1987), who analyse welfare effects of a consumption tax under the assumption of either perfect or myopic expectations for the consumer.

The critical factor explaining their result is the difference between the marginal social benefit and marginal social cost of saving, due to a tax on capital, in an initially distorted economy. The consumption tax leads to capital deepening, so that the price of capital services falls over time. When consumers have perfect foresight they predict these price reductions, and save less in a transitional period, which reduces welfare. The existence of myopic expectations contributes to reduce the wedge between the social and private return on capital. In these studies the steady state solution is independent of the transitional path. The positive welfare effect is only due to changes in the transitional path of consumption

¹²Expecting zero capital gains is of course correct in the steady state solution when actual price changes are zero in all simulations.

and saving towards the steady state solution. The analysis in this paper differs from these U.S. studies by using an intertemporal model for a small open economy implying a path dependent steady state solution, and analysing imperfect expectations by the investors. The initial distortions in the economy are also of course different.

The simulation shows that the welfare gain of the tax reform is approximately the same when the investors have unchanged expectations, as when the investors have perfect foresight. As discussed in section 4.2, the tax reform generates a reduction in the domestic costs and producer prices, giving negative capital gains in the user cost of capital. When the investors do not recognize these negative capital gains, the investments in real capital are too high compared to what is the optimal level of investment from the society's point of view. But, the existence of initial distortions, and the reallocations following the tax reform which exploit these initial distortions, actually improve the economy's welfare. When explaining this result it is convenient to start with the long run solution. Although the price expectations are zero in both simulations, the stationary solutions differ due to the path dependency. While the stock of real capital is approximately unchanged, both the level of net foreign debt and total employment are higher. The accumulation of net foreign debt has induced a welfare loss since the social marginal cost of net foreign debt is higher than the private marginal cost of net foreign debt. The marginal utility of wealth increases through the fulfillment of the transversality condition, which gives a negative income effect on full consumption in each period. Hence, there must be other reallocations along the path and in the stationary solution which contribute positively to total discounted utility

The negative capital gains in the user cost of capital are influencing the investment behaviour, both in the announcement period and after the implementation. When the investors have unchanged expectations they do not expect the negative capital gains from the beginning of the simulation period, which implies that the perceived user cost of capital is lower. The effect on the user cost is strongest for structures, see figure 4.7, and machinery, since they are both produced domestically, while much smaller for transport equipment. Hence, the differences between the two transitional paths are mainly caused by differences in the user costs of structures and machinery. In the announcement period investments in housing capital, dwelling services and machinery increase. Higher domestic demand for structures and machinery implies higher labour demand, which has a positive effect on the equilibrium wage rate. After implementation of the tax reform, the lack of negative capital gains implies that the user costs of structures and machinery adjust faster to their new lower level. The consumer price of housing is further reduced, and this is the main contributor to the reduction in the price of material consumption. The wage rate is also slightly lower, reinforcing the negative effect on the price of full consumption, see figure 4.2.

Savings are reallocated from financial to real capital in the announcement period, while savings in both real and financial capital are reduced after the implementation of the tax reform, see figures 4.1, 4.3 and 4.4. Hence, consumption is shifted forward in time, and is higher in the period 2000-2015, compared to the simulation with perfect foresight. The

stock of real capital is higher both in the announcement period and after the implementation, while net foreign wealth is lower along the whole path. The intertemporal reallocations of investment in real capital imply reallocations from production in traditional export industries towards production of structures and machinery in the announcement period, and towards consumer goods and services after the implementation of the tax reform. The trade balance is reduced in the announcement period due to higher domestic demand for investment goods, while after the implementation of the tax reform, export increases following lower domestic production costs. Full consumption is reallocated to material consumption, since material consumption is relatively cheaper than leisure along the path, implying higher labour supply and employment, see figure 4.6, contributing positively to overall welfare since the marginal productivity of labour is considerably higher than the marginal willingness to pay for leisure.

To summarise the effects of the investors having imperfect expectations in an initially distorted economy, the reallocation of saving from financial to real capital along the path and lower total savings induce a welfare loss due to the expectation error. The social marginal cost of net foreign debt is higher than the private marginal cost of net foreign debt and the social marginal return on real capital. On the other hand by exploiting the large existing tax wedge in the labour market, higher employment outweighs the negative welfare effect of the shift in the composition of savings along the path.

The sensitivity analysis w.r.t. the year of implementation and the importance of the announcement period¹³, supports the conclusion that the positive welfare effect of the tax reform is approximately independent of whether the investors have imperfect expectations or perfect foresight.

5 Concluding remarks

This paper has analysed the non-environmental welfare costs of carbon taxes and the possibilities of obtaining a double dividend with an environmental tax reform, in an intertemporal general equilibrium framework. There are several features of the model which make it substantially different from other CGE models used for analysing the effects of carbon taxes on the Norwegian economy. An intertemporal model where the agents have perfect foresight, gives endogenous accumulation of both real and financial capital, and a consistent welfare measure by total discounted utility. In addition producers are price takers in the world market, which implies that it is not possible to obtain terms of trade gains following domestic tax increases. The analysis shows that it is possible to obtain a double dividend by introducing a CO_2 tax of 700 NOK which increases the prices of heating oils, transport oils and gasoline of 50, 60 and 10 percent respectively, and using the tax revenue to reduce the payroll tax, by exploiting existing tax wedges in the labour market and between consumption and saving.

¹³Announcement effects are absent in both Ballard and Goulder (1985) and Ballard (1987).

The paper also analyses how imperfect price expectations for the investors influence the welfare costs of the tax reform. The welfare gain is approximately unchanged when changing expectations from perfect to imperfect, but the transitional paths are quite different. The reason for these differences is the negative effect of the tax reform on the domestic producer prices, implying negative capital gains in the user cost of capital along the transitional path with perfect foresight, while the negative capital gains are absent with unchanged expectations. This initialises reallocation of saving from financial to real capital along the path, increasing net foreign debt, which induces a welfare loss. This negative effect is though outweighed by the positive welfare effect of higher employment.

The results in this study should be kept in perspective. The welfare gain of the tax reform is very small. There are no economy-environment-economy feedbacks in the model, which would have given an additional positive effect on total welfare in this analysis. It is also obvious that the assumption of complete factor mobility must be important for the welfare costs of the tax reform. Analysing the effects of environmental tax reforms using a dynamic model framework with economy-environment-economy feedbacks and restricted short run factor mobility, is left for further research.

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Appendix A

Table A.1: Production Activities in MSG-6

MSG-6 Code	Production Activities
11	Agriculture
12	Forestry
13	Fishing
14	Breeding of Fish
21	Fish Products
22	Meat and Dairy Products
16	Grain, Vegetables, Fruit, Oils, etc.
17	Beverages and Tobacco
18	Textiles, wearing Apparel and Footwear
26	Furniture and Fixtures
27	Chemical and Mineral Products, incl. Mining and Quarrying
28	Printing and Publishing
34	Manufacture of Pulp and Paper Articles
37	Manufacture of Industrial Chemicals
41	Gasoline
42A	Diesel Fuel
42B	Heating Fuels, Paraffin, etc.
43	Manufacture of Metals
46	Manufacture of Metal Products, Machinery and Equipment
47	Hired Work and Repairs
48	Building of Ships
49	Manufacture and repair of oil drilling rigs and ships, oil production platforms etc.
55	Construction, excl. Oil Well Drilling
60	Ocean Transport - Foreign
63	Finance and Insurance
66	Crude Oil
67	Natural Gas
68	Services in Oil and Gas Exploration
69	Pipeline Transport of Oil and Gas

MSG-6 Code	Production Activities
71	Production of Electricity
72	Power Net Renting
73	Sales and Distribution of Electricity
75	Car and Other Land Transportation
76	Air Transport
77	Railroads and Electrical Commuters
78	Ocean Transport - Domestic
79	Post and Tele Communication
81	Wholesale and Retail Trade
83	Dwelling Services
85	Other Private Services
89	Imputed Service Charges from Financial Institutions
	Government Input Activities
	Central Government
92C	Defence Exclusive of Military Submarines and Aircrafts
92U	Military Submarines and Aircraft
93S	Central Government Education and Research
94S	Central Government Health-Care and Veterinary Services etc.
95S	Other Central Government Services
	Local Government
93K	Local Government Education and Research
94K	Local Government Health-Care and Veterinary Services
95K	Other Local Government Services

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ISSN 0803-074X

