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The Marginal Cost of Funds in the Presence of External Effects

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Abstract

The Marginal Cost of Funds (MCF) is useful in cost-benefit and tax reform analysis. This paper presents general equilibrium estimates of the MCF in an economy with environmental external effects. Environmental externalities affect the estimates in the following way: If increased taxes leads to substitution away from activities that have external effects, then the estimate of the MCF will be lower than would have been the case otherwise. Substitution into activities with external effects will increase the estimate of the MCF. Environmental externalities are uncertain. We treat them as random variables to account for the uncertainty.

Our results indicate that the "base-case" estimate of the MCF is reduced by around 0.2 when environmental externalities are taken into account. The impact of externalities however depends greatly on which tax is being used to increase public revenue. This indicates a significant potential for tax reform.

Keywords: General equilibrium model, the marginal cost of funds, environmental externalities, tax reforms

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1 Introduction

This paper presents estimates of the Marginal Cost of Funds (MCF) in an economy with environmental external effects. We do this because we think that environmental externalities are important in most economies. Estimates of the MCF should reflect these externalities. There exists a substantial literature that gives empirical estimates of the MCF without paying attention to the externalities[1].

The MCF is equal to the marginal cost to society of raising revenue through tax increases for a public project that does not affect private demand and supply schedules. This cost is equal to the money cost of the project plus the cost of distortions due to tax increases. Pigou (1947) referred to the latter term as the "indirect damage" of taxation. A unit size project thus has an MCF value of "one plus the indirect damage". There may be cases where a tax alleviates existing distortions. In these cases, the MCF will have a value below unity, or even below zero if the valuation of the distortions is sufficiently high.

The MCF is input to cost benefit analyses. It can be shown (see e.g. Atkinson and Stern (1974) or section 2 of this paper) that when projects do not affect private demand and supply schedules, the appropriate cost benefit criterion is to let through all projects with the property that the benefit is greater than, or equal to the money cost times the MCF. If the MCF is greater than unity, then the cost of a public project is greater than its money cost. The benefit must also be greater than the money cost for the project to be worthwhile. If the MCF is smaller than unity, the cost of a public project is smaller than its money cost. The benefit need therefore not be as great as the money cost for the project to be worthwhile. If the MCF is zero, the project is self-financing, and is worthwhile regardless of its benefits. If the MCF is exactly unity, the real cost is equal to the money cost. Only in this case should the benefit be compared with the money cost in cost benefit analyses.

The MCF is equally important in analyses of tax reform. If the MCF of one tax is lower than

[1]Examples are Stuart (1984), Ballard, Shoven and Whalley (1985), Fullerton and Henderson (1989) and Jorgenson and Yun (1990) for the US, Hansson (1984) and Hansson and Stuart (1985) for Sweden. There seems to be consensus that the MCF excluding external effects is significantly above unity. The literature is surveyed in Ballard and Fullerton (1992). One study that does include external effects is Ballard and Medema (1992). In this study, a CGE model of the US economy is used to calculate efficiency effects of taxes and subsidies in the presence of externalities. The findings of the paper suggests that the MCF of Pigouvian taxes are substantially below one. The MCF of traditional taxes are reduced when their effects on pollution are accounted for.

the MCF of another, then decreasing the tax with the higher MCF at the expense of the other, will improve welfare.

Conceptually, there are two ways estimates of the MCF may be affected by environmental externalities. One is when the object of taxation is the source of an externality. A tax on the distorting activity will reduce the externality. The value of MCF related to this tax will then be lower than if the external effect had not been accounted for.

Externalities also affect the MCF if taxation leads to substitution into, or away from activities that create distortions. In the former case the MCF is higher than it would have been otherwise. In the latter case it is lower. Whether the impact on the MCF is positive or negative, and how significant it is, is an empirical question that this paper hopefully will shed some light on.

The paper is organized as follows: Section 2 presents the theoretical framework for our study. Section 3 presents our empirical model. This is a static applied general equilibrium model for an open economy. Linked to the model is a sub-model calculating emissions to air and a sub-model estimating environmental external effects. We pay special attention to these sub-models. We treat the external effects as stochastic variables to account for the particular uncertainty involved when estimating them. This makes the MCF a stochastic variable as well. Section 4 presents our "base-case" estimate of the MCF and its frequency distribution. This is the estimate that results if all taxes are increased by the same factor to pay for a public project. Such an estimate is useful for cost-benefit analyses. Section 5 presents estimates of the MCF related to increasing various specific taxes, and different public projects. These estimates are also useful for cost-benefit analyses, but in addition they indicate the potential for tax reform. MCF estimates of different public projects, financed by an increase in all taxes, is presented in section 6. Section 7 concludes.

2 The framework

Consider a static small open economy with a public sector and exogenous producer prices. Public savings are exogenous. Otherwise a public project would be a free lunch within the realm of the model. One tax rate is endogenous in order to clear the public budget. Our CGE model is similar to this economy, as we model a static open economy with exogenous public savings. We may view the economy as the solution to the maximization problem

$$\max_{t_i} \quad W(p+t,y) \quad s.t. \quad t'c=p_g g \tag{1}$$

which just states the fact that the consumer maximizes his utility in an economy where t_i is used to clear the public budget. W is the welfare function, which we take to be measured in units of the numeraire (''money'') and to be independent of public goods (for data reasons), p is the vector of constant producer prices, t is the vector of taxes on consumption activities (one tax is identically zero), t_i is the tax on consumption activity i, y is lump sum income, c is the vector of consumption activities, p_g is the price of the public consumption activity and g is the public consumption activity. The Lagrangian corresponding to the problem is

$$\mathcal{L}=W(p+t,y)+\mu_i(t'c-p_g g) \tag{2}$$

The unique solution to the problem is of course the market outcome (with the market welfare level). Setting up the economy in this way is nevertheless useful to derive the Marginal Cost of Public Funds.

Using the envelope theorem, the money metric utility cost of a unit size public project is in this framework

$$\frac{\partial W}{\partial g}=-\mu_i\, p_g \tag{3}$$

where W now is the optimum welfare level. The optimum level depends on g. Formula (3) says that the cost (indicated by the minus sign) of a unit size public project is the price multiplied by a factor μ_i, the MCF. Note that if **c** was a function of g, this simple relationship would not hold, and the real cost of the project would not be equal to the MCF times the money cost. We reserve the term MCF strictly for the factor μ_i. The literature is somewhat ambiguous at this point[2]. Consider the first order condition of the Lagrangian with respect to t_i. It is equal to zero because t_i is endogenous. We have

$$\frac{\partial W}{\partial t_i}+\mu_i(c_i+t'\frac{\partial c}{\partial t_i})=0 \tag{4}$$

from which we derive the MCF related to increasing t_i as

[2]Our definition of the MCF follows Mayshar (1990). An alternative is to define it as the factor with which one must multiply the cost in cost benefit analysis, see Ballard and Fullerton (1992). The two definitions will give different estimates when projects affect private supply and demand schedules. Our definition perhaps has less elegance in terms of cost benefit analysis, but it has the advantage that it can be utilized immediately in pure (revenue neutral) tax reform analysis.

$$\mu_i = MCF_i = \frac{\frac{-\partial W}{\partial t_i}}{c_i + t' \frac{\partial c}{\partial t_i}} \tag{5}$$

This formula expresses the MCF as the ratio between the welfare cost of increasing a tax (to pay for a project), and the increase in tax revenue. In a first best world, the MCF is unity - taxation is just a transfer of resources from the private to the public sector. In a second best optimum, the welfare cost is greater than the tax revenue because of the efficiency loss that comes with distorting taxes. Thus the MCF is greater than one, and increasing in the required tax revenue. In a second best optimum with negative externalities, Pigouvian taxes will reduce the required tax revenue from distorting taxes. Thus the MCF is lower than if there were no negative externalities, but it is greater than one as long as some revenue from distorting taxes is required, see Sandmo (1975).

Outside of the second best optimum, the value of MCF will depend on which tax is increased to finance expenditure. The reason is that some taxes do more damage than others in a non-optimal situation. Both the nominator and denominator of equation (5) depends on which tax is being increased. Some taxes will have higher MCF values than the optimum value, others lower. It is easy to verify that this fact can be used to design tax reforms. Consider a revenue neutral reform. Such a reform satisfies the two requirements

$$\frac{\partial W}{\partial t_i} dt_i + \frac{\partial W}{\partial t_j} dt_j > 0 \tag{6}$$

$$\frac{\partial t' c}{\partial t_i} dt_i + \frac{\partial t' c}{\partial t_j} dt_j = 0 \tag{7}$$

Combining these, we obtain that t_j should increase if

$$\mu_i - \mu_j > 0 \tag{8}$$

i.e. the tax with the lower MCF should increase. The improvement in welfare is larger if the difference between the two values of the MCF is large. Thus an economy with great differences in its MCF-values will have more to gain from a tax reform than an economy with relatively equal MCF-values. We will see later that one impact of including environmental externalities in the MCF-estimates is that the differences become larger.

Given a method of financing, the value of the MCF will depend on the public project in question. For instance, the MCF of a health care project may differ from that of an education project. This occurs if more tax revenue can be raised in the process of producing health care inputs than from the production of inputs to education services. There are two ways this can happen. One is if the public sector itself pays tax on its purchases (or producers on their output). This of course makes the "real" cost of public purchases lower than the "money" cost. The other is if the producers are heavily taxed on their input purchases, and the producers of these inputs are heavily taxed etc. In primal terms, the marginal productivity of the factors employed is high. Let us expand on the utility function given that there exist environmental externalities. We assume that consumer utility can be written

$$W(p+t,y)=V(p+t,y)+B(p+t,y) \tag{9}$$

where V is the "standard" indirect utility function, and B, which is negative, is disutility from negative environmental externalities. This additive formulation of utility implies that the consumer demand functions do not include environmental externalities as arguments. We assume that B is observable to the agents that are affected (but not a choice variable). It is not observable to the outside observer however, who must treat it as a stochastic variable.

To avoid detail, we will in this section assume that one consumption activity is the source of all damage, and we assume a linear relationship between damage and its source. We write

$$B=-bc_k(p+t,y) \tag{10}$$

where c_k is the polluting activity and b is emissions per unit c_k times disutility per unit emissions.

In this framework the MCF is

$$MCF_i=\frac{\frac{-\partial V}{\partial t_i}}{c_i+t'\frac{\partial c}{\partial t_i}}-\frac{b\frac{\partial c_k}{\partial t_i}}{c_i+t'\frac{\partial c}{\partial t_i}} \tag{11}$$

The MCF is separated into two terms. The first term is the standard expression for the MCF in the case of no externalities. We note that it is unaffected by whether or not we include the externalities. This expression has been estimated in a number of recent papers. The second term is a measure of the influence of t_i on the disutility from pollution. The reason for this separation of terms is of course that utility is additively separable in utility from goods and the environmental externalities.

It is straightforward how the environmental externality adds to the estimate of the MCF. If t_i *increases* the consumption of c_k, the MCF is higher than it would have been otherwise. If t_i *decreases* the consumption of c_k, the MCF is lower than it would have been otherwise. More generally, the question is whether the tax that is increased leads to a substitution into polluting activities, or away from such activities. Of course if i=k the consumption of c_k will fall, substitution is away from polluting activities.

Thus taxes on such items as gasoline and heating fuel will probably have a lower MCF in our framework than they would have had otherwise. This need not imply, however, that the overall MCF is lower for these taxes than for other taxes. Since e.g., the gasoline tax already is higher than most taxes in the Norwegian system, the first term of the MCF is likely to be higher for this tax than for some other taxes. The determination of MCF values is an empirical question to which we now turn.

3 Structure of the model

The following is an account of the model structure with special emphasis on the sub-models for emissions and non economic welfare. Holmøy (1992) gives a more detailed documentation of the pure economic part of the model. Figure 1 shows the structure of the model in a visual form. Our description of the model follows the flow of this figure.

Utility is a nested function of consumption goods and leisure. Note that the environmental externalities are not represented in the utility function. The top level nest consists of a consumption aggregate and leisure. The labour supplies of men and women are in accordance with Norwegian econometric evidence as described by Aaberge, Dagsvik and Strøm (1990) (a 1979 data set), and Dagsvik and Strøm (1992) (a 1986 data set). Men's labour supply depend on the real wage. Women's labour supply depend on the real wage and the number of children. An important piece of econometric evidence for Norway is that the income effect on labour supply is insignificant. This is found both in the data averages, and in a clear majority of individual households in both data sets. (There is a tendency for a negative income effect in the poorest decile, and a positive income effect in the richest decile. These effects cancel in the aggregate). This property of the data will have effects on our results, as both theory and

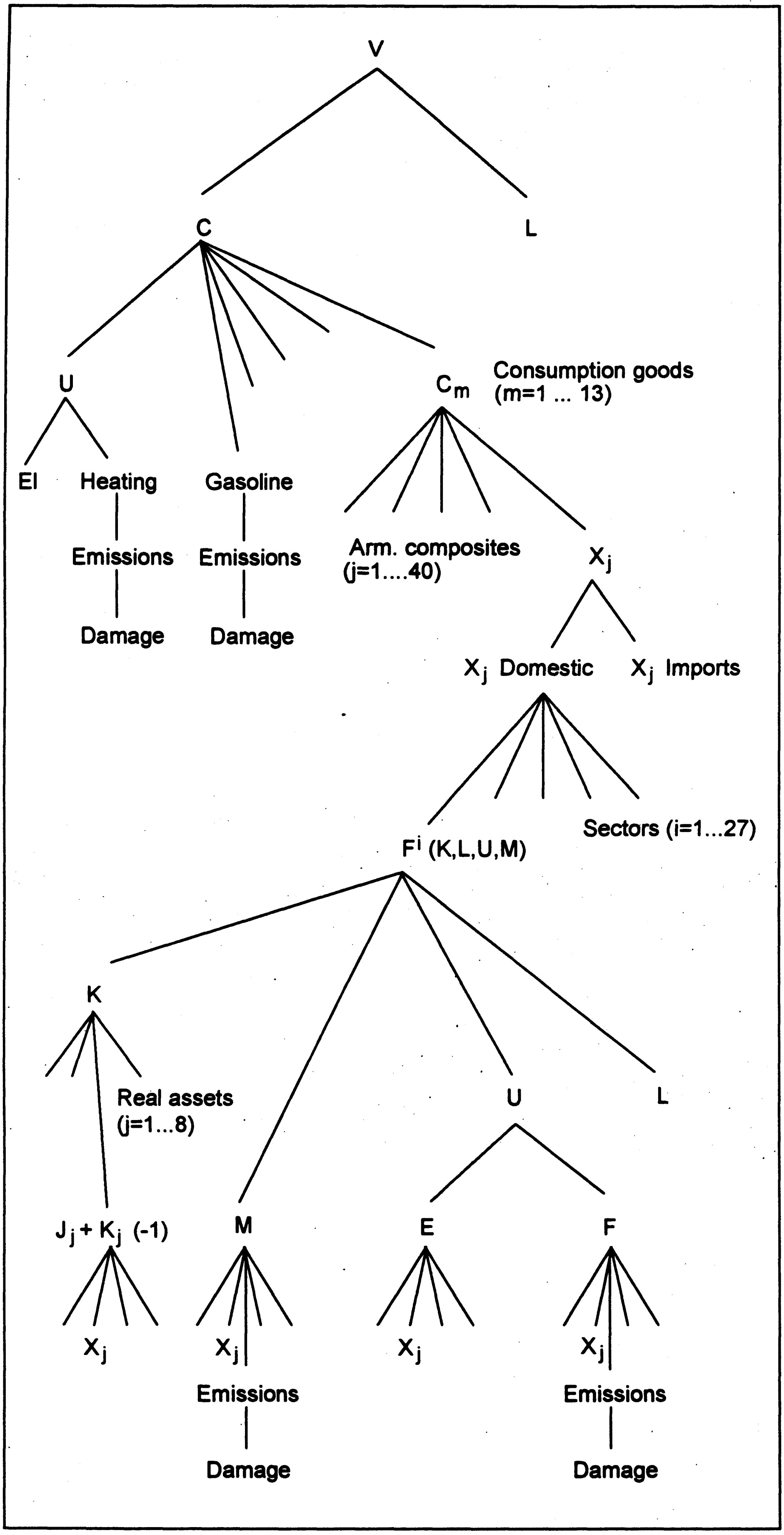

Figure 1. A summary of the model

The labor/leisure choice is described by a CES-type utility function.

Private consumption is described by a LES system of 13 goods.

Energy (U) is a CES aggregate of electricity and fuels.

Each consumption activity is an aggregate of up to 40 Armington composites.

Each composite is a CES aggregate of imported and domestic varieties.

Each domestic variety is produced by one or more of 27 industries.

Industry output is a c.r.s. function of inputs of real capital (K), labor (L), energy (U) and material inputs (M). Generalized Leontief flexible cost functions. Ten sectors have fixed coefficients.

Energy is a Generalized Leontief aggregate of electricity and fuels.

M, E, F, and real investment J are aggregates of Armington composites.

Emissions to air of SO_2, NO_x, CO, CO_2, VOC, CH_4, N_2O and particulates are calculated based on fuel consumption and industrial processes.

Health effects and other damage effects are calculated based on emissions and fuel consumption.

empirical evidence shows that most MCF values depends positively on the size of the income effect on labour supply. The labour supply elasticity of men is 0.37, and that for women (which increases in the number of children) is around 0.9 on average. These figures are close to the 1986 estimates.

Private consumption is distributed on 13 consumption goods according to a linear expenditure system with demographic translating, and a CES aggregate for stationary energy consumption. The parameters are calibrated pooling micro- and macroeconometrics, using the method described in Aasness (1992) and microestimates based on Aasness, Biørn and Skjerpen (1993). Housing (1.3), gasoline (1.5) and some services (1.6) have high expenditure elasticities. The expenditure elasticity of energy is quite low (0.26). When real income falls because a public project is being financed, household demand for the more elastic goods is cut back the most. When prices increase, consumption of the most elastic goods decreases most. These properties of the data will influence our results. The elasticity of substitution within the energy aggregate is 1.5. This is based on the econometric work of Bye (1989). An elasticity of substitution of 1.5 implies high price elasticities of heating fuel and electricity for a given level of energy consumption. It says that the demand for heating fuel will increase 1.5 per cent compared with electricity when the relative price of electricity increases 1 per cent, and vice versa.

The separability assumptions place some restrictions on the allowed responses to economic signals that should be born in mind. For instance, one could argue that the demand for gasoline increases (cet.par.) when leisure increases. In our model this is ruled out by separability.

Each good of the model is a fixed coefficient mix of up to 40 Armington composites. Fuel, for instance, consists of the three composites transport fuels (predominantly gasoline), other fuels and (in some sectors) wholesale and retail trade to take account of handling and service. The domestic varieties of the Armington composites are produced in fixed shares in one or more of the 27 sectors of production.

Production behaviour and technology are modeled in dual terms by Generalized Leontief (GL) cost functions. Output (gross production) is produced according to a constant return to scale technology. Two stage budgeting is assumed. At the "top" level there are four input factors, labour, real capital, material inputs and energy. At the "bottom" level, demand for energy is divided into electricity and fuels according to a GL sub function. Material input is a fixed coefficient aggregate of the 40 Armington composites. Ten sectors (seven public sectors, two sectors related to oil, and electricity production) have exogenous input coefficients. In the public sectors and oil, production volumes are exogenous as well.

The parameters of substitution in the cost functions are estimated on national accounts data by Bye and Frenger (1985). The estimates are similar to those reported in Longva and Olsen (1983), see also Glomsrød, Vennemo and Johnsen (1992). An important reason for estimating a flexible form technology has been to let the data decide whether energy and capital are complements or alternatives. It turns out that capital and energy are macro complements, most particularly in traditional exporting industries, as are material inputs and energy. Energy and labour are alternatives, as are capital and labour. All factors (including capital) are assumed to be freely moveable and malleable. With this cost structure, we may expect producer taxation of energy to reduce the productivity of capital and increase the productivity of labour, leading to a lower rate of return of capital, higher wages and increased labour supply (cet.par.). Capital and net investment (which is backward-looking) are exogenous. Gross investment is endogenous, as sector/asset specific depreciation rates influence the economy wide capital depreciation.

The exchange rate is the numeraire of the model. Goods are measured in constant base-year value terms, as prices (except user costs of capital and wages) are equal to unity in the base year of the model. Gasoline and other fuels are however measured in physical quantities as well, to facilitate the calculation of emissions, which is based on physical fuel use.

To get an idea of the workings of the model, begin by arbitrarily fixing the wage rate and rate of return to capital. The zero profit condition and the input demand functions will then simultaneously find commodity prices and the cost-minimizing techniques in terms of input coefficients. The quantity side of the model may be solved as a traditional input-output model with fixed coefficients. The requirement that real capital demand equals exogenous supply determines the scale of production. The demand for labour, and the current account follows as residuals. Now relax the assumption of a fixed wage and rate of return to capital. If the residual demand for labour is low compared with supply, the wage rate decreases to ensure labour market equilibrium. If the residual current account is too low compared to the exogenous requirement, the rate of return adjust downwards, to improve ''competitiveness''. It is useful to think of the wage and the rate of return as an implicit exchange rate.

The model tracks the emissions to air of eight pollutants, of which SO_2, NO_x, CO and particulates are assumed to cause local environmental damages[3]. For each industry, emissions from mobile combustion (EG), stationary combustion (EF), and industrial processes (EM) are calculated, based on projections of the use of gasoline (G), fuel (F) and material inputs (M).

[3]The other emissions calculated by the model are VOC, CO_2, CH_4 and N_2O. Possible costs caused by these pollutants are not accounted for.

Emissions from private consumption are linked to the use of gasoline and fuels. We have the following equations:

$$EG_{i,s}=CG_{i,s}\times G_i \tag{12}$$

$$EF_{i,s}=CF_{i,s}\times F_i \tag{13}$$

$$EM_{j,s}=CM_{j,s}\times M_{j,s} \tag{14}$$

where j runs over production sectors, i runs over production sectors plus the household sector and s is the pollutant. $Ck_{i,s}$, k=G,F,M, are coefficients calculated as the ratio between base year type k emissions of pollutant s from sector i, and the use of emission carrier k in sector i (Rypdal (1992)). Estimates of base year emissions are in accordance with the Norwegian national emission inventory.

Our final sub-model calculates a probability distribution for economic benefits from reduced levels of local air pollution and traffic volume. There exists a number of studies on the valuation of environmental goods in Norway, see the survey of Navrud and Strand (1992) for many examples. Many valuation studies concern phenomena that have small links to the national economy, either because they are small relative to the national economy, or because their relation to economic variables is unclear. The studies that lend themselves to integration in a CGE model are the ones that can be linked to economic variables at the level of aggregation in the model, and studies likely to have a non-negligible national importance. Our model includes acidification of lakes and forests, corrosion of some important materials due to an acid atmosphere, and costs of health deterioration. Polluting activities also impose other externalities than pollution costs on society. Traffic noise, accidents, road damage and efficiency loss during traffic congestion are specified in the model.

As external effects are not priced in the market, their values are difficult to estimate. The studies forming the background for our estimates rarely conclude with any specific value on the environmental cost in question, but assign the cost to a likely interval. As there is no information concerning the probability distribution of any of the estimates, we assume them to be independently and uniformly distributed between the lower and upper bound of the reported intervals. The appendix gives details of the sub-model and the values of likely intervals for the estimated parameters.

The distribution of total benefits is a sum of products of uniformly distributed variables. From this information one can readily calculate the expectation and variance of the distribution of total benefits. We are however also interested in the full probability distribution of the total benefits, for instance in order to estimate the likelihood for the MCF to be less than one. As the full distribution is tedious to compute, it is approximated by stochastic simulations. The sub-model repeatedly draws parameter values from the respective uniform distributions, and calculates the probability distribution of the difference in total costs or benefits between two scenarios.

We treat the externalities described by the model as consumer externalities while strictly speaking they are a mixture of producer and consumer externalities. Most or all of corrosion and road damage (public production) are producer externalities. The more or less pure consumption externalities are acidification of lakes and traffic noise. The rest is shared by producers and consumers: acidification of forests, costs of health deterioration, traffic accidents and congestion. The reason we treat all externalities as consumer externalities is partly for simplicity, and partly because the data material does not allow us to separate out consumer and producer effects. We believe that the mistake we make is not too great, as forgone production corresponds to foregone consumption. We view our simplification as one of the sources of uncertainty of the MCF-estimates.

Some externalities directly affects the public budgets. Road maintenance is for instance almost completely undertaken by the public sector in Norway. Parts of the costs associated with health damages and traffic accidents are carried by central and local health services. Changes in traffic volume and local pollution may accordingly alter the revenue required to maintain existing standards on some public goods, and by that the level of taxation. Effects like this are however not accounted for in the present model.

We now turn to a description of the individual externalities. The estimates concerning forest damages are based on a project report from The Commission of Forest Damages (Ministry of Environment, 1988). Forest damages in Norway are mainly caused by high ozone levels, abundant nitrogen supply and acidification of the soil. The sub-model links benefits from less forest damage to reduced SO_2 and NO_x emissions. Forest acidification damages from SO_2 emissions are higher than damages from NO_x, but NO_x also contributes to the damages through the formation of ozone. We therefore assume that marginal damages from NO_x and SO_2 are equal. Pollution costs on forests includes costs caused by reduced growth (about two-thirds of total forest damage costs), and costs associated with reduced recreational value of the forests (one-third of total costs). The main source of Norwegian forest damages is however transboundary pollution. Domestic pollution causes only between 5 and 10 per cent of the damages.

NO_x and SO_2 emissions also cause acidification of fresh water lakes. This includes losses in recreational values, losses in sport fishing possibilities and losses in catch. Total recreational value and the total value of sport fishing possibilities are estimated by willingness to pay studies (Strand, 1980). The State Pollution Control Authority reports that approximately one tenth of Norwegian lakes are is heavily damaged due to acidification. We assume that the same proportion of recreational and sport fishing possibilities is destroyed. Almost 80 per cent of the total lake acidification costs are due to losses in sport fishing possibilities, while losses in recreational value accounts for about 16 per cent. The value of the losses in catch is estimated by the Ministry of Environment and accounts for the last 4 per cent of total lake acidification costs. As with forest damages, the main source of acidification is transboundary pollution. Norwegian emissions cause only 5-10 per cent of the damages.

Several different pollutants cause damages to real capital (Glomsrød and Rosland, 1988). The costs of corrosion will depend on the size and composition of the capital stock. The sub-model however relates changes in corrosion costs to changes in SO_2 emissions only, effectively ignoring that the public project may alter the composition of the capital stock.

Costs of health deterioration are based on analyses by the State Pollution Control Authority. The analyses concern health benefits from reduced emissions of SO_2, NO_x, CO and particulates in the capital and largest city, Oslo. Emissions have to exceed a threshold level to cause health damage. The threshold levels are recommended by the World Health Organization (WHO). Cost estimates associated with one person being above these threshold levels are based on studies carried out by Lave and Seskin (1977). They study the link between sulphur concentration in the air and health costs due to increased mortality and morbidity. On recommendation from an expert group appointed by the State Pollution Control Authority, the estimates are reduced by more than 50 per cent to account for the lower concentration levels in Norway compared with the US. The health cost from CO emissions is adjusted upwards compared to the cost of SO_2 emissions. This is to account for the fact that while most other pollutants affect only a relative small and particularly vulnerable part of the population, CO affects everyone. The health cost from NO_x emissions is adjusted upwards to account for high concentration of NO_x compared to other pollutants. The cost caused by emissions of particulates is adjusted upwards because particulates carry toxins and substances that may cause cancer.

Only the part of changes in emissions that occur in densely populated areas will lead to changes in health quality. In the sub-model, these fractions are stochastic variables. As a lower limit, we assume that only emissions that occur in Oslo cause any health damages. As an upper limit we assume that the five most populated areas in Norway are affected in the same way. However, neither the main model nor the sub-model for local benefits has a geographical dimension. We take the fraction of total mobile and stationary emissions occurring in Oslo in the base run as estimates for the lower limit. The upper limit is estimated correspondingly. The effects that the public projects we consider may have on the habitational pattern is thereby ignored.

Estimates of costs associated with traffic are also based on studies by the State Pollution Control Authority and concerns the capital Oslo. The estimates include costs of road maintenance and health services associated with accidents, productivity losses due to traffic noise, congestion and accidents, and welfare losses due to noise and accidents. We link traffic costs to the changes in gasoline and auto diesel demand. Road capacity is assumed constant. As with health damages, the geographical allocation of a given reduction in traffic volume is important when calculating the benefits from less congestion and noise. We assume that 10 per cent of the change in gasoline and auto diesel consumption will cause changes in congestion and noise costs. This number corresponds to the ten largest Norwegian cities' share of total diesel and gasoline consumption in the model base year.

Our description of the sub-model for environmental benefits has made it clear that these either are tied to emissions of various components, or to gasoline and auto diesel. However, heating oil, gasoline and auto diesel are the dominant sources of emissions. The externalities are therefore (directly and indirectly) tied to consumption of heating oil, auto diesel and gasoline.

We believe that the sub-model described above includes the main local environmental costs of emissions and traffic. There are however some effects that are left out, mainly because no appropriate data could be found. Damages caused by high ozone levels near the ground are for instance only included as an upward adjustment in the contribution of NO_x to forest damages. Ozone however also causes damages to health and agriculture. Our estimate of corrosion costs does not include damages to cultural valuable buildings or damages due to other pollutants than SO_2. Potential costs due to global warming are not included. Norwegian emissions of greenhouse gases however contribute only marginally to climatic changes and any reduction in emissions would only cause marginal benefits.

4 Base-case estimate of the MCF

To estimate the MCF, we proceed in the following way: Our starting point is a reference equilibrium calibrated to the Norwegian National accounts of 1987. In our base-case estimate, we introduce a small (around 100 mill. NOK, or $15 mill.) public project that consists of purchases of material inputs, electricity and fuel in proportions fixed from the reference equilibrium. The revenue required for this project is covered by a proportional increase in all taxes. Transfers are unchanged. To estimate the MCF, we use a discrete version reminiscent of formula (11). The total loss in private utility, calculated as utility from goods and leisure plus the change in the value of the externalities, is in the denominator. The value of the public purchases of goods and services is in the nominator. We make 5 000 independent draws from the probability distribution of each of the environmental costs involved. The probability distribution of the MCF is then calculated. The estimate of the MCF is a measure of the expected average MCF of the economy, i.e. the average of the MCF values of the individual taxes. This average is also informative of the MCF of the second best optimum. We find it likely that the optimum MCF value is lower than the average of the non-optimal values[4].

Table 1. Base case estimate of expected marginal cost of funds.

The Marginal Cost of Funds	Contribution from ordinary economic activity	Contribution from external effect
1.48	1.67	-0.19

Table 1 shows our base-case estimate of the MCF. We find the MCF to be significantly above unity. The estimate of 1.48 means that when the cost of increasing taxes is taken into account, the benefit from a project that does not affect demand and supply need to be 148 per cent of the

[4]This is not obvious. It depends on the weights being used to calculate the average. In our base-case, we form the tax rate Θt_i and increase Θ. This gives an estimate of

$$\bar{\mu}=\Sigma_i \alpha_i \mu_i$$

where the weights are the impact on revenue

$$\alpha_i=\frac{t_i(c_i+t'\frac{\partial c}{\partial t_i})}{\Sigma_i t_i(c_i+t'\frac{\partial c}{\partial t_i})}$$

Whether $\bar{\mu}$ is higher than the optimal μ depends on the correlation between μ_i and α_i.

money cost to be worthwhile. The MCF would however have been 1.67 if negative external effects were not accounted for. Thus the external effect contributes negatively to the MCF. Obviously increased taxes alleviate the environmental externalities.

Bear in mind that the externalities are tied to consumption of heating oil, auto diesel and gasoline. If consumption of these goods decrease, the environmental externalities decrease as well. There are two effects that explain why the externalities decrease. We may call them the *activity effect* and the *intensity effect*. The activity effect is the effect of the change in the activity level. The intensity effect is the effect of the change in fossil fuel intensity.

It is easiest to treat consumption and production separately. In the present simulation, it turns out private consumption falls more than public consumption increases. Fuel is saved because demand is scaled down. That is, assuming for the moment that private and public consumption use fuels in equal intensities, fuel is saved because the sum of private and public consumption goes down. This is the activity effect. What happens is that the real wage decreases when taxes increase. This has two reasons. One is that the income tax increases. The other is that prices increase, mainly because the VAT increases. When the real wage falls, people substitute away from labour into leisure - and reduce their consumption.

The activity effect appears on the production side as well, because when demand falls, production is scaled back, which at constant fuel demand per unit of output saves fuel. Labour is saved as well. Thus labour demand is scaled back to meet the reduction in supply.

The other reason for the save on the environment is that the fossil fuel intensity in public consumption is lower than the corresponding intensity in private consumption. This means that even if the activity effect is absent, aggregate fuel consumption will fall. Note that the fuel intensity in public consumption is fixed, but the fuel intensity in the part of private consumption that is reduced (the marginal fuel intensity) depends on the configuration of prices and income changes that brings about the reduction. That is, it depends on which tax is increased (as does the activity effect). In the present simulation the intensity effect in consumption is not very important, as the fuel intensity is only one percentage point lower in public consumption (six versus seven per cent).

The intensity effect in production has to do with internal and external substitution, that is whether there is internal substitution away from fuel inside industries (because of factor price movements), and whether there is external substitution away from fuel intensive industries. In the present simulation, the fuel intensity in industries increases, stimulating (cet.par.) the externalities. Thus, total fuel demand from industries is approximately constant. The activity and intensity effects in production is of approximately the same size.

We conclude that it is a real wage cut and subsequent substitution away from labour that reduces the externalities in this scenario. The expected contribution from the external effect is around fifteen per cent of the total estimate of the MCF. This is certainly too large to be ignored. On the other hand, both 1.48 (with external effects) and 1.67 (without such effects) lie in the interior of the interval for the MCF's that are estimated in the literature.

Figure 2 shows the probability distribution of the MCF. The figure shows that it is highly likely for the MCF to be between 1.4 and 1.6. The ten per cent decile is 1.42, and the 90 per cent decile is 1.54. If all environmental costs takes on their minimum value, the MCF estimate is 1.61. The probability that the "true" MCF is equal to or larger than the traditional MCF (1.67) is accordingly zero. If all environmental costs take on their maximum value, the estimated MCF is 1.31. It should be clear from these figures that even when accounting for the uncertainty, the MCF is quite high. Even in the most favourable case, the benefit need to be around 130 per cent of the cost for a project to be worthwhile. Keep in mind that this is an average figure, however. As we will see below, the MCF varies a great deal between means of financing.

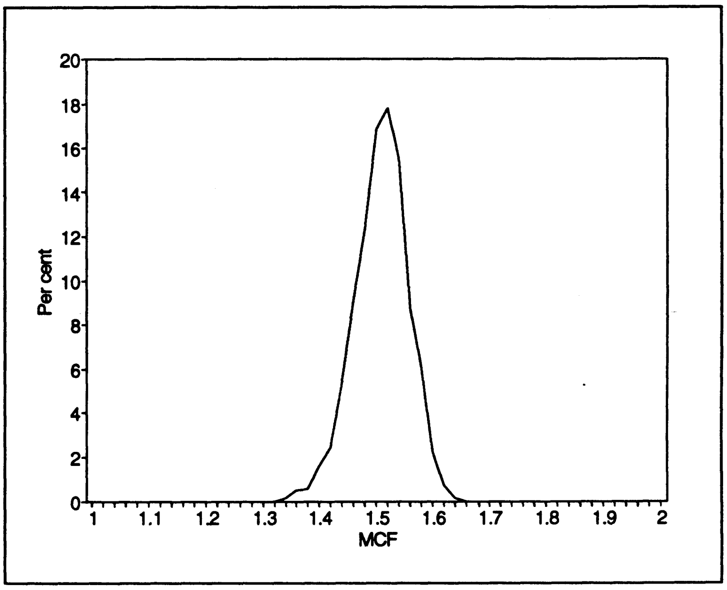

Figure 2. Probability distribution of the base-case MCF

Table 2 shows the contribution of the different external effects to the overall MCF estimate. The most important contributors are the health benefit of reduced NO_x emissions, and the benefits associated with reduced traffic volume. The reason NO_x emissions are more important for health than other emissions is that the project implicitly reduces NO_x emissions more than other emissions (80 ton less NO_x, versus 47 ton less SO_2 and only 4 ton less particulates). NO_x emissions are mainly a function of gasoline and auto diesel consumption (there are still many cars without catalytic converters in Norway), while SO_2 is tied to heating oil and some material inputs. The numbers indicate that gasoline consumption is reduced more than heating oil consumption. This has to do with the differences in price and income elasticities between the two (recall that gasoline is much more elastic), and on the production side with the fact that total

Table 2. Some economic benefits of a tax increase. Negative contributions to the MCF and per cent of change in total benefits

Forests and lakes	0,0008	0,4
Health benefits	0,0621	32,4
NO_x	0,0589	30,8
CO	0,0001	0,1
SO_2	0,0014	0,7
Particulates	0,0017	0,9
Corrosion	0,0020	1,0
Traffic accidents	0,0356	18,6
Traffic congestion	0,0299	19,0
Road damage	0,0363	15,6
Noise	0,0248	13,0
Total	0,1915	100,0

industry fuel demand does not change much. Industries mainly consume heating oil.

Another part of the reason for the greater benefit from NO_x reductions is that a given reduction in NO_x affect more people than the same reduction in, say SO_2, since NO_x concentrations are higher to begin with. A third part of the explanation is that per-affected-person health damage from NO_x is valued higher than damage from SO_2. This too is due to concentration levels.

The highest reduction in emissions occurs for CO, which has gasoline as its main source. It declines 570 tons. The reason the health benefit from this is small, is that CO concentrations are small to begin with. Evaluated in terms of the size of the likely intervals, health effects in general are among the most uncertain estimates in the model. The upper values are more than five times as high as the lower values.

Society also benefits from less noise, fewer accidents and less road damage, in addition to a considerable road traffic efficiency gain. These are tied to consumption of gasoline and auto diesel, and reflect the decrease in the demand for those goods. The uncertainty in the size of these benefits is also considerable: It ranges from an upper value that is three times the lower value for noise and congestion, to 6.5 times higher for accidents.

Smaller benefits follow from reduced acidification of forests and lakes, and reduced corrosion. The reason is not that these are insignificant problems, but that the problems are caused by European emissions of SO_2, NO_x and some other gases.

5 Financing and the MCF

This section discusses how different ways to finance a public project may influence the MCF. We look at the same general project as before. The methods of financing we consider are income tax financing, VAT-financing, lump sum financing, gasoline tax financing, mineral oil tax financing and CO_2 tax financing. The lump sum tax alternative is perhaps best interpreted as a reduction in lump sum type transfers like social security. Together these methods of financing account for around 3/4 of total tax revenue and transfers in Norway.

As in the base-case, the MCF is the sum of two parts, the "traditional" MCF, and the impact from the external effects. Some results concerning the traditional MCF are given in table 3.

Table 3. The traditional MCF related to different means of financing

All taxes	1.67
Lump sum tax	1.17
Income tax	1.75
VAT	1.35
Gasoline tax	1.76
Mineral oil tax	1.71

We note that there are considerable differences in the traditional MCF between ways of financing. The poll tax is the cheapest, and financing through the gasoline tax is the most expensive. Income tax financing is also quite expensive.

These result for the traditional MCF can to some extent be explained by the additive structure of consumer utility. The poll tax has the lowest MCF, because it only has income effects, while other taxes have substitution effects as well. More substitution is not necessarily the same as more distortion of course. It all depends on how the substitution interacts with existing distortions. When the utility function is additive, it is however possible to show that more substitution does indeed mean more distortion.

One can also show that an additive utility function favours indirect taxation over direct taxation, which explains why the MCF of the income tax is high. It can also be shown that when a tax is high in an additive system, the cost of increasing it further is high. This explains the high traditional MCF of the gasoline tax. See Vennemo (1993) for the results on the traditional MCF under additive utility.

The MCF of the VAT is best explained by the linear homogeneity of the budget constraint. From the budget constraint, increasing a comprehensive VAT is equivalent to increasing the income tax and the poll tax. Therefore the MCF of comprehensive VAT financing will lie between that of the poll tax and that of the income tax. The Norwegian VAT is not totally comprehensive, as some services are exempted from VAT. But it is close enough to make the analogue with a comprehensive VAT relevant.

Similarly, increasing all taxes is equivalent to increasing the VAT and the income tax, plus some smaller taxes. Therefore we would expect the MCF of increasing all taxes to lie between that of the VAT and the income tax, as indeed it does.

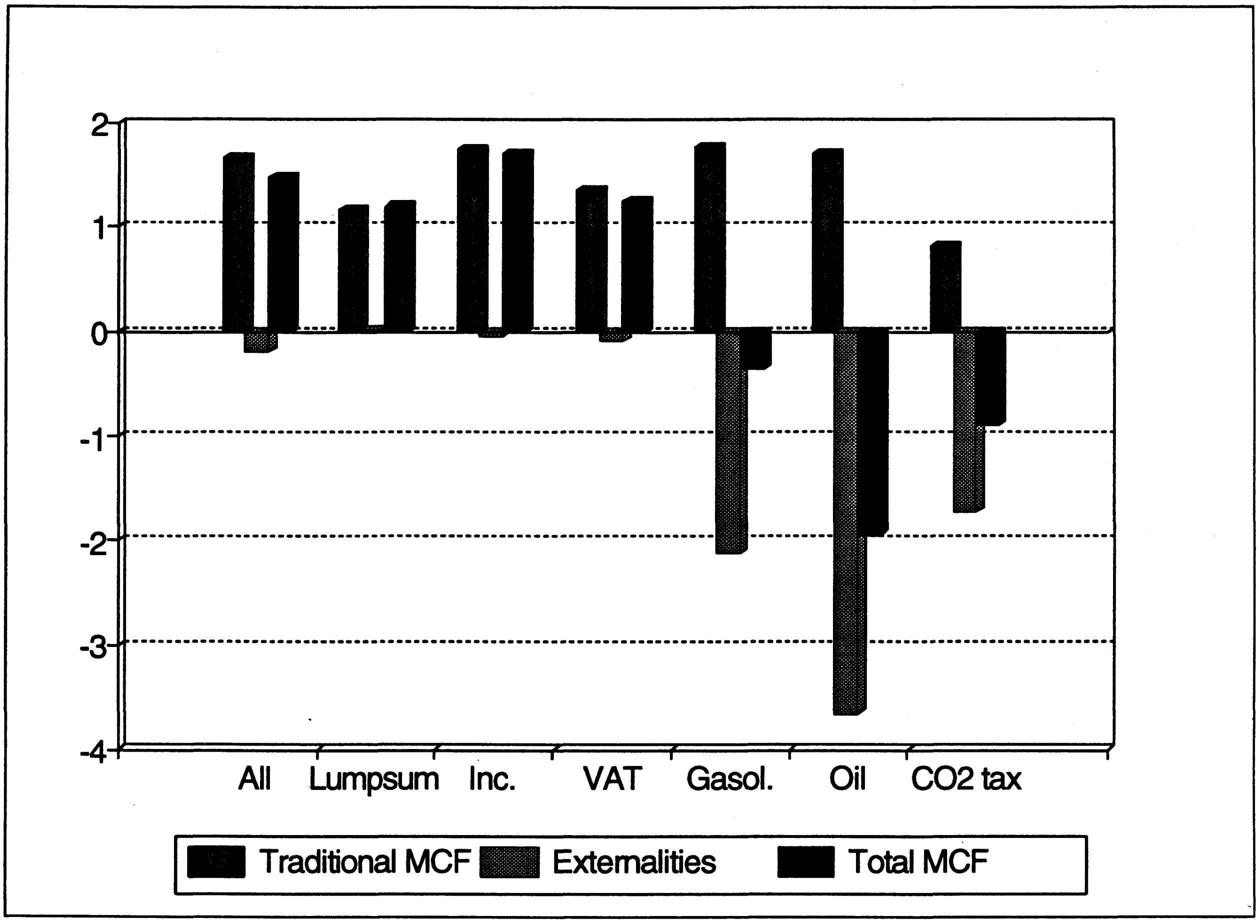

Figure 3. Traditional MCF, impacts of external effects and total MCF under different means of financing

As figure 3 shows, both the spread of MCF-values and the ranking of taxes is turned upside down when environmental externalities are taken into account[5]. The negative MCF-values related to taxes on fossil fuels and carbon makes perhaps the biggest impression. A negative MCF value means that the projects is self-financing in the sense that the benefit *from raising revenue alone* is larger than the cost. The consumer values reduced pollution more than she dislikes higher taxes. Note that this is more than a standard statement that the tax on fossil fuels is too low to optimally correct for externalities. In the standard case, it is assumed that the tax revenue is returned to the consumer. In our case, the consumer values reduced pollution more than she dislikes higher taxes *and* the fact that the tax revenue will be wasted.

Taxes on fossil fuels all cause great reductions in external effects. In the case of the gasoline tax, the reason is the intensity effect: More than 60 per cent of total decrease in private consumption is gasoline consumption. The reason is that the price of gasoline increases. The price

[5]The exact values are: Lump sum: 1.20, income tax: 1.70, VAT: 1.26, gasoline -0.35, mineral oil -1.94 and CO_2 tax -0.90.

increase is not dramatic: The consumer price of gasoline increases 0.7 per cent, compared with constant, or slightly decreasing prices of other consumer goods. But since all effects are marginal, the relative response in gasoline consumption is nevertheless considerable. The size of the response of course has to do with the large price elasticity of gasoline.

Figure 4 shows the probability distribution of the MCF of the gasoline tax. The uncertainty in the MCF estimates is much larger in this case than in our base case. This is because the MCF is the sum of two terms, of which one is treated as a non-stochastic variable (the traditional MCF) and the other is treated as a stochastic variable (the disutility from negative external effects). As one may see from figure 3, the stochastic term in the base case is quite small compared to the fixed term. In the case of the gasoline tax, the fixed term is dominated by the stochastic term.

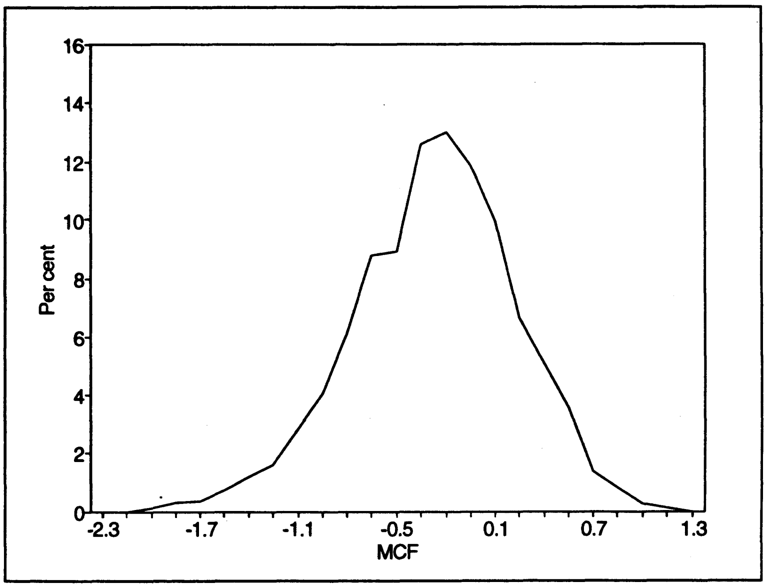

Figure 4. Probability distribution of the MCF of the gasoline tax

The estimated expected MCF of the gasoline tax is -0.35. The probability for the MCF to be positive is 0.24. The probability for the MCF to be above one is however almost neglectable . If all environmental costs take on their minimum values, the MCF is 1.07, which is well below the traditional MCF of 1.76. The minimum value of the MCF is -2.10, which occurs if all environmental costs take on their maximum value.

Why is it so beneficial to decrease gasoline consumption? Calculations by Brendemoen et.al. (1992) show that the damage per litre amounts to around 7 NOK. By contrast, the gasoline tax was only 2.20 NOK. Thus consumers do not pay nearly the true social cost, which leads to a significant over-consumption. If we had performed a series of simulations in which the tax on gasoline gradually had been increased towards 7 NOK, we would expect the MCF to climb past zero, and eventually past one.

The tax on mineral oil yields even greater benefits than the gasoline tax. This is because of its effect on diesel consumption. Brendemoen et.al. estimate the external marginal cost of diesel consumption to be over 9 NOK per litre, while the tax on mineral oil is only 0.15 NOK (in

1987)! The other kinds of mineral oil generate much smaller externalities by comparison (less than 0.50 NOK).

Both households and industries reduce their mineral oil consumption, but the scale of production doesn't change much. The intensity effect explain the reduction.

The model assigns diesel a fixed share of mineral oil. That is slightly inaccurate. Households hardly consume diesel at all, whereas industries have a higher diesel share than the average assumed in the model. When the mineral oil tax increases, households switch their heating requirement from fuel to electricity. This contributes about 35 per cent of the total reductions in externalities as measured by the model, but hardly anything of it is diesel. One could therefore argue that the reduction in externalities should actually be 35 per cent lower than measured by the model (giving a MCF in the case of the mineral oil tax of -0.66). That would be an overstatement, however, because the industry diesel share in reality is higher than assumed by the model, and because household consumption of heating fuels do carry some externalities.

Given the size of the externalities related to the gasoline tax and mineral oil tax, it is not surprising that there is also a significant reduction in (local) externalities related to the CO_2 tax. One would maybe expect, however, that the CO_2 tax would place itself in between the two others in terms of reductions in externalities, as it is a tax both in gasoline and mineral oil. The reason that is not the case, is that the CO_2 tax has a broader basis than the other two. In particular, the CO_2 tax incorporates process emissions in industries, which do not create health damage.

An interesting aspect of the CO_2 tax is that the conventional MCF-estimate (excluding external effects) is below unity. This is due to the following general equilibrium effect: The tax increases the unit cost of producers, including exporters. The increase in cost decreases the rate of return and the wage rate to restore competitiveness. The decline in the wage level extends to wages in the public sector. Thus public labour costs go down. This saves tax payers money and helps pay for the project. The necessary increase in the CO_2 tax is so low that the consumer decline in "conventional utility" money equivalents is lower than the value of the project itself, yielding a traditional MCF below one.

The other alternatives are not vulnerable to external effects. In the case of income tax financing, which is the most expensive once external effects are accounted for, one would maybe think that the activity effect would reduce the externality considerably. The reason is that it reduces the real wage, reduces labour supply, and eventually reduces the size of the economy. The activity effect is however outweighed by the intensity effect in production, where producers substitute away from labour into heating oil to a greater extent than in other scenarios.

Lump sum financing is the only method of financing we have looked at that actually increases the external effects. The reason here is the intensity effect. When only income effects are at work, the small income elasticity of heating oil in private consumption makes the private reduction in heating oil consumption less than the public increase. At the same time, the activity effect is less pronounced, making the reduction in private consumption smaller than in the other scenarios. If labour supply had depended of income, the activity effect would have been more important. If labour supply had fallen with lump sum income (as is often assumed), a lump sum tax would have increased labour supply, which would have increased private consumption, expanded the economy, increased the demand for fuels and worsened the external effect more than in our simulation.

The case of increasing all taxes lies in the middle in terms of the importance of the externalities, as it is an average of the specific taxes. This section has however shown that the average covers an enormous spread in the importance of the external effects between different sources of revenue. Taxes on fossil fuels are excellent candidates for financing public expenditure. A tax reform where taxes on fossil fuels are increased, and the VAT and labour income tax is decreased, looks promising.

6 Projects and the MCF

This section discusses how the MCF may differ between projects in different branches of the public sector. The branches we consider are defence, central and local education and research, central and local health service, and "other" central and local services. All projects are equally large (100 mill. NOK, or $15 mill.), and are financed by an increase in all taxes. The results are given in table 4.

As table 4 shows, there are some interesting differences in the MCF between projects. The largest MCF (central health care) is 17 per cent larger than the smallest (central education and research). The presence of external effects tends to make the differences larger. The MCF of local health care (then the highest) is fourteen per cent larger than that of central education and research before the external effects are taken into account.

Comparing local with central services, there is no reason to say that one is more expensive than the other. There is a weak tendency for the external effects of local services to be greater than those of central services, however. Comparing health care with education, defence and

Table 4. The MCF of different projects. Financed by increasing all taxes

Project	Total MCF	Trad. MCF	External effects
General project	1.48	1.67	-0.19
Defence	1.49	1.68	-0.19
Central education and research	1.39	1.57	-0.19
Local education and research	1.47	1.66	-0.19
Central health care	1.63	1.72	-0.09
Local health care	1.55	1.79	-0.24
Other central services	1.42	1.64	-0.21

"other", it is clear that health care have the most expensive projects, and education have the least expensive. Defence and "other" are in the middle.

The required increase in the tax rate is larger for the more expensive projects. As noted in section 2, one reason some projects require a higher increase in the tax rate than others is that some producers pay less tax than others. Some producers are subsidized even. Another reason is that the public sector itself pays tax on its purchases. Some projects bring in less tax from the public sector itself than others.

A high tax rate tends to be reinforced by the system. For instance, a high tax makes the consumer substitute away from labour into leisure because a high tax generates a greater fall in the real wage. The government loses tax revenue twice from such substitution. It loses revenue from the wage income tax, and it loses VAT revenue (and revenue from excise taxes).

Despite the interesting differences between projects, the size of them is much less than between methods of financing. We would say the differences are smaller than the likely interval of uncertainty in the estimates.

7 Concluding remarks

In this paper we have estimated the MCF of different taxes and kinds of public expenditures, when welfare effects from environmental changes are accounted for. We summarize our findings in the following conclusions:

1. A general public project financed by a proportional increase in all taxes has an expected MCF of 1.48. The traditional MCF of the same project is 1.67. As taxes increase, real wages decrease and households substitute consumption goods for leisure, causing polluting activities to decrease. Accounting for reduced environmental externalities significantly reduces the MCF. When the negative external effects take on their minimum values, the MCF is 1.61.

2. Including external effects in the MCF estimates of specific taxes is of great importance. Measured by the traditional MCF, lump sum financing is the cheapest way of financing a general public project, while income taxation, oil and gasoline taxation is the most expensive. Accounting for changes in externalities alters this order dramatically. Taxes on gasoline and oil by far become the cheapest ways of financing a public project.

3. The large differences in MCF between taxes suggest a considerable potential for welfare gains through tax reforms. Which taxes to increase and which ones to reduce in order to improve welfare is highly dependent on the inclusion of externalities in the MCF estimates.

4. The MCF differs somewhat between different public projects.

Our results can be compared with those of Ballard and Medema (1992). In that paper, pollution is caused by production processes only and it is linked to the level of output. Externalities caused by consumption is not considered. The polluting industries have the option to adopt abatement technology in the presence of a Pigouvian tax or subsidy, causing inputs of capital and labour to increase.

This is similar to the explicit factor substitution that takes place in our model. A gasoline tax for instance causes producers to substitute capital and labour for fuels, and consumers to substitute other consumption goods for fuels. In the Ballard and Medema model, such a tax would induce producers to increase capital and labour input while decreasing emissions. Consumer behaviour would be unaffected.

In the Ballard and Medema paper, effects of pollution on production processes are captured by increases in the use of intermediate inputs. Externalities that affect consumers (health damages only), enter the utility function. In our paper, effects on production and on consumers are not spelled out separately. However, our model has the advantage of including a wide range of external effects, in addition to health damages. This causes our estimates of the MCF to be well below the estimate of Ballard and Medema. For instance, our estimate of the MCF in the case of gasoline taxation is 1.11 if we include health effects only, versus -0.35 when all externalities are included. Ballard and Medama's MCF estimate in the case of Pigouvian taxes is 0.731. Our conventional estimates of the MCF for the Norwegian economy are in general higher than for the US economy, mainly because of a relatively high level of taxation in Norway compared with in the US, and the fact that labour supply is independent of income.

Appendix. Model for calculating benefits from reduced pollution and traffic.
For details, see Alfsen, Brendemoen and Glomsrød (1992).

Type of costs	Marginal cost		Parameters
Acidification of water	$b_1\ \Delta(SO_2 + NO_x)$	b_1	Thousand 1990-NOK per ton
Acidification of forests	$b_2\ \Delta(SO_2 + NO_x)$	b_2	Thousand 1990-NOK per ton
Health damage from pollutant j=SO_2, NO_x, CO, particulates	$b_3^j(\Delta M_j * a_m j + \Delta S_j * a_s j)$	b_3^j	Cost per person above threshold value times no. of persons exposed. Thousand 1990-NOK per ton
		$a_m j$	Share of emissions from mobile sources causing health damage. %
		$a_s j$	Share of emissions from stationary sources causing health damage. %
		ΔM_j	Change in emissions from mobile sources. Tons
		ΔS_j	Change in emissions from stationary sources. Tons
Corrosion	$b_4\ \Delta SO_2$	b_4	Thousand 1990-NOK per ton
Road traffic	$b_i\ \Delta$(petrol + diesel); $i=5,...,8$	b_5	Cost of accidents per thousand ton fuel. Thousand 1990-NOK
		b_6	Cost of congestion per thousand ton fuel. Thousand 1990-NOK
		b_7	Cost of damage to roads per thousand ton fuel. Thousand 1990-NOK
		b_8	Cost of noise per thousand ton fuel. Thousand 1990-NOK

Appendix (cont.)

Type of costs	**Parameter**	**Lower value**	**Upper value**
Acidification of water	b_1	0.2	0.3
Acidification of forests	b_2	0.41	0.51
Health damages SO_2	b_3^{SO2}	47	251
	a_m^{SO2}	9	27
	a_s^{SO2}	3	11
Health damages NO_x	b_3^{NOx}	188	1036
	a_m^{NOx}	8	28
	a_s^{NOx}	3	10
Health damages CO	b_3^{CO}	0.06	0.31
	a_m^{CO}	9	31
	a_s^{CO}	5	23
Health damages particulates	b_3^{Par}	188	1019
	a_m^{Par}	6	8
	a_s^{Par}	8	26
Corrosion	b_4	1	9
Traffic accidents	b_5	770	5000
Congestion	b_6	1000	3000
Damage to roads	b_7	1000	4000
Noise	b_8	1000	3000

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