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*Brita Bye and Karine Nyborg*

# The Welfare Effects of Carbon Policies: Grandfathered Quotas versus Differentiated Taxes

**Abstract:**
Recently, it has been demonstrated that pre-existing distortionary taxes can substantially increase the costs of market-based instruments which do not raise revenue, such as non-auctioned emissions quotas. Revenue-raising market-based policy tools, such as carbon taxes, encounter other problems: The redistribution of property rights implied by introduction of such instruments is politically controversial, and in practice, tax rates are often differentiated to reduce political resistance. In the latter case, marginal abatement costs are not equalized between polluters. When comparing a policy with differentiated carbon taxes to a policy of free-issued quotas, financed through distortionary taxes, it is thus not obvious which alternative yields the highest social welfare.

In this paper, we use a numerical intertemporal general equilibrium model for the Norwegian economy to compare the welfare effects of a differentiated carbon tax regime, exemplified by the current Norwegian carbon tax structure; a system of grandfathered tradable emission permits; and a uniform carbon tax regime. Grandfathered tradable quotas yield substantially lower welfare than the other two alternatives. However, differentiated taxes produce almost as high welfare as uniform taxes.

**Keywords:** Dynamic equilibrium analysis, Free issued quotas, Environmental tax reforms.

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

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**Address:** Brita Bye and Karine Nyborg, Statistics Norway, Research Department, Box 8131 Dep. N-0033 Oslo, Norway. E-mail: Brita.Bye@ssb.no, Karine.Nyborg@ssb.no, Statistics Norway, Research Department.

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# 1. Introduction

Environmental economists have long argued that market-based instruments provide more cost-efficient tools for environmental protection than traditional command-and-control measures. A major reason for this view is that the price signals of market-based instruments enable the regulatory authority to equalize marginal abatement costs between polluters even in the absense of extensive information on polluters' cost structures.

However, in the recent double dividend debate, a new insight has emerged (Bovenberg and de Mooij 1994; Goulder, 1995; Goulder et al., 1997; Parry, 1997, Parry and Williams, 1999): If there are pre-existing distortionary taxes in the economy, the price effects of market-based instruments may amplify the distortions. This *tax interaction effect* implies that the costs of such policy tools may be - *ceteris paribus* - higher, and perhaps much higher, than previously thought.[1] On the other hand, the revenues raised from instruments like emission taxes and auctioned tradable emission quotas can be used to reduce the distortionary taxes. This *revenue recycling effect* can, *ceteris paribus,* at least partially offset the tax interaction effect.[2] However, some market-based policy tools do not raise revenue, and thus cannot produce revenue recycling effects. In particular, non-auctioned tradable emission permits provide price signals which yield equal marginal abatement costs between polluters, but also tax interaction effects. These permits produce no public revenue, and hence no revenue recycling effects. Recently, it has been demonstrated that non-auctioned tradable emission permits may be a very costly means to achieve environmental policy goals when initial tax distortions are present (Parry et al., 1999; Goulder et al., 1999). For example, Goulder et al. (1999) found that achieving the $NO_x$ emissions requirements of the US 1990 Clean Air Act Amendments would be more costly under tradable permits than under performance standards, unless the permits were auctioned and the revenue used to reduce distortionary taxes.

This argument seems to indicate that one should move further in the direction of using green taxes or auctioned tradable emission quotas as policy instruments for environmental protection. However, as pointed out by Pezzey and Park (1998), revenue-raising market-based instruments face an overwhelming political problem: "Existing, regulated levels of emissions tend to be regarded as de

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[1] See Parry et al. (1999). For an intuitive understanding of the tax interaction effect, note that although a tax on a polluting consumption good ensures that environmental effects are internalized, it will also widen any exisiting tax wedge between leisure and consumption.

[2] Goulder et al. (1999) claim that the revenue recycling effect typically only partially offsets the tax interaction effects. However, several empirical studies (e.g. Bye 1999a, 1999b, Håkonsen and Mathiesen, 1997) have found that the revenue recycling effect is dominating, i.e. a "strong double dividend". This may occur when the initial tax system is not second-best optimal.

facto rights, and will be defended by the interest groups which benefit from them" (Pezzey and Park, 1998, p. 547).[3] If the ex ante policy regime is one of non-tradable emission permits, and the government wishes to switch to a market-based policy instrument, one way to do this is simply to make the existing permits tradable, in which case polluters keep their previous *de facto* property rights.[4]

Introducing auctioned quotas or emission taxes, on the other hand, shifts the property right of pollution quotas from polluters to the government, so that polluters have to pay to get their previous rights back. Such deprivation of implicit property rights is likely to trigger political resistance. According to the interest group theory of Becker (1983), pressure groups increase their lobbying activities up to the point where their marginal efforts equal the marginal payoff of lobbying, given the lobbying activities of everybody else. If the existing system is in a political Nash equilibrium, and the government proposes to introduce an environmental tax, this must be expected to set off a wave of lobbying activity by prospective losers. Protest actions imply real costs, of course, but this will not be our focus here. However, protest actions may also, at least partially, be successful; and as a consequence, final policy design may be modified, for example by a differentiation of tax rates, which may lead to a much less cost-efficient instrument than the textbook ideal.[5]

A common feature of many European systems of environmental and energy taxes, is indeed that of extensive exemptions and differentiation of tax rates (see Ekins and Speck, 1999). In the Norwegian system for $CO_2$ taxes, the $CO_2$ tax on gasoline is for example more than twice as high as for other fuel oils (measured per ton emission of $CO_2$). Several industries have substantially reduced tax rates, or no carbon tax at all. For North sea oil and gas production, on the other hand, tax rates per ton $CO_2$ are almost as high as for gasoline, and thus much higher than the implicit emission taxes paid by mainland industries. Such differentiated taxes will not equalize marginal abatement costs[6] between polluters, which was, after all, one main reason for advocating market-based instruments in the first place.

In this paper, we will compare three types of market-based instruments for $CO_2$ emission control: A differentiated $CO_2$ tax, exemplified by the current Norwegian carbon tax system; a uniform $CO_2$ tax,

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[3] See also Vollebergh et al (1997).

[4] These rights become even more valuable than before, of course, since they can now be traded.

[5] "In fact, the compromises and 'imperfections' inherent in the design and implementation of incentive-based systems virtually guarantee that they also will be unable to realize the formal least-cost result" (Cropper and Oates, 1992, p. 699.)

[6] As there is currently no economically feasible cleaning technology for $CO_2$ emissions, "abatement cost" cannot be interpreted as meaning end-of-pipe abatement in this context. However, "abatement" may still take place in the sense that production levels are reduced, or fuel is substituted by other inputs.

which in our model framework is equivalent to auctioned tradable emission permits; and a system of grandfathered $CO_2$ emission quotas, i.e. tradable emission permits which are issued for free to previous polluters.[7] The case of differentiated taxes was studied neither by Parry et al. (1999) nor by Goulder et al. (1999), since their models do not take producer heterogeneity into account. Our analysis is conducted using a numerical multi-sector general equilibrium model for the Norwegian economy. The tax reforms are made revenue neutral through changes in the payroll tax. As in Parry et al. (1999), we assume that there are fixed $CO_2$ emission coefficients associated with combustion of fossil fuels, so that a fossil fuels tax is equivalent to an emission tax.

Compared to the case of grandfathered quotas, differentiated taxes do raise revenue, but have the disadvantage that they do not equalize marginal abatement costs. Thus, when comparing differentiated taxes to grandfathered quotas, the quota alternative may in fact yield the highest welfare of the two regimes, even if taxes produce more revenue. Our numerical simulations can obviously not provide general conclusions about differentiated tax regimes, since the welfare properties of such systems must depend on (among other things) exactly how taxes are differentiated. Nevertheless, we believe that the example of the Norwegian carbon tax system has some interest, since it provides an example of a regime which has indeed proved to be politically feasible in practice. The perhaps somewhat surprising conclusions from our simulations are that although free issued quotas yield lower welfare than uniform carbon taxes, as expected, differentiated taxes produce almost the same level of welfare as uniform taxes. One reason for the latter is that differentiated taxes produce more public revenue than the uniform tax, given the level of $CO_2$ emissions. This implies that other distortionary taxes - that is, the payroll tax - can be kept lower in the differentiated tax regime.

In section 2, an outline of the numerical model is provided. Section 3 specifies the policy alternatives we examine, while section 4 discusses whether there are *a priori* reasons to expect one alternative to be welfare superior to the others. Section 5 presents our results, while section 6 concludes.

## 2. Basic features of the computable general equilibrium model

To analyse the welfare effects of environmental policy reforms, we use a numerical intertemporal general equilibrium model for the Norwegian economy, MSG-6.[8] Since the model gives a detailed description of taxes, production and consumption structures in the Norwegian economy, with a special

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[7] Unlike Parry et al. (1999), we will not study command-and control regimes.

[8] The MSG model has been developed by Statistics Norway, and earlier versions of the model have been used routinely by the Norwegian Ministry of Finance for long-term forecasting and policy analysis.

emphasis on demand and supply of energy commodities, it is well designed for analysis 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. A more detailed description of the model is found in Bye (1999a) and Fæhn and Holmøy (1999).

## 2.1. 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 and malleable[9].

The model of producer behaviour in the MSG-6 model is described in detail by Holmøy and Hægeland (1997). The model incorporates both the small open economy assumption of given world market prices, and avoids complete specialisation through decreasing returns to scale. 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. Empirical analyses of Norwegian producer behaviour support the existence of some domestic market power, see e.g. Klette (1994) and Bowitz and Cappelen (1994). 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 model consistent capital gains in the user cost of capital. The tax code in the model represents the system of the 1992 tax reform, which established approximate equality between the effective tax rates levied on most of the different capital incomes.[10]

## 2.2. Consumer behaviour

Consumption, labour supply and saving result from the decisions of an infinitely lived representative consumer, maximising intertemporal utility with perfect foresight. The consumer chooses a path of full consumption, i.e material consumption and leisure, 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 after tax labour income and net transfers). The distribution of full consumption on material consumption and leisure is determined by the equality of

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

[10] However, with significant positive or negative capital gains during transitions, the effective rate of capital taxation will deviate from the neutral rate.

the marginal rate of substitution between leisure and material consumption, and the corresponding consumer real wage rate. The environmental benefit from reduced fossil fuel combustion is not modelled explicitly in the numerical model. However, in all model simulations reported in this paper, $CO_2$ emissions are kept exogeneously fixed; thus, the relevant welfare effects of the studied policy alternatives are still captured by the model. For further details, se Appendix B.

Total material consumption is allocated across 17 different consumer goods according to a nested OCES (Origin adjusted Constant Elasticity of Substitution), see Holtsmark and Aasness (1995).[11] 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.

## 2.3. 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 baseline scenario, implying revenue neutrality in each period.

Intertemporal equilibrium requires fulfillment of the two transversality conditions; the limit value of net foreign debt and real capital must both be zero, as time goes to infinity. 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 consumer's rate of time preferences, at least in the last part of the simulation period.[12] 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.

[11] See figure B.2, appendix B.
[12] See appendix B for further details.

## 3. The policy experiments

The main purpose of this paper is to compare the welfare effects of different market-based environmental policy instruments when pre-existing distortions in the economy are present. We compare three regimes: A differentiated tax regime, which will be our base case; a uniform tax regime, and a regime of grandfathered tradable carbon emission permits. To make the policy alternatives comparable, we have imposed the restriction that aggregate $CO_2$ emissions are kept at the same level in all three cases. Also, introduction of any alternative policy instrument has been made revenue neutral as compared to the base case scenario by corresponding changes in the payroll tax.[13]

The baseline scenario, or the *differentiated tax scenario* (alternative 1) is a simulation of the current (1999) Norwegian system for carbon taxation. Obviously, this represents a carbon tax system which has demonstratedly been politically feasible to implement. As mentioned in the introduction, the existing carbon tax in Norway differs substantially between different kinds of fossil fuels and between industries, see Table 1. For most fossil fuels, especially for gasoline, the carbon tax is levied on top of other commodity taxes,[14] which is also the case in this analysis.

In the *uniform tax scenario* (alternative 2), all industries and consumers, and all kinds of fossil fuels are taxed by the same tax rate. The tax rate is determined endogenously to generate the same $CO_2$ emissions as in alternative 1. The revenue effects are offset by a corresponding change in the payroll tax, ensuring that the nominal deficit follows the same path as in alternative 1.

In the *quota scenario* (alternative 3), tradable $CO_2$ emission permits are issued for free to previous polluters (grandfathering), defined here by each sector's emissions in the baseline scenario. The right to receive quotas is assumed to be independent of current production; thus, if a production plant shuts down, its owners will still receive quotas, which they can sell to earn a quota rent.[15] With this assumption, the allocation of quotas does not affect firms' exit-entry decision.[16] The quota price is determined endogenously, while the aggregate $CO_2$ emission level is set equal to the emission level in alternative 1. In our model, the quota regime is formally equivalent to a uniform $CO_2$ tax combined with a lump-sum transfer from the government to those who receive quotas. This virtual lump-sum subsidy is financed through increased payroll taxes.

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[13] The initial payroll tax rate differs between industries. However, when using the payroll tax to keep reforms revenue neutral, the rate of change in the payroll tax is equal for all industries.

[14] 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 $SO_2$.

[15] See the discussion in Holtsmark (1999).

**Table 1. Carbon taxation in Norway, 1999. NOK[*] per ton $CO_2$.**

| | |
|---|---|
| **Fuels** | |
| Gasoline | 397.00 |
| Light fuel oils, diesel | 173.20 |
| Heavy fuel oils | 148.00 |
| Coal for energy purposes | 189.40 |
| Coke for energy purposes | 144.00 |
| Coal and coke for processing (Ferro alloys-, carbide- and aluminium industry) | 0.00 |
| Gas (land-based use not covered by the petroleum tax legislation) | 0.00 |
| **North Sea petroleum extraction** | |
| Oil extraction | 335.10 |
| Natural gas extraction | 381.00 |
| **Industries with reduced rates:** | |
| *Wood processing industry, herring flour industry* | |
| Light fuel oils, transport oils (petrol, diesel etc.) | 86.60 |
| Heavy fuel oils | 74.10 |
| **Industries with exemptions** | |
| Air transport | 0.00 |
| Foreign carriage by sea | 0.00 |
| Domestic goods traffic by sea | 0.00 |
| Inshore fishing | 0.00 |
| Fishing and catching in foreign waters | 0.00 |
| Cement and leca production | 0.00 |

[*] 1 USD = 7.74 NOK (August 9, 1999)

*Source: Statistics Norway*

# 4. Anticipated welfare effects

Parry et al. (1999) identify three effects contributing to the total welfare effect of a revenue neutral environmental policy change in the case of reducing carbon emissions. The first is denoted the *primary welfare gain*, which consists of the environmental benefit from reduced fuel combustion, net of the reduction in the consumer surplus for users of fossil fuels. The second is the *revenue recycling effect*, which is the efficiency gain from using additional carbon tax revenues, if any, to reduce distortive tax rates, e.g. labour taxation. The third is denoted the *tax interaction effect*, which has three components. The first of these is the efficiency loss from the reduction in labour supply occurring when carbon taxes increase: A higher carbon tax increases goods prices, reducing the real wage rate

[16] MSG-6 assumes decreasing returns to scale. If the right to receive quotas were contingent on positive production levels, quotas would affect firms' profits and thus entry-exit. Neutrality of the quota allocation further requires that quota rents are taxed by the same rate as firms' profits.

and thus labor supply. Such a reduction in labour supply further reduces revenue from the labour taxes, and the cost of replacing this revenue is the second component of the tax-interaction effect. Because higher carbon taxes raise the price of consumption, nominal government spending must rise to hold real spending constant. The third component is the efficiency loss from raising this additional revenue.

Before we turn to the numerical results, let us just sketch some theoretical arguments concerning what results to expect. Compared to alternative 1 (differentiated taxes), alternative 2 (uniform tax) will have a higher primary welfare gain, since abatement costs are equalized across sectors and fuels, implying lower welfare costs to consumers of fossil fuels. However, welfare may still be higher in a differentiated tax system, due to revenue recycling and tax interaction effects: For a given aggregate emission level, the uniform tax may produce either less or more public revenue than differentiated taxes. A loss of revenue must be financed through distortionary taxes, which will in turn have negative welfare effects (i.e. a negative revenue recycling effect). Further, since preexisting taxes differ between sectors, both for fossil fuels and other resources, there will generally also be tax interaction effects: Reducing a high fuel tax rate may for example yield more significant welfare effects if pre-existing distortionary taxes on this particular fuel are substantial. Payroll tax rates, effective tax rates on capital and subsidized electricity prices vary, and in addition there are distortions due to the Norwegian trade protection system and the existence of domestic market power. Changes in the carbon tax rates may amplify or reduce the importance of each of these distortions. The sign of the net welfare change induced by all these complex effects is difficult to predict *a priori*.

As regards the difference between alternatives 1 and 3 (quotas), the latter instrument does not produce revenue, and a change from policy alternative 1 to 3 would thus yield a negative revenue recycling effect. There will also be tax interaction effects as above, since tax rates (quota prices) are generally different in the two scenarios, but it is not clear whether this effect is overall positive or negative. However, a change from 1 to 3 must be expected to produce a positive primary welfare gain: Since marginal abatement costs are unequal in alternative 1, but equal in 3, aggregate abatement costs will be lower in the quota alternative.

Concerning alternative 2 (uniform taxes) and 3 (quotas), these two differ formally only in the sense that lump-sum transfers, and thus also the level of distortionary taxes, are higher in the latter case.[17] Thus, one would expect that welfare is higher in alternative 2 than in 3.

Although intuition may suggest that the uniform tax scenario is welfare superior to the other two, one actually cannot on purely theoretical grounds conclude that uniform taxes outperform differentiated taxes. Further, if differentiated taxes and grandfathered quotas are the only politically feasible alternatives, we cannot tell a priori which of these two alternatives will produce highest welfare. While the former does produce public revenue, the latter minimizes primary abatement costs; and it is not obvous, which of these two advantages turns out to be most important. We do believe that the case study presented here still has general interest, however, in that it illustrates some important mechanisms that come into play in an environmental policy setting with pre-existing distortionary taxes.

# 5. Numerical results

## 5. 1. Baseline alternative

The effects of the different policies are measured as deviations from the baseline scenario (alternative 1). The model is calibrated to the benchmark year (1992). We simulate a baseline alternative by keeping all tax rates and other exogenous variables constant at their benchmark values. The exception is, the system of differentiated carbon taxes, which is substituted by the 1999 system of carbon taxation, see Table 1. 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.[18] The steady state solution of the model is path dependent. In the other policy simulations both the path and the long run stationary solution differ from the baseline alternative. The tax reforms are implemented immediately, minimizing announcement effects.

## 5. 2. A comparison of policy alternatives: Results

Below, we will focus on the long run solution, since the transitional dynamics have relatively low impact on welfare effects. In Table 2 below, the long run effects for some important variables are summarized. The variable "full consumption" (see Appendix B) is an aggregate of material

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[17] Empirically, they differ with respect to the $CO_2$ tax level (i.e. level of the quota price) as well, since this variable is determined endogenously in the model simulations and is influenced by the higher payroll tax in alternative 3.

[18] The steady state solution is reached after approximately 30 periods.

consumption and leisure, and its long run value indicates the representative consumer's (non-environmental) utility in the steady state. [19]

**Table 2. Long run effects. Percentage deviation from the baseline scenario (alternative 1)**

| | Uniform carbon tax (alternative 2) | Carbon quotas (alternative 3) |
|---|---|---|
| Full consumption | 0.007 | -0.12 |
| Material consumption | -0.03 | -0.35 |
| Leisure | 0.06 | 0.24 |
| Employment | -0.08 | -0.31 |
| Real capital | -0.12 | -0.29 |
| Export surplus | -0.43 | -0.54 |
| Wage costs per hour | 0.10 | 0.35 |
| Price of leisure | -0.58 | -1.37 |
| Price of material consumption | -0.43 | -0.39 |
| Payroll tax rate | 4.00 | 10.00 |
| Uniform carbon tax/quota price[1)] | 97.2 NOK* | 92.1 NOK* |

* 1 USD = 7.74 NOK (August 9, 1999)

1) Absolute levels in NOK.

The main sources of welfare effects of the reforms are found in markets where the initial total tax wedges are large. Notably, in the labour market, the marginal social value of leisure is considerably lower than the marginal social utility of consumption generated by additional labour supply, due to direct and indirect taxation of labour.[20] Also, there are initial tax wedges caused by 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. In addition, as mentioned in section 4, there are pre-existing differences between the industries in the taxation of resources, including fossil fuels, which generate welfare effects. The uniform tax scenario (alternative 2) increases welfare (total discounted utility) by 0.026 percent as compared to the differentiated tax scenario. The uniform carbon tax is 97.20 NOK (12.60 USD) per ton $CO_2$ emissions, which implies a substantial fall in the carbon tax on gasoline, while the production of industrial

[19] Here, we will only provide a brief description of the main welfare effects generated by the tax reforms considered. More detailed discussions of sources of welfare effects of similar environmental tax reforms analysed with the MSG6 model can e.g. be found in Bye (1999a, 1999b).

[20] The total tax wedge between private and social marginal return on labour in the Norwegian economy includes three main components: the marginal tax on wage income, payroll tax and VAT and indirect taxes on consumer goods. The total tax wedge is approximately 2,4 (see Bye, Holmøy and Strøm (1999))..

chemicals, metals and refined oil products experience a large increase in their fossil fuels costs for processing purposes. The uniform carbon tax required to keep $CO_2$ emissions unchanged, generates less revenue than the differentiated tax system of the baseline scenario. Thus, the payroll tax rate increases by 4 percent to keep the tax reform revenue neutral, corresponding to an increase of approximately 0.6 percentage points in the overall payroll tax rate. This induces an increase in the hourly wage costs of 0.1 percent, in spite of reduced labour demand and a corresponding reduction in the equilibrium consumer wage rate (net of tax) of 0.58 percent.

The welfare effect is sligthly positive, even though employment and the stock of real capital is reduced. Capital is reallocated from real to financial capital, and increased savings in financial capital have a positive welfare effect as mentioned above. In addition, there are capital stock reallocations away from housing. The marginal utility of housing capital is comparatively low, since the effective tax rate on housing capital is small. Hence, reallocations towards other capital goods, as well as inter- and intra-industry reallocations towards less labour intensive production, contribute positively to overall productivity. The negative effect of lower employment and stock of real capital is also modified by decreasing returns to scale in production.

Manufacturing of industrial chemicals and metals are negatively affected by a uniform carbon tax. These industries use subsidised hydropower intensively in the baseline alternative, but reduce their demand for electricity when a uniform carbon tax is introduced. This induces a fall in the average electricity price of 1.4 percent. Together with lower carbon taxes, this fall in the energy costs induces a negative shift in the cost curve for most industries, which is not outweighed by higher labour costs. Together with lower domestic demand for investment and consumption purposes, this negative shift leads to a fall in the domestic producer prices. However, for production of industrial chemicals, metals and refined oil products, costs increase. These industries represent a relatively large share of total exports; consequently, aggregate export is reduced. Import is reduced through lower domestic demand for investment and consumption purposes, especially along the transitional path towards the new stationary solution, but domestic demand is also reallocated towards the home market due to the fall in the domestic producer prices. Net financial wealth is accumulated along the path, which is mirrored by the lower long run export surplus. In sum, the uniform tax alternative produces a small, but positive welfare gain as compared to differentiated taxes, even though the economy experiences an efficiency loss through higher taxation of labour. If marginal abatement costs could be equalized without increasing the labour taxation, i.e. if the decreased carbon tax revenues could have been financed through lump-sum taxation, the welfare gain would of course have been larger.[21]

The quota alternative (alternative 3) implies a redistribution of carbon tax revenue from the government to the private sector. This is financed by a 10 percent increase in the payroll tax. Compared to the baseline scenario, the quota alternative implies a reduction in welfare of 0.23 percent. Quite similar mechanisms are present as in the uniform tax alternative, but the positive primary welfare effect of equalized marginal abatement costs is more than outweighed by the negative effects of a higher payroll tax. Wage costs per hour increases by 0.35 percent, giving an upward shift in the cost curve for nearly all industries. Lower consumption and production in the economy following the higher payroll tax imply a lower uniform quota price (92.10 NOK = 11.90 USD) than the required uniform tax in alternative 2.

The results support the hypothesis that freely issued tradeable quotas induce a substantial welfare loss compared to a uniform tax, due to the loss of tax revenue, when lump sum taxation is not available. But why is the welfare gain of changing from a differentiated carbon tax system to a system of uniform tax rate so small? Although second-best theory of optimal taxation recommends uniform Pigouvian taxes on polluting commodities and factor inputs in production, it also tells us that overall tax levels should be adjusted to take other considerations than pollution into account.[22] Sandmo (1975) demonstrated that the optimal commodity tax in a second-best economy with externalities should be a weighted average of what we may call a Ramsey term, reflecting efficiency effects on the general economy, and the Pigouvian term. In the case of independent demand, goods with low elasticity of demand should be taxed relatively more. Further, relatively more weight should be put on the Ramsey term compared to the Pigou term when the initial burden of taxation (the marginal costs of public funds) is generally large.

Although Sandmo's result is based on a model of constant returns to scale, and therefore not directly consistent with the MSG-6 model,[23] his results suggest an intuitive explanation of our numerical

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[21] In that case, total discounted utility would have increased by 0.17 percent (rather than just 0.026 percent). Since lump sum transfers have no real effects in the model, while a higher payroll tax has negative effects on the economy, the uniform carbon tax must be higher (103 NOK per ton $CO_2$ emissions) to keep carbon emissions at the baseline level. The total tax revenue effect from the uniform carbon tax would still be lower than in the baseline scenario, but this is financed by a lump sum withdrawal from households.

[22] See Bovenberg (1999), Bovenberg and van der Ploeg (1994).

[23] Diamond and Mirrlees (1971) demonstrated that it is not optimal to tax non-polluting input factors in production. However, note that their model is based on constant returns to scale, or alternatively a 100 percent profit tax, so the result is not immediately transferable to the MSG-6 model.

results: Compared to a uniform carbon tax (for given $CO_2$ emissions), the current differentiated carbon tax system seems to be quite efficient in collecting carbon tax revenue, even if it is not all that efficient in reducing marginal abatement costs. In particular, note that the carbon taxes on the production of North Sea oil and gas are very high in the differentiated system (see Table 1). Since these activities are quite regulated and thus insensitive to changes in the carbon tax, the reduction in their carbon taxes rates gives a substantial revenue loss[24]. Naturally, replacing these revenues by increased labour taxation yields significant welfare effects.

# 6. Concluding remarks

Recent research has demonstrated that the costs of using market-based environmental policy instruments are substantially increased if initial tax distortions are present in the economy. For policy instruments which produce public revenue, this revenue can be used to reduce preexisting distortionary taxes, offsetting at least parts of these costs.

Freely issued (grandfathered) carbon emission permits do not yield public revenue, and may thus be much more costly than uniform carbon taxes. However, uniform carbon taxes appear to be politically controversial. In practice, carbon taxes tend to differ substantially between sectors and/or fuels; implying that abatement costs are not equalized. Still, in the literature on instrument costs with preexisting tax distortions, there has been little focus on differentiated tax regimes.

Our initial hypothesis motivating this project was that a system of differentiated carbon taxes may indeed produce less welfare than a regime of grandfathered tradable emission permits, even with pre-existing tax distortions, due to the former regime's higher direct abatement costs. Using a numerical intertemporal general equilibrium model for the Norwegian economy, we compare the welfare effects of a differentiated carbon tax regime, reflecting current Norwegian carbon taxation, to a uniform tax regime and a system of grandfathered quotas.

The differentiated tax regime performs very well in the numerical simulations. Discounted utility under differentiated taxes is lower than under uniform tax rates, but the difference is hardly distinguishable. To achieve the same level of $CO_2$ emissions with a uniform tax as with the current differentiated tax regime, the $CO_2$ tax revenue is significantly reduced. Consequently, other

[24] Approximately 1 bill. NOK. Note that this effect may possibly be overestimated in our model simulations: While we assume constant carbon emission coefficients, the emission coefficients for North sea petroleum production have in fact decreased over time, and one cannot exclude the possibility that this is related to the high carbon taxes.

distortionary taxes must be increased. The question of whether the above is simply a coincidence, or whether Norwegian politicians have in fact deliberately designed the carbon tax system to extract as much revenue as possible, remains to be answered.

Since the welfare level of the differentiated tax regime does not differ much from that of the uniform tax regime, it is hardly surprising that the quota alternative produces significantly lower welfare than both tax alternatives. Thus, our initial hypothesis is not confirmed for the Norwegian case: According to our simulations, grandfathered carbon emission quotas is a less cost-efficient policy instrument than the current carbon tax system. This conclusion, however, may obviously come out different for other economies with other differentiated tax regimes.

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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 Appeal 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 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 Aircraft |
| 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 etc. |
| 95K | Other Local Government Services |

# Appendix B

## Consumer behaviour

In year $t$ the representative consumer chooses a path of "full consumption", $F$, by maximising intertemporal utility given by

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

subject to the intertemporal budget constraint, see Bye and Holmøy (1997) for further details. $\sigma_F$ is the intertemporal elasticity of substitution in full consumption. The intertemporal utility maximisation gives the demand for full consumption

$$\text{(B.2)} \quad F_s = \left[\frac{1 + r(1 - t^D)}{1+\rho}\right]^{\sigma_F t} (\lambda PF_s)^{-\sigma_F} ,$$

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 $PF$ 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

$$\text{(B.3)} \quad PF_s = \left[\alpha_C PC_s^{(1-\sigma_C)} + (1-\alpha_C)\left(\frac{PLE_s}{1+g}\right)^{(1-\sigma_C)}\right]^{\frac{1}{1-\sigma_C}} ,$$

where $PC$ is the price index of material consumption and $PLE$ is the price of leisure (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.

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.3).

(B.4) $$C_s = \alpha_C \left( \frac{PC_s}{PF_s} \right)^{-\sigma_C} F_s$$

(B.5) $$LE_s = (1 - \alpha_C) \left( \frac{PLE_s / (1+g)}{PF_s} \right)^{-\sigma_C} F_s$$

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

(B.6) $$L_s^S = T - \frac{LE_s}{1+g}.$$

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.

## Intertemporal equilibrium

A necessary condition for reaching a steady state solution is

(B.7) $$1 + r\left(1 - t^D\right) = (1+\rho)(1+g)^{\frac{1}{\sigma_F}}$$

which is a "razor's edge" condition since *r*, $t^D$, $\rho$ and *g* are all considered as exogenous. In the analyses, equation (B.7) is assumed to hold at all points in time.

## 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 of these 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).

In the consumer model 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 0.6, 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 0.4, see also Bye, Holmøy and Strøm (1999) 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 Holtsmark and Aasness (1995).

**Figure B.1. Production technology**

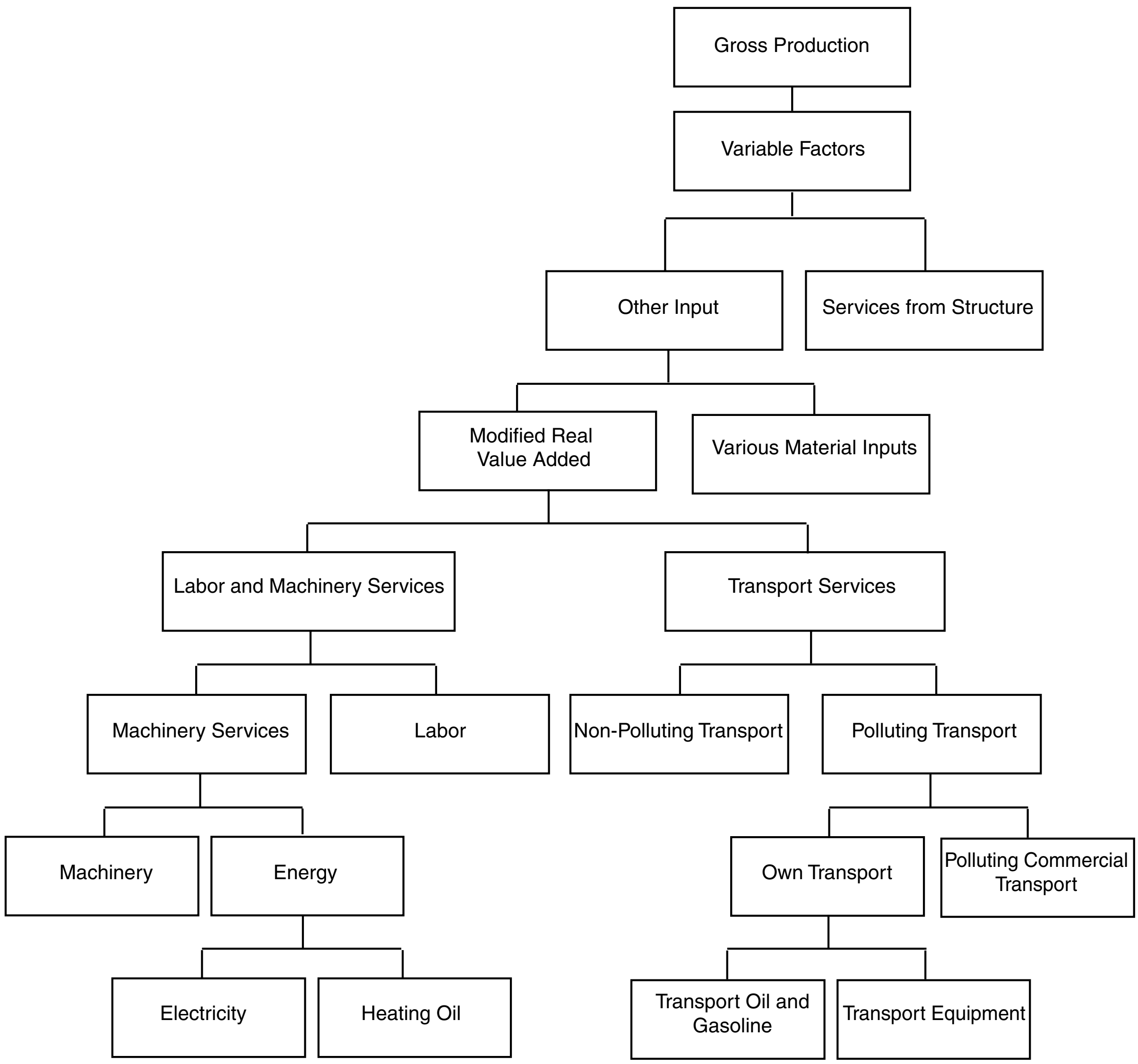
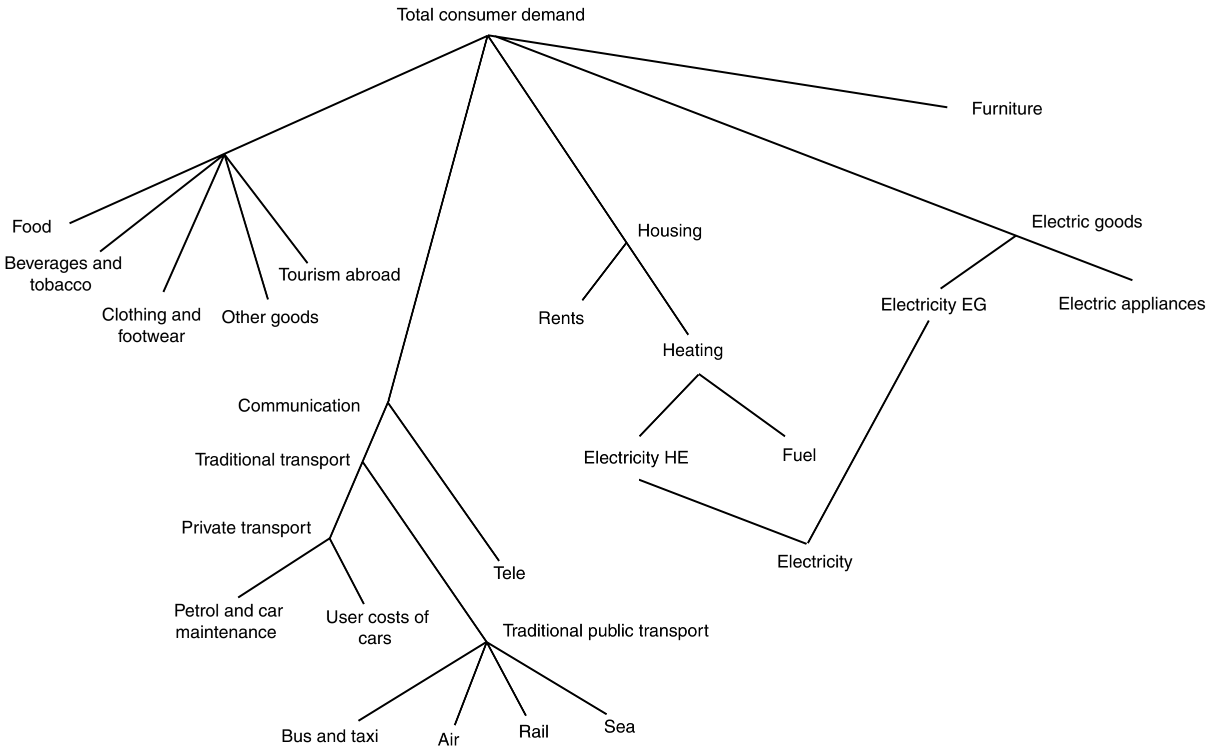


**Figure B.2. Material Consumption**



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