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## **Labour Market Rigidities and Environmental Tax Reforms: Welfare Effects of Different Regimes**

**Abstract:**

The working of the labour market is important for the total welfare effects of tax reforms. This paper analyses, by using a computable general equilibrium model for the Norwegian economy, how different assumptions about labour mobility between industries and wage formation influence the non-environmental welfare effects of an environmental tax reform. Three different alternatives are analysed; competitive labour market, immobility and wage rigidity, and wage formation through union wage bargaining. The welfare effects differ substantially between the alternatives, depending especially on the total tax wedge on labour.

**Keywords:** Dynamic equilibrium analysis, Imperfect labour markets, Environmental tax reforms.

**JEL classification:** C68, D58, D60, D90, H20, J51, J60, Q43.

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# 1 Introduction

In the recent years there has been a vast literature which analyses the possibilities of obtaining a double dividend of an environmental tax reform, i.e. not only a better environmental standard, but also a less distortionary tax system, thereby improving economic welfare. The theoretical literature gives in general little support for the double dividend hypothesis if the economy initially is characterised by a second best optimum, see e.g. Bovenberg and de Mooij (1994) and Bovenberg and van der Ploeg (1994a,b). However, existing tax systems are in general not second best optimal. Hence, there may be a potential for welfare improvements by introducing an environmental tax reform if the tax reform reduces other imperfections in the economy, see e.g. Bovenberg and van der Ploeg (1996) and Bye (1996a) which both consider an economy with involuntary unemployment, and Bovenberg and de Mooij (1996) who analyses how inefficiencies in the initial tax system affect the potential for a double dividend.

Bovenberg and van der Ploeg (1996) and Bye (1996a,1997) all find that the existence of unemployment either due to restricted labour mobility, wage rigidity or alternative wage formation processes, imply additional tax wedges on labour which have welfare implications when analysing tax reforms. There are though few general rules of welfare effects of tax reforms in an initial distorted economy, and in practise each tax reform or distortion must be examined on its own. The purpose of this paper is to analyse how different assumptions about labour mobility and wage formation influence the total non-environmental welfare effects of an environmental tax reform. The labour market imperfections are presented in a stylised way, and the policy analysis are performed using a disaggregated dynamic computable general equilibrium framework of the Norwegian economy with a detailed specification of the tax structure. The empirical significance of the different tax wedges are explored, and the numerical simulations show the importance of changing the total tax wedge on labour for the welfare effect of an environmental tax reform.

Numerical analyses of a revenue neutral environmental tax reform with an increase in the carbon tax combined with a reduction in the payroll tax for the Norwegian economy, indicate that the non-environmental welfare effect is positive due to exploitation of initial inefficiencies in the tax system, Bye (1996b) and Håkonsen and Mathiesen (1997).<sup>1</sup> The results are often challenged because they rely on the assumption of labour being perfectly mobile between industries and labour market equilibrium in each period.<sup>2</sup> The labour market may rather be characterised by some degree of restricted labour mobility and non-

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<sup>1</sup>This is in contrast to numerical simulations of corresponding tax reforms for the U.S. economy where the non-environmental welfare effect is negative, see e.g. Jorgenson and Wilcoxon (1993), Goulder (1995b) and Bovenberg and Goulder (1995).

<sup>2</sup>Or more precisely, it is assumed that the number of unemployed is constant, equal to the number in the benchmark year.

competitive wage formation. In this paper we focus on three alternative labour market specifications; competitive labour market, restricted labour mobility and wage rigidity in some carbon intensive industries, and wage formation through union wage bargaining<sup>3</sup>. The last two alternatives cause involuntary unemployment, which implies an additional wedge for the unemployed since they experience a shadow price of leisure which is lower than the after tax wage rate.

The main sources for welfare effects of the environmental tax reform are found in markets where the initial tax wedges are large as in the labour market, where the social marginal value of leisure is considerably lower than the social marginal utility of consumption generated by labour, due to taxation of labour and consumption. In the stylised presentation of the labour market imperfections we especially focus on how the labour market specification influences the total tax wedge on labour. In a situation with initial involuntary unemployment, the rationing of the labour supply can be interpreted as if there is a “virtual” tax on labour in addition to the other taxes. Hence, the initial total wedge on labour is larger than in the case of equilibrium in the labour market. On the other hand with restricted labour mobility out of some of the carbon intensive industries, the additional “virtual” tax on the rationed part of the labour implies a negative welfare effect of the environmental tax reform.

With a carbon tax of 360 NOK (approximately 50 USD) per ton  $CO_2$  emissions<sup>4</sup> and rebatement of the tax revenue through the payroll tax, the strong double dividend hypothesis<sup>5</sup> is supported in all three alternatives, but the effect is largest in the wage curve case and smallest in the restricted labour mobility case. The differences in welfare effects are mainly due to the different total wedges on labour in the three alternatives. Hence, the assumptions about the working of the labour market are important for the welfare effects of different tax reforms. Sensitivity analyses with higher carbon taxes indicate that there are diminishing returns in non-environmental welfare of further reallocation of resources from the pollution intensive industries to other industries.

The paper is organized as follows: Section 2 outlines the three alternative labour market specifications, while section 3 presents the computable general equilibrium model and the implementation of the different labour market specifications in this model. The results of the environmental tax reform are then presented in section 4.

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<sup>3</sup>Pissarides (1998) illustrate the importance of the wage determination process and the working of the labour market for the employment and wage effects of employment tax cuts.

<sup>4</sup>Which implies that all industries and all kinds of fossil fuels are taxed at the same level as the current carbon tax on gasoline.

<sup>5</sup>See Goulder (1995a) for different interpretations of the double dividend issue. In Goulder’s terminology this paper only considers the strong double dividend.

## 2 The labour market

This section outlines the three alternative specifications of the labour market. We concentrate on stylised partial model frameworks, while details of the implementation in the computable general equilibrium model are further outlined in chapter 3 and appendix B.

### 2.1 Competitive labour market

The reference case is the *competitive* labour market where firms and workers are price takers, and the wage rate equilibrates aggregate labour demand and supply. Labour is assumed to be homogenous and fully mobile between the industries.

### 2.2 Restricted labour mobility

This alternative is characterised by segregated labour markets where labour supply is rationed in one of the markets. The wage rate is assumed to be determined in the non-rationed part of the labour market, while there is wage rigidity in the rationed market. This assumption is reasonable in Norway due to nation-wide unions and wage negotiations setting a minimum “floor” to wages in various industries with local bargaining as a supplement. With this specification we are able to measure the welfare effect of not reallocating labour between the industries when some industries experience large cost increases due to a more ambitious environmental policy by the government. Restricted labour mobility can be rationalised by the following: Pollution intensive industries such as production of industrial chemicals, metals and refined oil products, are especially suffering following an environmental tax reform with an increase in the carbon tax combined with a reduction in the payroll tax, see Bye (1996b) and Mathiesen (1995,1996). These industries have limited possibilities to reduce the tax burden through substitution, since the use of fossil fuels such as coke and coal is closely connected to the production processes in the industries. The production sites in these industries are mainly corner stone enterprises in rural areas where alternative employment is nearly absent, at least in the short run, if the fired workers do not move to another geographical area. To keep the population in these areas approximately unchanged has been one of the main aims of the Norwegian policy towards these corner stone enterprises. By assuming a net loss of individual welfare associated with employment in another geographical area, the labour supply can be considered as industry specific, generating involuntary unemployment<sup>6</sup>. Alternatively, the difference between the wage rate and the shadow price of leisure for the rationed consumer can be interpreted as the necessary subsidy for keeping the population in the area.<sup>7</sup>

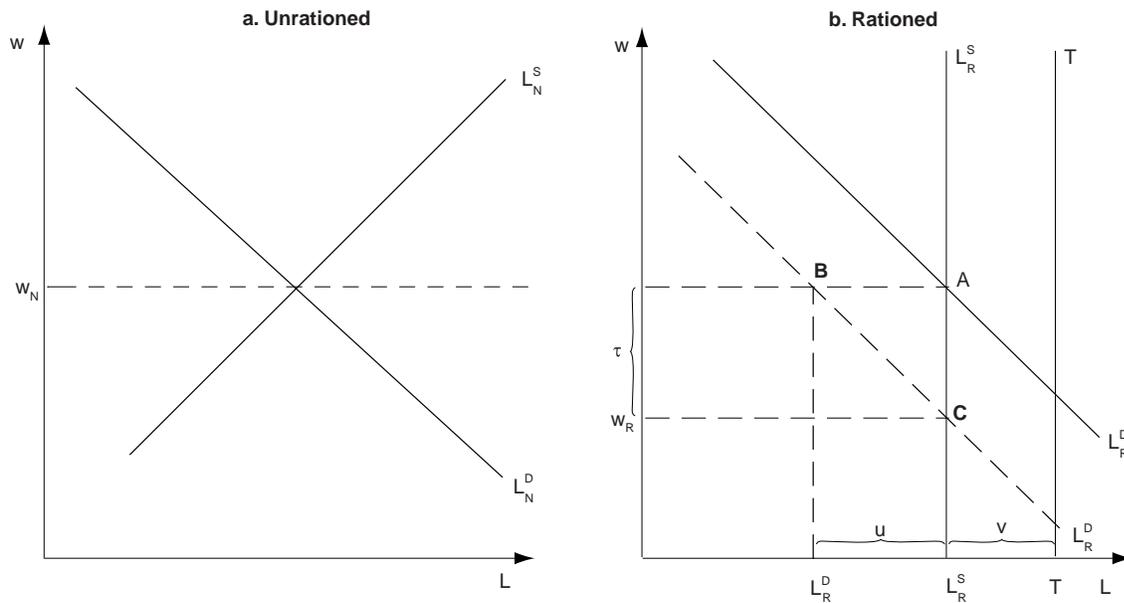
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<sup>6</sup>E.g. if the costs of moving outweigh the difference between the alternative wage rate obtained by being employed in another geographical area and the unemployment benefit.

<sup>7</sup>We assume a linear relationship between labour and population.

The labour market in this alternative is illustrated in figure 2.1. To simplify we assume an economy with only two industries. Industry A is characterised by an elastic labour supply curve,  $L^S$ , and equilibrium in the labour market, while industry B is characterised by an industry specific inelastic labour supply  $L_R^S$ . The wage rate  $W_N$  is determined by equilibrium between labour demand  $L_N^D$  and labour supply  $L_N^S$  in the unrationed industry, and due to labour market contracts this is also the wage rate in the rationed industry. Figure 2.1 also illustrates the effects on industry B of a negative shift in the labour demand, following the environmental tax reform which reduces production and labour demand in industry B. Given the wage rate  $W_N$  there is now involuntary unemployment in the rationed industry given by  $U = L_R^S - L_R^D$ . Leisure (voluntary unemployment),  $V$ , is the difference between total available time  $T$  and the voluntary labour supply  $L_R^S$ .  $U + V$  is then total leisure after the tax reform. The difference between the wage rate and the shadow price of leisure,  $W_R$ , in the rationed industry, may be interpreted as a “virtual” tax on labour,  $\tau = W_N - W_R$ , which is generated by the tax reform.

**Figure 2.1. Labour market, unrationed and rationed industries**



### 2.3 Wage curve

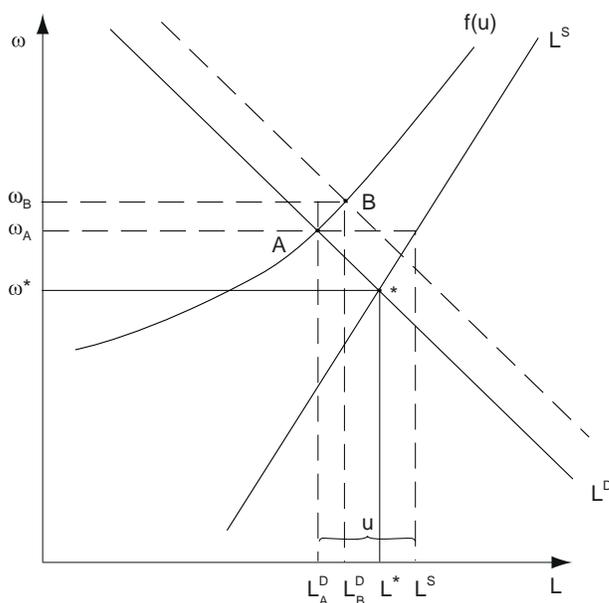
The third labour market specification is an alternative wage formation process following from models of union wage bargaining. Recent econometric studies of wage formation in Norway, Nymoen (1989), Johansen (1995) and Bowitz and Cappelen (1997), find support for the wage bargaining framework. The studies are based on a symmetric Nash bargaining model between a firm and a trade union, following Nickell and Andrews (1983) and Hoel and Nymoen (1988). The optimal wage rate is determined by maximising the joint product of the union’s utility function which is dependent of the wage rate, the alternative wage,

the level of employment and the firm's profit function. The level of employment follows from the demand function, given the wage rate. The solution to this problem implies that the wage rate is homogenous of degree one in producer prices, consumer prices and the alternative wage.<sup>8</sup> The unemployment rate enters the model through the definition of outside utility, but it also influence the bargaining power. Due to the price homogeneity of the wage equation, the real wage rate  $\omega$  depends on the rate of unemployment, illustrated by the following equation

$$(1) \quad \omega = f(U), \quad f'(U) < 0, \quad f''(U) < 0,$$

which is increasing in a real wage-employment diagram.<sup>9</sup> The wage curve is less steep than the labour supply curve  $L^S$ , but approaching this asymptotically, see figure 2.2.<sup>10</sup> A tight labour market represented by low unemployment, implies that the union demands higher real wage.  $L^D$  is the labour demand curve, and the competitive equilibrium is denoted by  $*$ . The wage curve equilibrium is in  $A$ , with higher real wage rate and lower employment than in the competitive equilibrium. Unemployment  $U$  is determined by the difference between labour supply and labour demand  $L_A^D$  at the wage rate  $\omega_A$ . The consumers are rationed in the labour market, and their shadow price of leisure is lower than the wage rate.

**Figure 2.2. Labour market, wage curve**



<sup>8</sup>Income taxes and payroll taxes are included in a restrictive way together with the relevant prices.

<sup>9</sup>See also Blanchflower and Oswald (1994) for a discussion of such a wage curve.

<sup>10</sup>Linear labour supply curve is a simplification.

The difference between the market wage rate and the shadow price of leisure for the consumer in both these alternative labour market specifications, implies the existence of a “virtual” tax on labour which strengthens the existing tax wedge between work and leisure, creating an efficiency loss compared to the competitive case. In the model with immobility and wage rigidity the environmental tax reform induces lower employment (combined with involuntary leisure at a low value) which gives a welfare loss. With the wage curve model there is initial involuntary unemployment, and from figure 2.2 it is easily seen that shifts in labour demand imply larger quantity effects on employment compared to the competitive equilibrium which adapts to a steeper labour supply curve. Hence, the environmental tax reform may give a welfare gain due to an increase in total employment, which may be larger than with the competitive model since the initial total wedge on labour is larger, see also Bovenberg and van der Ploeg (1996).

This section only presents partial labour market models and disregards general equilibrium effects through changes in prices, labour supply etc.. As the numerical simulations will show, the total welfare effect will also depend on whether the change in labour supply can be attributed to changes in either voluntary or involuntary leisure, which have different shadow prices due to different total wedges on labour.

### 3 Basic features of the computable general equilibrium model

To analyse the importance of the different labour market specifications for the welfare effects of environmental tax reforms, the alternative labour market specifications are implemented in a disaggregated intertemporal general equilibrium model for the Norwegian economy, MSG-6. Since the model gives a detailed description of the tax structure and 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 has 41 private and 8 governmental production activities, all listed in appendix A, and 17 consumer goods. The next sections briefly outline some of the important features of the model.

#### 3.1 Producer behaviour and technology

The structure of the production technology is represented by a nested tree-structure of CES-aggregates given in figure B.1, appendix B. 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<sup>11</sup> and malleable.<sup>12</sup> The model of

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<sup>11</sup>Except labour in the immobility alternative, see Sections 2 and 4.

<sup>12</sup>Except in the production of electricity, see Holmøy, Nordén and Strøm (1994).

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 and there is constant return to scale, 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 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, will give a possibility of unrealistic terms of trade gains. The MSG-6 model incorporates both the small open economy assumption of given world market prices, and avoids specialisation through decreasing returns to scale. The producers are then 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 of producer behaviour is described in detail by Holmøy and Hægeland (1997), but a brief description is given in appendix B. 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 between the domestic market and the world market, when maximising profit. The entry-exit condition for the marginal firm requires that the after tax pure rents equal fixed costs. The dynamics due to intertemporal behaviour is captured by the user cost of capital. The user cost formulas are derived from a standard arbitrage condition, see Holmøy, Nordén and Strøm (1994) for a detailed description. 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 which are endogenous in MSG-6, the effective rate of capital taxation will deviate from the neutral rate.

## 3.2 Consumer behaviour

The two models of imperfections in the labour market outlined in section 2, both imply that some consumers are rationed in the labour market. We assume that the consumer is at the same level of utility, independent of whether he is rationed in the labour market or not, which implies that the rationed consumer is compensated with a lump sum transfer. This implies that the intertemporal model of consumer behaviour is identical for all three labour market specifications. The model of consumer behaviour is only briefly described here, while more details are given in appendix B.

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”,  $F$ , which is a homothetic CES-aggregate of leisure,  $LE$ , and material consumption,  $C$ , by maximising

$$(2) \quad U_t = \sum_{s=t}^{\infty} (1 + \rho)^{t-s} U(F_s)$$

where  $\rho$  is the subjective rate of time preference and  $U(F_s)$  is the utility function. 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 in period  $t$  following from the utility maximisation, is represented by the indifference curve  $F_t$  in figure 3.1. In each period full consumption is distributed between leisure and material consumption depending on whether the consumer is rationed in its labour supply or not. The distribution of full consumption on material consumption and leisure is determined by the equilibrium between the marginal rate of substitution between leisure and material consumption, and the corresponding relative price. We can write this first order condition for utility maximisation as

$$(3) \quad \frac{F'_{LE}}{F'_C} = \frac{(PL/(1 + t_A))(1 - t_L)}{P(1 + t_C)}$$

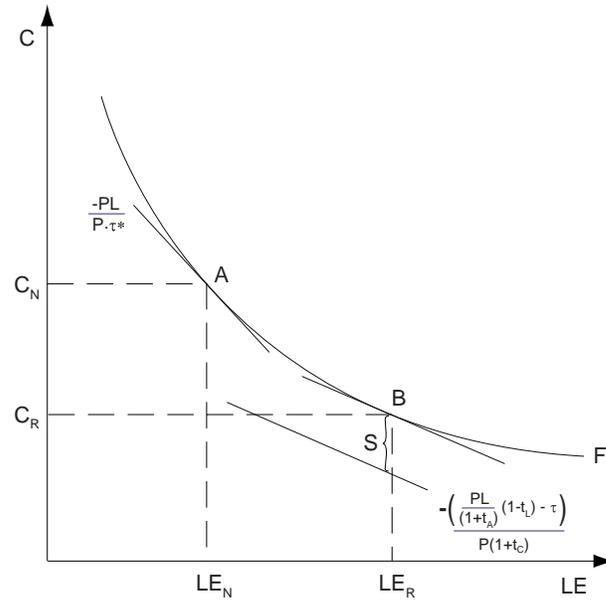
Where  $F'_i$  is the marginal utility of good  $i$ ,  $i = C, LE$ .  $P(1 + t_C)$  is the consumer price of material consumption which includes consumer taxes  $t_C$ , and  $(PL/(1 + t_A))(1 - t_L)$  is the price of leisure (net of consumer wage rate).  $PL = W(1 + t_A)$  is the producer wage cost which includes the payroll tax  $t_A$ . The term  $\tau^* = \frac{(1+t_C)(1+t_A)}{(1-t_L)}$  is the effective tax wedge between the social and private marginal terms of trade between leisure and material consumption.  $\tau^*$  illustrates that the tax rates reinforce the substitution effect between leisure and material consumption.

If the consumer is rationed in labour supply, total consumption of leisure,  $LE_R$ , includes involuntary leisure (unemployment), implying a lower marginal utility of leisure compared to the unrationed case. The first order condition for optimal consumer behaviour in the rationed case can be written as

$$(4) \quad \frac{F'_{LE_R}}{F'_C} = \frac{(PL/(1 + t_A))(1 - t_L) - \tau}{P(1 + t_C)}$$

which gives the distribution of full consumption determined in equation (2) on involuntary leisure and material consumption. The first order condition in equation (4) determines the additional “virtual” tax on labour,  $\tau$ , implying that the shadow price of leisure for the rationed consumer,  $(PL/(1 + t_A))(1 - t_L) - \tau$ , is lower than the net of tax consumer wage rate.

**Figure 3.1. The consumption-leisure choice, unrationed and rationed consumer**



### Competitive labour market

In competitive equilibrium the wage rate is determined by equilibrium in the labour market. The demand for material consumption and leisure is determined by the level of full consumption  $F_t$  and the first order condition given in equation (3), see A in figure 3.1.

### Restricted labour mobility

In this case the labour market imperfections are caused by the assumption of industry specific labour supply in the three pollution intensive industries production of industrial chemicals, metals and refined oil products, see the comments in Section 2.2. These industries constitute the rationed sector, and the wage rate is determined by equilibrium in the unrationed part of the labour market. Due to the assumption of equal income distribution between the rationed and unrationed consumers, the representative consumer is maximising the intertemporal utility function given by equation (2). We assume for convenience that the demand for full consumption following from the utility maximisation, is  $F_t$  in figure 3.1, even though the level of full consumption will change with imperfections in the labour market. This implies that A is the point of adaption for the unrationed household (denoted by subscript  $N$ ), while B is the point of adaption for the rationed consumer (denoted by subscript  $R$ ). The shadow price of leisure for the rationed consumer, or more precisely the additional “virtual” tax on labour,  $\tau$ , is determined by equation (4). Since the rationed and unrationed consumer are both at the same level of utility, the rationed consumer is compensated with an amount of money  $S$  (see figure 3.1).

## Wage curve

The alternative wage formation generated by a union wage bargaining process, is represented by the wage curve in equation (1) (which is a simplified version, see appendix B for further details). Following the intertemporal utility maximisation, the representative consumer distributes full consumption on leisure, determining labour supply, and material consumption according to equation (3), given the wage rate determined by equation (1)<sup>13</sup>. Labour demand is smaller than labour supply at this wage rate, giving involuntary unemployment. As in the previous case we assume for simplicity that  $F_t$  denotes the level of full consumption following from the intertemporal utility maximisation. Due to the existence of involuntary unemployment total consumption of leisure is  $LE_R$ , and the consumer is in B in figure 3.1, experiencing the “virtual” tax on labour,  $\tau$ , determined by equation (4).

## Material consumption

The total of material consumption is allocated across  $M$  different consumer goods according to a nested OCES (Origin Adjusted Constant Elasticity of Substitution) structure as shown in figure B.2 (appendix B), Holtmark and Aasness (1995), independent of the labour market specification. The OCES demand system implies that the Engel elasticities are not equal to 1. The demand system is well 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.

## 3.3 The government and intertemporal equilibrium

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 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 real government spending follow the same path 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.

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<sup>13</sup>It may be questioned whether the existence of a trade union maximising the unions utility over the wage rate and the number of employed in each period, is fully consistent with a perfectly foreseen consumer maximising total discounted utility of material consumption and leisure. But, both the union’s and the representative consumer’s utility will depend on the level of employment and the overall utilisation of resources in the economy. Incorporating the bargaining framework through the wage equation may then be a reasonable approximation for combining the intertemporal general equilibrium framework with the bargaining models.

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. A necessary condition for reaching a steady-state solution is equality between the real interest rate and the rate of time preferences, at least in the last part of the simulation period<sup>14</sup>. 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, see Bye and Holmøy (1997) for a description of the numerical solution procedure. The endogeneity of the domestic prices in the model prevents the solution from reaching steady state immediately.<sup>15</sup>

## 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 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 solution with constant growth rate and relative prices.<sup>16</sup> The long run growth rate is set to zero. This simplifies the solution of the model without significantly affecting the marginal multipliers in the model. In the reference case, which is identical for the competitive and the restricted labour mobility alternatives, the labour market is assumed to be in equilibrium and no consumers are rationed in labour supply.<sup>17</sup>

In the wage curve alternative, the wage curve is also present in the reference path. We have simulated a new reference path which corresponds to the competitive one except for the wage determination process, which generates initial unemployment.<sup>18</sup> The policy

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<sup>14</sup>See appendix B for further details.

<sup>15</sup>The intertemporal model with perfect foresight expectations is solved by using a Stacked time algorithm developed by Intex Solution Inc., Massachusetts, USA.

<sup>16</sup>The steady state solution is reached after 40 periods.

<sup>17</sup>In both the competitive and the restricted labour mobility alternatives the base year level of unemployment is treated as an exogenous reduction in total labour. In the restricted labour mobility alternative, unemployment is measured as the number of unemployed in the policy simulations compared to the reference path with no endogenous unemployment.

<sup>18</sup>In the wage curve alternative base year labour supply is calibrated given the base year level of unemployment.

experiments are then simulated by using this model with the wage curve, and all effects are measured as percentage deviations from the reference path generated by the wage curve model.

## 4.2 The environmental tax reform

This section analyses how the welfare effect of an environmental tax reform, measured by changes in total discounted non-environmental utility, depends on labour market rigidities causing involuntary unemployment. The environmental tax reform is characterised by an increase in the *unilateral* carbon tax, and the revenue is rebated through the payroll tax.

In Norway the existing carbon tax differs substantially between different kinds of fossil fuels and between industries. In 1995 the carbon tax on gasoline was 360 NOK (approximately 50 USD) per ton  $CO_2$ , nearly twice as much as the carbon tax on other fuel-oils and coke and coal. 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 fossil fuels, especially for gasoline, the carbon tax is levied on top of other commodity taxes<sup>19</sup>, 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 simulations we simulate two different levels of the carbon tax, 360 NOK and 700 NOK (approximately 100 USD) per ton  $CO_2$ . The focus is on the effects of the tax reform with a carbon tax of 360 NOK (denoted tax reform A), which implies that all industries and all kinds of fossil fuels are taxed at the same level as the current carbon tax on gasoline. It is optimal from an efficiency point of view to tax all carbon emissions by the same tax rate, independent of the fossil fuels and where it is used. The sensitivity simulations with a carbon tax of 700 NOK (denoted tax reform B) analyse whether the results are monotonic in the carbon tax. A carbon tax of 360 NOK increases the price of heating oils with 22 percent and transport oils with 25 percent, while a carbon tax of 700 NOK gives an increase in the price of heating oils, transport oils and gasoline of approximately 50, 60 and 10 percent respectively. The carbon tax is implemented immediately, and kept constant at this level for the rest of the simulation period. By implementing the tax reform immediately announcement effects are minimised. The initial payroll tax rate differs between the industries, but the revenue neutral rate of change in the payroll tax is equal for all industries.

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<sup>19</sup>In 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  $SO_2$ .

### 4.3 Long run effects

**Table 4.1. Long run effects**

Percentage deviation from the reference path

	Competitive		Restricted labour mob.		Wage curve <sup>1</sup>	
	360 NOK	700 NOK	360 NOK	700 NOK	360 NOK	700 NOK
Full consumption	0.08	-0.02	0.02	-0.18	0.23	0.22
Material consumption	0.20	0.19	0.03 <sup>2</sup>	0.01 <sup>2</sup>	0.34	0.41
Leisure	-0.03	-0.20	-0.07 <sup>2</sup>	-0.35 <sup>2</sup>	0.13	0.04
Employment	0.03	0.19	-0.05	0.03	0.08	0.26
Real capital	-0.25	-0.33	-0.31	-0.45	-0.26	-0.31
Net foreign wealth	1.49	2.35	2.11	3.70	1.25	1.86
Wage costs per hour	-1.72	-3.22	-1.70	-3.19	-1.81	-3.36
Price of leisure	0.27	0.80	0.19 <sup>2</sup>	0.74 <sup>2</sup>	0.18	0.72
Price of material consumption	-0.65	-0.76	-0.62	-0.69	-0.66	-0.76

1. Measured as deviations from a reference path with a corresponding wage curve.
2. Unrationed consumer

#### 4.3.1 Competitive labour market

With tax reform A (carbon tax of 360 NOK) total non-environmental welfare, measured as total discounted utility, increases by 0.2 percent while the  $CO_2$  emissions are reduced by 7.9 percent, supporting the strong double dividend hypothesis. Bye (1996b) gives a more detailed description of the short- and long run effects of such a tax reform in the case of a competitive labour market. The main sources for welfare effects are found in markets where the initial tax wedges are large as in the labour market, where the marginal value of leisure is considerably lower than the marginal utility of consumption generated by the additional labour supply, due to direct and indirect taxation of labour, see the comments to equation (3) in section 3.2. In addition, there are initial tax wedges caused by the capital taxation. The taxation of interest income implies that the social marginal value of savings is larger than the private marginal value. Increased savings contribute positively to welfare due to this discrepancy between the private and social marginal rate of return.

The steady state level of full consumption increases by 0.08 percent, which gives a positive income effect on both material consumption and leisure. The payroll tax is reduced by 11.3 percent which gives an average reduction in the payroll tax rate of approximately 2 percentage points, and hourly wage costs by 1.72 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 in favour of labour since labour becomes relatively cheaper, and inter-industry substitution in favour of more labour intensive industries. In the long run equilibrium the wage rate paid to the employees is 0.27 percent higher. Due to the reduction in the domestic producer prices the price on material consumption is reduced by 0.65 percent, implying that material consumption has become relatively cheaper than leisure. In the long run material consumption is 0.20 percent higher and consumption of leisure is 0.03 percent lower, so labour supply and employment measured in man hours increase by 0.03 percent with the environmental tax reform.

The tax reform's effects on the domestic costs and prices differ between the industries according to both the intensity of fossil fuels in the production process, and the initial differences in the payroll tax between the industries. The rate of change in the payroll tax following the tax reform is identical for all industries. 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 to reduce the tax burden through substitution 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 9 to 18 percent, contributing to a reduction in total export in the long run.

The reduction in hourly wage costs, together with a reduction in the electricity price<sup>20</sup>, 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. In 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 induces substitution over to domestic products such that total import is reduced in the long run.

Partly due to lower production in the pollution intensive industries, wealth is reallocated from real to financial capital. This reallocation has a positive welfare effect since 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. In addition there are reallocations within the stock of real capital towards housing. 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. Hence, reallocations within the stock of structures in favour of housing contribute negatively to overall productivity.

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<sup>20</sup>Electricity is mainly produced by hydro power, not affected by environmental taxes.

To summarise the main long run effects of the tax reform, exploiting existing tax wedges contributes positively to welfare. 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 labour. In addition the reallocation of wealth from real to financial capital has a positive welfare effect. These effects outweigh the negative effect on non-environmental welfare of increased tax wedges on fossil fuels due to higher carbon taxes. The positive effects on environmental quality and feedback effects of lower emissions, are not included in the numerical simulations.

### 4.3.2 Restricted labour mobility

In this case 20 percent (4450 persons) of the employees in the pollution intensive industries becomes unemployed and total employment is reduced by 0.05 percent. This implies a welfare loss compared to the competitive case, but the welfare effect is still slightly positive (full consumption increases by 0.02 percent). The tax reform does still have positive effects on the non rationed (and non polluting) industries which outweigh the negative effects on the rationed (and pollution intensive) industries. The main effects of the tax reform as described in section 4.3.1 with the competitive model, are still present with restricted labour mobility and wage rigidity. The main differences are found in the labour market and for the consumers, dependent on whether they are rationed in the labour market or not. This is the case even though the assumption that all consumers are at the same level of utility and have the same level of full consumption, have placed a strong restriction on the income distribution. The further discussion will concentrate on these effects.

In the simulations it is assumed that the elasticity of labour supply in the unrationed part of the labour market equals the elasticity of labour supply for the whole labour market in the competitive case. The elasticity of labour demand is approximately the same as in the competitive case, hence changes in supply and demand in the unrationed part of the labour market will not differ much from the competitive case. The income effect from change in full consumption is only slightly positive, which together with a higher price of leisure have an overall negative effect on the consumption of leisure compared to the competitive case, and labour supply increases in the unrationed part of the market.

The environmental tax reform implies a negative shift in labour demand for the pollution intensive industries due to an increase in the production costs, which is accompanied by a reduction in production of 9 to 18 percent. The unemployed receive unemployment benefit which increases the government's expenses such that the revenue neutral reduction in the payroll tax is smaller (10.4 percent) than in the competitive case (11.3 percent), which influence the overall effect on labour demand. The reduction in the payroll tax induce substitution to more labour intensive production within the industries, and an increase in the demand for more labour intensive products, having an overall positive effect on labour demand for the unrationed industries.

For the representative rationed consumer material consumption is reduced by 7.7 percent compared to the reference path, while the shadow price of leisure is 51 percent lower than the equilibrium wage in the unrationed part of the labour market. The shadow price of leisure reflects the new level of involuntary leisure consumed by the rationed consumer, which is approximately 10 percent higher than in the reference path.

To summarise the difference between the two simulations of the environmental tax reform with and without rigidities in the labour market, it is important to note that the wedge between the marginal utility of leisure and the marginal utility of consumption generated by labour supply, is significantly larger for the rationed labour suppliers after the implementation of the tax reform. The reduction in total employment due to this increased wedge, is the main contributor to lower welfare compared to the competitive case. The reduction in welfare may be interpreted as the welfare costs of keeping the population unchanged in these rural areas.

### 4.3.3 Wage curve

Before we start discussing the effects when the wage formation process is characterised by a wage curve as given in equation (B.25), it is worth reminding that the wage curve is more elastic than the labour supply curve, see figure 2.2. This is confirmed by the results of the environmental tax reform analysis. Employment increases by 0.08 percent which is more than in the competitive case, while the wage rate (price of leisure) increases by 0.18 percent, which is less than in the competitive case. The long run level of full consumption is 0.23 percent higher than in the reference path. The  $CO_2$  emissions is reduced by 8 percent, such that the double dividend hypothesis is satisfied. The increase in employment is the main source of this welfare improvement. As discussed earlier the initial total wedge on labour is higher in a situation with initial involuntary unemployment since the shadow price of leisure is lower than the after tax wage rate. Both the tax wedge on labour and the rate of unemployment are reduced. The payroll tax is reduced by 11.6 percent, which is slightly more than in the competitive case. This has a positive effect on the demand for labour.

Compared to the competitive case the reduction in the long run stock of real capital is approximately the same, while the reduction in net foreign debt is smaller. This is due to differences in the adjustments to the tax reform in the beginning of the simulation period.<sup>21</sup> These differences are mainly caused by the wage curve which is more elastic than the labour supply curve, implying smaller changes in the wage rate and hence labour costs along the transitional path.

Higher full consumption implies a positive income effect on both leisure and material consumption. Material consumption increases by 0.34 percent, while voluntary leisure

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<sup>21</sup>Bye (1996b) discusses the transitional effects of such an environmental tax reform.

increases by only 0.13 percent, due to a fall in the relative price between material consumption and leisure. Together with an increase in employment of 0.08 percent, this implies reallocations from unemployment (involuntary leisure with a shadow price below after tax wage rate) both to voluntary leisure (shadow price equal to after tax wage rate) and to employment. Both these reallocations have positive welfare effects.

To summarise the effects of the simulation with the wage curve, it clearly states that the positive welfare effect of an increase in employment is larger in a situation with initial involuntary unemployment, than with initial equilibrium in the labour market, due to the higher initial wedge on labour in the first case. In addition the reallocation from involuntary to voluntary leisure contributes positively. The simulations support the hypothesis that welfare is improved the most by reducing the largest initial tax wedge.

#### 4.4 Sensitivity analysis

The results of the sensitivity analysis with a carbon tax of 700 NOK (tax reform B) are also given in table 4.1. The effects on the long run level of full consumption are negative (except for the wage curve alternative), which imply non-monotonicity in the results.<sup>22</sup> Hence, a strong double dividend of the environmental tax reform is obtained with moderate levels of carbon taxes. This result is supported by an additional simulation of a corresponding tax reform with a carbon tax of 500 NOK, where the results are in between the results with tax reform A and tax reform B, given in table 4.1, with some modifications for the wage curve case. The negative effect on full consumption is largest in the restricted labour mobility case, and nearly negligible in the wage curve case. I will further concentrate on the main differences from tax reform A, and start with the effects in the competitive case.

In the *competitive case* the effects of tax reform B on full consumption and total welfare are slightly negative.<sup>23</sup> The increase in the price of leisure (the wage rate) is made possible by the revenue neutral reduction in the pay roll tax of 22 percent, compared to 11.4 percent with tax reform A. The wage rate is reduced by 3.22 percent, giving additional within industry substitution to labour and inter industry substitution to more labour intensive industries. Hence, employment increases by 0.19 percent. In addition saving in real capital is further replaced by saving in financial capital, reducing the long run stock of real capital while net foreign wealth is higher. Total labour productivity is lower. Inter

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<sup>22</sup>This is also supported by the wage curve alternative.

<sup>23</sup>In Bye (1996b) the welfare effect of a corresponding tax reform is slightly positive. The discrepancy between these two simulations is due to a correction of the base year (1992) return in the  $CO_2$  intensive industries in the simulation presented in this paper. The return is upgraded to a normal year since the return in the base year was very low (negative). This adjustment of the return is absent in Bye (1996b), which gave a relatively higher welfare gain when resources were moved from the  $CO_2$  intensive industries to other industries with higher return.

industry substitution to more labour intensive industries also imply reallocations to less productive industries as the primary industries. Further reallocation within the stock of structures in favour of housing also contributes negatively to overall productivity.

From table 4.1 we see that the price of material consumption is reduced by 0.65 percent with tax reform A and 0.76 percent with tax reform B. The main explanation of this lack of difference is the fact that with tax reform A the price of gasoline for the households is approximately unchanged since they initially pay a carbon tax approximately equal to 360 NOK. Hence, it is the reduction in the domestic producer prices which induces the price fall of material consumption. With tax reform B the price increases of fuel oils and gasoline are substantial, which counteracts the further reduction in the producer prices of consumer goods.

With tax reform B fossil fuels turn out to be quite heavily taxed. Since fossil fuels denote a limited tax base, and the numerical simulations do not take into account the positive welfare effect of increased environmental quality of lower emissions, the high carbon tax generates costly distortions (in terms of the welfare measure used) in the consumption of fossil fuels, which are not outweighed by a smaller reduction in the broadly based payroll tax. This supports the well-known result from the second best theory of optimal taxation that the larger the non-environmental welfare cost of taxation, the more weight should be put on the efficiency term of taxation relative to the Pigovian term, see e.g. Sandmo (1975). Hence, there are diminishing returns of reallocating resources from the pollution intensive industries to other industries<sup>24</sup>.

In the *restricted labour mobility case*, the effects of tax reform B are mostly similar to the effects in the competitive case, but the fall in full consumption is larger. This is because the number of unemployed in the rationed industries increases to more than 9000 persons (0.4 percent of total employment), inducing an additional welfare loss.

With the *wage curve model* the results are somewhat different. The long run level of full consumption is only slightly lower with tax reform B compared to tax reform A<sup>25</sup>, such that both tax reforms have significantly positive welfare effects. Employment increases by 0.26 percent, while voluntary leisure increases by 0.04 percent. Hence, reallocation of time from involuntary leisure with a low shadow price to employment and voluntary leisure, induces a positive welfare effect which outweighs the negative effects on welfare of the reallocations in the competitive case. Compared to tax reform A, unemployment is further reduced and relatively more of the unemployed are reallocated towards paid work. In the wage curve case the sensitivity analysis confirms that welfare gains may be obtained by reallocating resources to markets where the initial total tax wedges are

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<sup>24</sup>The production and export in the pollution intensive industries are reduced by approximately 20 to 30 percent.

<sup>25</sup>With a  $CO_2$  tax of 500 NOK the stationary level of full consumption is 0.24 percent higher. Hence, the simulations may illustrate that the "optimal"  $CO_2$  tax is higher in the wage curve alternative, due to the larger initial tax wedge on labour.

largest, which is the case with the “virtual” taxation of unemployed labour.

## 5 Concluding remarks

This paper illustrates the importance of different kinds of labour market specifications for the welfare effects of an environmental tax reform which involves an increase in the carbon tax and a revenue neutral reduction in the payroll tax. The main sources of welfare effects are found in markets with initial large tax wedges as in the labour market, where the marginal value of leisure is considerably lower than the marginal value of labour for the firms, due to direct and indirect taxation of labour. We have especially focused on how the labour market specification influences the total wedge on labour. We focus on three alternative specifications for the labour market; competitive labour market, restricted labour mobility and wage rigidity, and wage formation through union wage bargaining generating a wage curve.

With a general carbon tax of 360 NOK per ton  $CO_2$  emissions, the strong double dividend hypothesis is supported in all three alternatives, but the effect is largest in the wage curve case and smallest in the restricted labour mobility case. The differences in welfare effects are mainly due to the different implicit tax wedges on labour in these three alternatives. In a situation with initial involuntary unemployment as with the wage curve, the rationing of the labour supply can be interpreted as if there is a “virtual” tax on labour in addition to the other taxes. Hence, the initial tax wedge on labour is larger than in the case of labour market equilibrium. Therefore, the positive welfare effect of an increase in employment following from a tax reform is also larger. On the other hand, with restricted mobility of the employees in some of the carbon intensive industries, the additional unemployment implies a welfare loss. Sensitivity analyses with higher carbon taxes indicate that there are diminishing returns in non-environmental welfare of further reallocation of resources from the pollution intensive industries to other industries.

The differences in welfare effects are striking, and it is clear from this analysis that assumptions about the working of the labour market are important for the welfare effects of different tax reforms. The labour market in Norway may be characterised by a combination of labour immobility and wage bargaining: The mobility of labour in the carbon intensive industries is likely to be restricted, while bargaining dominates the wage formation process in the unrestricted part of the economy. Hence, the welfare effects of the tax reform may be somewhere in between the two alternatives; restricted labour mobility and wage curve.

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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
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 Commutors
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

## B Structure and parameter values of the computable general equilibrium model

### B.1 Producer behaviour and technology

The model of producer behaviour is described in detail by Holmøy and Hægeland (1997). Only a brief description is given here. 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

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

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

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

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

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

For convenience the firm label  $i$  is suppressed. Equation (B.2) is the transformation frontier.  $P^W$  is the world market price and  $\sigma^{HA}$  is the elasticity of transformation between deliveries to the domestic and the world market. Equation (B.3) is the cost function. There is 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,  $\gamma$  is the firm specific productivity parameter and  $\rho$  is the elasticity of scale,  $0 < \rho < 1$ . Each domestic firm produces a different variety of the composite industry product. Equation (B.4) is the subjective demand function for the firm, where  $\sigma^{HH}$  is the subjective demand elasticity and  $\beta$  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 of monopolistic competition. According to Holmøy and Hægeland (1997) 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 and Hægeland (1997) it is shown that following from the profit maximisation, the deliveries to the domestic market and the export markets are given by

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

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

where  $m^H$  is the mark-up factor.  $X^H$ ,  $X^A$  and  $B^H$  are determined by equations (B.5) and (B.6), and the true demand function (see Holmøy and Hægeland (1997)).

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,

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

The firm's subjective demand elasticity,  $\sigma^{HH}$ , is assumed to be equal to the elasticity of substitution between the different domestic varieties, Holmøy and Hægeland (1997). 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.

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

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

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

where  $\sigma^{HI}$  is the elasticity of substitution between the domestic composite good and the composite import good. In (B.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 (B.7), see Holmøy and Hægeland (1997). The entry-exit condition for

the marginal firm  $N$  (the number of firms,  $N$ , is endogenous) requires that the after tax pure rents equal fixed costs  $C_N^F$ .

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

where  $t^D$  is the effective profit tax rate.

## 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 B.1.), are adjusted to parameters of a Generalized Leontief (GL) cost function estimated on time-series data from the national accounts, see Alfsen et al (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. 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 in different industries 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. For further details of the calibration of the model of producer behaviour, see Holmøy and Hægeland (1997).

## B.2 Consumer behaviour

The model of consumer behaviour is described in more details in Bye and Holmøy (1997). The representative consumer is assumed to be at the same level of utility, independent of whether he is rationed in the labour market or not.<sup>26</sup> In year  $t$  the representative consumer chooses a path of “full consumption”,  $F$ , by maximising

$$(B.11) \quad U_t = \sum_{s=t}^{\infty} (1 + \rho)^{t-s} \frac{\sigma_F}{\sigma_F - 1} F_s^{\frac{\sigma_F - 1}{\sigma_F}}$$

where  $\rho$  is the subjective rate of time preference and  $\sigma_F$  is the intertemporal elasticity of substitution in full consumption subject to an intertemporal budget constraint requiring that the present value of full consumption in all future periods does not exceed total wealth

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<sup>26</sup>The rationed consumer is compensated with a lump sum transfer.

(current nonhuman wealth plus the present value of labour income and net transfers). This gives the following demand for full consumption

$$(B.12) \quad F_s = \left[ \frac{1 + r(1 - t^D)}{1 + \rho} \right]^{\sigma_F t} (\lambda P F_s)^{-\sigma_F},$$

where  $r$  is the world market interest rate on financial wealth,  $t^D$  is the tax rate on capital income,  $\lambda$  is the marginal utility of wealth and  $P F$  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

$$(B.13) \quad P F_s = \left[ \alpha_C P C_s^{(1-\sigma_C)} + (1 - \alpha_C) \left( \frac{P L E_s}{1 + g} \right)^{(1-\sigma_C)} \right]^{\frac{1}{1-\sigma_C}},$$

where  $P C$  is the price index of material consumption and  $P L E$  is the price of leisure (net of tax wage rate) measured in efficiency units such as labour, implying that the price of leisure must be adjusted with  $g$ , the factor augmenting technical change.  $\sigma_C$  is the elasticity of substitution between material consumption and leisure and  $\alpha_C$  is the intensity parameter for material consumption.

The intertemporal elasticity of substitution,  $\sigma_F$ , equals 0.3, Steigum (1993). Econometric estimates of  $\sigma_F$  vary considerably between different sources, and 0.3 is in the lower end of the range of the estimated parameters. 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). The share of leisure in the full consumption aggregate is set equal to 0.51, see Bye and Holmøy (1997) for details. The calibration of the parameters in the complete demand system for material consumption is based on detailed econometric studies using both micro and macro data, see Holtmark and Aasness (1995).

### B.2.1 Competitive labour market

In each period full consumption is distributed between leisure and material consumption, and the demand functions follow from applying Shepard's lemma to equation (B.13).

$$(B.14) \quad C_s = \alpha_C \left( \frac{P C_s}{P F_s} \right)^{-\sigma_C} F_s$$

$$(B.15) \quad L E_s = (1 - \alpha_C) \left( \frac{P L E_s / (1 + g)}{P F_s} \right)^{-\sigma_C} F_s$$

Then total labour supply  $L_s^S$  is determined by

$$(B.16) \quad L_s^S = T - \frac{L E_s}{1 + g}.$$

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 wage rate is determined by equilibrium between labour supply and labour demand.

### B.2.2 Restricted labour mobility

The demand for full consumption following from the intertemporal utility maximisation, is given by equation (B.14). For the *unrationed* consumer (denoted by subscript  $N$ ) we have the following demand functions (applying Shepard's lemma to equation (B.13)<sup>27</sup>)

$$(B.17) \quad C_N = \alpha_C \left( \frac{PC}{PF} \right)^{-\sigma_C} F$$

$$(B.18) \quad LE_N = (1 - \alpha_C) \left( \frac{PLE}{PF} \right)^{-\sigma_C} F$$

Then total labour supply  $L_N^S$  is determined by

$$(B.19) \quad L_N^S = T - LE_N.$$

For the *rationed* consumer (denoted by subscript  $R$ ), total consumption of leisure  $LE_R$  is given by

$$(B.20) \quad LE_R = T - L_R^S + U_R$$

where  $L_R^S$  is the industry specific supply of labour for the rationed household.  $U_R = L_R^D - L_R^S$  is involuntary unemployment. The shadow price of leisure,  $PLE_R$  is then determined by the demand function for leisure, where the level of leisure is given by equation (B.20)

$$(B.21) \quad LE_R = (1 - \alpha_C) \left( \frac{PLE_R}{p(PC, PLE_R)} \right)^{-\sigma_C} F.$$

$p(PC, PLE_R)$  is the CES price index of full consumption which the rationed household actually faces when they choose the optimal level of material consumption, given the rationed level of leisure and the level of full consumption. Material consumption for the rationed household  $C_R$  is given by

$$(B.22) \quad C_R = \alpha_C \left( \frac{PC}{p(PC, PLE_R)} \right)^{-\sigma_C} F.$$

$C = C_N + C_R$  is the total of material consumption.

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<sup>27</sup>To simplify the exposition we abstract from technical change  $g$  and the time subscript  $s$ . Subscript  $N$  denote unrationed.

### B.2.3 Union wage bargaining case

The model of consumer behaviour is given by equation (B.11) - (B.16), while the wage rate is determined by the following wage curve (Bowitz and Cappelen (1997)).

$$(B.23) \quad \log(W) = -0.1 \cdot \log(U) + 0.5 \cdot [\log(PC) - \log(1 - TG)] \\ + 0.5 \cdot [\log(PYF) - \log(1 + TF)] + 0.5 \cdot \left(\frac{1 - TM}{1 - TG}\right) + \log(\nu)$$

$W$  is wage rate per man hour,  $U$  is the rate of unemployment,  $PC$  is the consumer price index,  $PYF$  is the factor price deflator in manufacturing,  $\nu$  is value added per hour worked (productivity indicator),  $TG$  is the average income tax for households, and  $TF$  is the average payroll tax for manufacturing. The wage equation exhibits the property of price homogeneity such that the real wage rate depends negatively on the rate of unemployment,

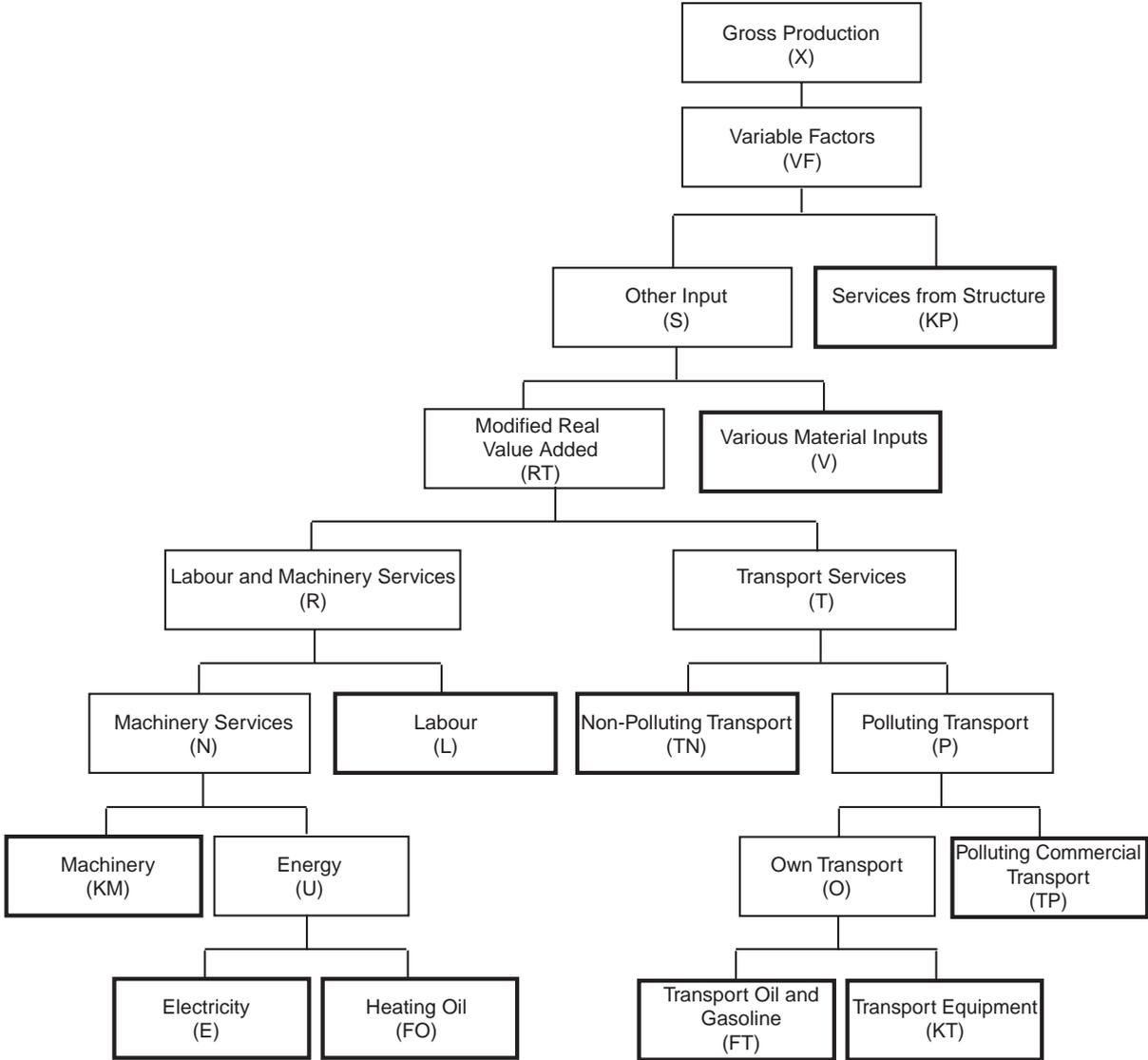
### B.2.4 Intertemporal equilibrium

A necessary condition for reaching a steady-state solution is

$$(B.24) \quad 1 + r(1 - t^D) = (1 + \rho)(1 + g)^{\frac{1}{\sigma_F}}$$

which is a “razor’s edge” condition since  $r$ ,  $t^D$ ,  $\rho$  and  $g$  are all considered as exogenous. In the analyses, equation (B.24) is assumed to hold at all points in time.

**Figure B.1. Production technology**



**Figure B.2. Material Consumption**

