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Evidence from Norway

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# The environmental drag on long-term economic performance:
## Evidence from Norway

**Abstract:**
The environmental drag is the cost to society of environmental constraints. This paper estimates the long-run environmental drag on the Norwegian economy. We employ a model called DREAM (dynamic resource / environmental applied model). This is an applied general equilibrium model extended to include important environmental linkages.
After having explained the structure of our model, the paper presents macroeconomic effects, and impacts on growth and welfare of environmental constraints. To check robustness we perform a number of sensitivity analyses. Most of our results are remarkably robust to alternative assumptions. Contrary to widespread opinion, a low discount rate increases the environmental drag on welfare. Reducing the rate of technological progress will have similar effects.

**Keywords:** Environmental drag, dynamic CGE model, Norway

**JEL classification:** D58, O41, Q29, Q39

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Notting really matters much,
it's doom alone that counts.
Bob Dylan, "Shelter from the Storm"

# 1 Introduction

Economic activity is a superstructure on a fragile ecological system. The two systems affect, and are affected by each other. To many, a pressing question is whether the economy can -- or should -- grow in the long run in the face of ecological constraints. "Can" refers to whether the economy-ecology integrated system eventually evolves to the point where economic growth is impossible. "Should" refers to whether continued economic growth is desirable when one accounts for various environmental externalities that increase with production.

This paper addresses these issues. We assess empirically the size of the *environmental drag* on economic development. The environmental drag is the cost of ecological constraints on economic development, for instance the non-availability of infinite amounts of cheap resources or pollution. The environmental drag is large if ecological constraints radically slow down economic growth, or the welfare costs of ecological constraints are large. The concept measures to what extent the economy can or should grow over time. Economists have made valuable theoretical contributions to the study of the environmental drag. For instance, Dasgupta and Heal (1974) show that a steady state growth path only exists if non-renewable resources are unessential in production. Tahvonen and Kuuluvainen (1993) show that a steady state path of an economy with pollution only exists if the discount rate is "small", that is smaller than the marginal productivity of capital as the capital stock goes to zero, and smaller than the growth rate of the renewable resource as the resource stock goes to zero. This must be the case for all levels of emissions (including very small ones) and all levels of stock pollution (including very large ones). For a more policy oriented discussion of the same issues, see Nordhaus (1992).

To estimate the environmental drag we employ a complete dynamic general equilibrium (CGE) model DREAM (dynamic resource/environment applied model). The dynamic CGE model is generally recognised as a powerful tool for conducting medium to long-run applied economic analysis of energy and the environment (see, e.g., Jorgenson and Wilcoxen (1993)). Our model is in our view particularly well suited to analyse the environmental drag because it treats the economy and the ecology as a simultaneous, extended dynamic general equilibrium system. There are linkages, in the form of environmental externalities, back and forth between the economy and the environment. Predecessors in this field include the "DICE" model of Nordhaus (1993) and the model of Kverndokk (1993). These global models focus on the interdependence between economic activity and CO2-emissions. A study by Glomsrød, Vennemo and Johnsen (1992) includes most of the environmental linkages of the present paper, but they are modelled as unidirectional effects. Brendemoen and Vennemo (1994) take that methodology further. See also Håkonson and Mathiesen (1995). There is a large literature that describes emissions to air associated with economic activity. Jorgenson and Wilcoxen (1993) survey that literature.

We compare two simulations on our extended dynamic applied general equilibrium model. In one simulation, we assume that there are no linkages between the environment and the economy. Call this the traditional scenario on the traditional economic model. In the other simulation, we introduce the mutual dependence between the economy and the ecosystem as an additional constraint on economic development. Call this the feedback scenario on the feedback model. The outcome of our comparison is an estimate of the environmental drag.

Nordhaus (1992) presents some estimates of global environmental drags in a related contribution. The main drag is the non-availability of cheap energy resources, which according to the paper reduces long-term growth by 0.15 percentage points per year. Local pollutants reduce growth by 0.04 percentage points, while greenhouse warming reduces growth by 0.03 percentage points. In a study of the US, Jorgenson and Wilcoxen (1990) find that environmental regulation reduced annual economic growth by 0.2 percentage points over the period 1974-1985. The long run reduction in growth is significantly lower. Assuming a rational political process one can interpret this as an estimate of the willingness to pay for avoiding environmental drags.

We study the environmental drag of a particular country, Norway. Norway is neither a big economic power nor particularly important in the global ecology. It may therefore represent the vast majority of countries that are ordinary members of the world community. The environmental impacts covered by the study are effects on health, materials and nature by air pollution. In addition, we account for costs related to road traffic, like noise, road damage, congestion and accidents.

The paper proceeds as follows: Section 2 describes our model, with a special emphasis on environmental linkages. We believe that results to come out of a CGE model (or any other model) are no better than the model allows. Therefore we describe the model in some detail. Section 3 presents the main set of results. Section 4 explores the sensitivity of these results to central parameters of the model. Section 5 indicates effects of introducing some channels of interdependence of a more exploratory nature. Section 6 concludes.

# 2 The model

Below is a verbal description of the model. A complete technical documentation can be found in Vennemo (1994).

## 2.1 Overview

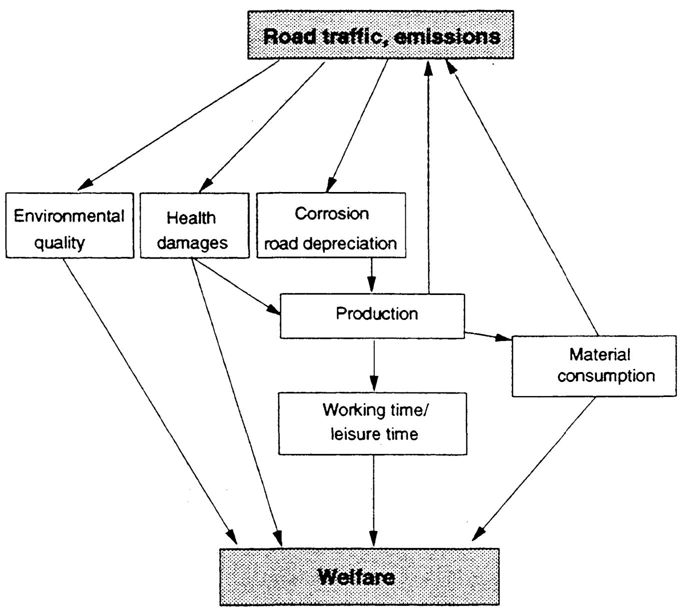
Our model is a growth model of Cass-Koopmans type. The economy of Norway is reasonably stylised as a small, open economy. A small open economy faces an exogenous interest rate and prices on competitive products. An infinitely lived consumer with perfect foresight maximises utility from goods and leisure. There are nine industries. Six of them have competitive producers with perfect foresight. One of these produce tradables. This (large) industry determines the wage, which in combination with the exogenous interest rate and self fulfilling expectations of the future user cost of capital, determines the output prices of non-tradables.

Trade balances intertemporally. The annual trade balance reflects intertemporal optimisation by consumers and producers, and changes with underlying economic conditions. This treatment is similar to current work in trade theory, see Obstfeld (1982) for an early contribution. A lump sum tax clears the public budget. We impose annual budget balance. This is an innocent assumption because Ricardian equivalence holds in this model.

The feedback model version tracks emissions to air of seven important pollutants, and road traffic volumes. The emissions to air and the traffic volumes form the impacts from the economy to the environment.

We identify three links from the environment to the economy, see figure 1. There is a link between the environment and consumer welfare. Another concerns labour productivity. The third link goes from environmental quality to the rate of capital depreciation. The basis for these is the models of environmental effects of macroeconomic policy developed by Brendemoen, Glomsrød and Aaserud (1992) and Glomsrød, Nesbakken and Aaserud (1994). They emphasise eleven external effects of economic activity, namely acidification of lakes, acidification of forests, health damage and annoyance from exposure to $NO_x$, $SO_2$, CO and particulate matter, corrosion of building materials, noise from traffic, traffic accidents, congestion and road depreciation.

**Figure 1.** The dynamics of the feedback model




The feedback model is limited to impacts of fossil fuel emissions and material inputs, and of course gives only a rough indication of environmental effects of economic activity. Its merit is the general equilibrium perspective on the link between the economy and the environment. Higher fossil fuel consumption can be expected to increase emissions to air and road traffic, creating environmental externalities that will feed back into the economic model.

## 2.2 Producer behaviour

Output is produced in multi-level CES production functions. At the top level, material input and a capital-energy-labour composite combine into gross production. The elasticity of substitution is zero; material input is a fixed factor. This is a standard assumption in CGE models, and a reasonable approximation to the data of Norway (compare, e.g. Glomsrød, Vennemo and Johnsen (1992), table 2).

The capital-energy-labour composite aggregates labour and a capital-energy composite, while energy aggregates fuel oil and hydro power, all in successive CES-nests. The elasticities of substitution, which differ among the "endogenous" industries, are derived from Alfsen, Bye and Holmøy (1995), and from Mysen (1991).

| | Tradables | Petroleum refining | Construction | Wholesale and retail trade | Housing | Other services |
|---|---|---|---|---|---|---|
| Material input vs. labour-capital-energy | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Labour vs.capital-energy | 0.72 | 0.0 | 0.0 | 1.08 | 0.16 | 0.8 |
| Capital vs.energy | 0.52 | 0.0 | 0.02 | 0.7 | 0.16 | 0.67 |
| Heating fuel vs. electricity | 0.42 | 0.0 | 0.13 | 0.37 | 0.0 | 0.18 |

**Table 1.** Elasticities of substitution in industries

The elasticities of substitution are listed in table 1. Elasticities of substitution are generally below unity, indicating an inelastic production structure.

Capital demand is determined so that the value of the marginal productivity of capital equals the user cost of capital. The user cost of capital includes self-fulfilling expectations of future prices. Labour demand is such that the value of the marginal productivity of labour equals the price of effective labour input. There is an exogenous trend increase in labour productivity.

Besides the endogenous industries listed in table 1, we model three exogenous industries: the significant production of crude oil and gas, production of hydro-power[1], and a public sector, all heavily regulated.

## 2.3 Consumption

The infinitely lived consumer in the model is a simplifying device with some merit via the extended family argument of Barr (1974). Distributional issues are ignored. We assume preferences to have a multi-level CES structure. The intertemporal elasticity of substitution is 0.5, a value broadly consistent with econometric evidence in Norway (Steffensen (1989), Biørn and Jansen (1982), Frisch (1959)). In the first stage of a three-stage budgeting procedure, the consumer spends total wealth on full consumption, i.e. consumption of goods and leisure. This aspect of her behaviour can be described by an Euler-equation that relates the interest rate, the rate of pure time preference, growth in full consumption and the elasticity of marginal utility in a familiar textbook way.

[1]Norway presently produces hydro-power to cover domestic demand for electricity.

The consumer spends full consumption on leisure and consumer goods. Time series evidence in Norway points to a low wage elasticity of *labour force participation* (0.0 for men, 0.2 for unmarried women, Zakariassen (1994)). Cross section studies find a larger, but similar response (0.2 for men, 0.4 for women, Dagsvik and Strøm (1992)) and a significantly larger uncompensated wage elasticity of *labour supply*: 0.3 for men, 0.9 for women. Further, Dagsvik and Strøm (1992) report a low (≈0.0) income effect on labour supply, indicating that uncompensated and compensated elasticities are fairly close. Based on this information, we assume an uncompensated labour supply elasticity of 0.3 and a compensated elasticity of 0.4. This gives credit in a time-series model to the time series information while using the cross-section information as well. We calibrate the time endowment and the elasticity of substitution between leisure and consumption to obtain the labour supply elasticities. Consumer expenditure is spread on housing, tourism abroad and a general composite good capturing the rest in a Cobb-Douglas system.

## 2.4 Welfare

The welfare function of the feedback model is additive in welfare from full consumption and welfare from the environment. The arguments in the welfare function are in other words consumption of goods and services, consumption of leisure and consumption of environmental services. The traditional model of course excludes welfare from the environment.

The welfare function has the following properties: It rationalises the household behaviour we have just outlined. It implies in the feedback model that environmental quality does not affect the choices made by the consumer. It implies that the marginal willingness to trade an environmental good of any period for full consumption in the same period equals the base year empirical estimate. The willingness to trade an environmental good of any period for full consumption of a later period equals the discounted value of the same parameter. We discuss this hypothesis below.

Changes in welfare is measured by equivalent changes in (human plus financial- and real-capital) wealth, i.e. the welfare change of a price increase is measured by the equivalent change in wealth at the original set of prices. This is the traditional equivalent variation method in a dynamic context. To arrive at a unit free measure of welfare change, we divide equivalent variation by (traditional scenario) wealth.

Between the traditional model and the environmental feedback model there is a difference in welfare even at constant prices. This difference is measured in monetary terms and can be interpreted as equivalent to a reduction in wealth, i.e. we treat it too by a equivalent variation method.

## 2.5 Emissions and traffic

The feedback model tracks emissions to air of seven pollutants. CO and $PM_{10}$ (particulates) cause local pollution problems. $SO_2$ and $NO_x$ cause local pollution and contribute to the formation of acid rain, and NMVOC (non-methane volatile organic compounds) generate ground level $O_3$ (ozone), causing local, regional and global environmental problems. Finally $CO_2$ and to a lesser degree $CH_4$ (methane) are important greenhouse gases.

For each pollutant and industry, emissions from mobile combustion, stationary combustion and industrial processes are assumed proportional to consumption of gasoline, fuel oil and material inputs respectively. Emissions from private consumption are proportional to households' gasoline and fuels consumption. Some emissions (e.g. from firewood) are exogenous. The "emission coefficients" are calibrated to base year data on emissions by source and industry relative to the relevant emission carrier. Exogenous abatement reduces the emission coefficients over time according to projections by the Norwegian Pollution Control Agency.

We use gasoline and auto-diesel consumption to proxy traffic. The argument is that other things being equal, the change in gasoline and auto-diesel consumption captures the change in traffic reasonably well.

## 2.6 The environment

Several authors value environmental goods in Norway, see the survey of Navrud and Strand (1992) for examples. Many studies concern phenomena that have small ties to the national economy, for instance because they focus on a small habitat or a limited geographic area. We focus here on problem areas that can be linked to economic variables at the level of aggregation of the model, and problems that are likely to be affected by economic policy and have a non-negligible national importance. The parameters describing the interaction between the economy and the environment are difficult to pin down, for obvious reasons. Our parameter values serve as illustrations rather than precise estimates. With that in mind, we now go on to describe the environmental linkages incorporated in this study.

### *2.6.1 Depreciation*

$SO_2$, $NO_x$ and some other pollutants induce corrosion on different sorts of capital equipment. From Brendemoen, Glomsrød and Aaserud (1992) we have data on the relation between $SO_2$ and corrosion costs associated with building and similar capital assets. Air pollution also harms buildings and monuments of cultural value. This effect, while probably important, is not included in the model for data reasons.

For public capital, there is a different source of depreciation: road traffic. Traffic wears down the roads and increases road depreciation. This creates a burden on public expenditures that eventually crowds out private activity. The weight of vehicles is important for road depreciation: the heavier a vehicle, the more it wears down the road. With weight characteristics assumed constant over time, the amount of traffic is a reasonable proxy for the determinants of road depreciation.

### *2.6.2 Productivity*

The environment affects labour productivity in several ways. For instance, reduced air quality increases respiratory illnesses, asthmatic reactions etc., which lead to more sick leaves and a decline in labour productivity. From Brendemoen, Glomsrød and Aaserud (1992) we get data for this relationship. The bottom line is an expert panel appointed by the Norwegian Pollution Control Agency that estimated the productivity cost of one person being above the WHO threshold level of pollution from $SO_2$, $NO_x$, CO and particulates, respectively. The panel based their estimates on evidence from Lave and Seskin (1977) and others. Dispersion models for emissions to air have been used to identify the number of people exposed to higher than threshold levels of pollution as emissions increase. Only urban emissions are assumed to do harm.

A large number of traffic casualties that are unable to work adds up to a decrease in labour productivity in macro. We model traffic casualties along the lines of Glomsrød, Nesbakken and Aaserud (1994). Data for gasoline and diesel consumption are combined with assumptions on gasoline and diesel efficiency to derive estimates of vehicle kilometres. Estimates for vehicle kilometres are combined with evidence on road capacity investments to derive an estimate of congestion.

We assume the number of traffic casualties (with person injuries) to be proportional to gasoline (cars) and diesel (trucks, buses) vehicle kilometres, and inversely related to congestion. We estimate the reduction in the labour force to be a fraction of casualties "this year" that accounts for short term injuries and injuries to dependants, plus diminishing fractions of casualties over the last 8 years that account for medium term injuries, plus a constant annual fraction of casualties over the last 37 years that accounts for permanent injuries and deaths. The average remaining working life for the permanently injured or dead would have been 37 years.

In a long-run model, we face the question of what happens if emissions affecting the supply of labour and capital grow without bounds. An upper bound for pollution induced corrosion is assumed to be 7.5 percent, 3 times the actual base year rate of depreciation. A rate of 2.5 percent implies that the average building is reduced by one half in around 30 years, while a corrosion induced rate of 7.5 percent implies that the same deterioration occurs in about 9 years. For labour productivity loss, maximum values are assumed to be 3 percent for $NO_x$ and particulates, and 1.5 percent for $SO_2$ and CO. An upper boundary for productivity loss from traffic noise is set to 1 percent. None of the maxima are binding within the first 101 years of the feedback scenario.

We model the external effects as second order truncated polynomials to ensure a smooth approach to the maximum values. This implies a decreasing marginal impact which may be too optimistic in some cases.

#### *2.6.3 Welfare from environmental services*

Human welfare obviously depends on the quality of environmental services. We obtain point estimates of the marginal cost of environmental degradation from Brendemoen, Glomsrød and Aaserud (1992), who rely on a variety of sources. These are monetary cost estimates that can be directly compared with monetary gains in consumption or wealth. We assume constant marginal costs of degradation as an approximation. A more sophisticated approach would include income and price effects, like for instance having the marginal cost increase with income as it seems reasonable that environmental services are income elastic (this conjecture is however not born out by some of the few empirical studies of the matter, see e.g., Kanninen and Kriström (1993)), or having the cost increase in environmental damage. However, the data quality at the moment precludes any sophisticated modelling. Our cost estimates are uncertain even as marginal cost approximations, but they do indicate a likely interval.

As described above, emissions of $NO_x$, $SO_2$, CO and particulates are assumed to harm labour productivity. But an increased risk of illness or even death as a result of air pollution has a welfare dimension as well. Besides, some of the most vulnerable parts of the population are non-workers, like children and the elderly. Somewhat arbitrarily we claim the welfare cost of air pollution to be one half the productivity cost.

Estimates of external costs of road traffic (road damage, noise and congestion) are based on studies by the Norwegian Pollution Control Agency and concern the capital Oslo. The geographical allocation of a given increase in traffic volume is important when calculating external costs from traffic. We assume that 30 percent of traffic cause congestion costs. This number corresponds to the ten largest Norwegian cities' share of total diesel and gasoline consumption in the model base year.

Traffic accidents with person injuries are more reasonably related to all traffic. The welfare cost of traffic accidents is quite prosaic as measured by the model: It consists of estimated medical expenses, material expenses and administrative expenses.

The external effects described so far cover major impacts of domestic production and consumption. In addition we have included acidification of forests and lakes.

### 2.7 Baseline input

We simulate the model on baseline input aggregated from input compiled by the Ministry of Finance for the last long term projection of the Norwegian economy. The projection ends in 2030. From then on, we assume exogenous values consistent with a steady state.

The Ministry of Finance projects moderate growth with average annual GDP growth to 2030 about 1.7 percent. This has to do with a foreseen zero growth in the labour force and a reduction in the growth contribution from the petroleum and hydro-power industries, which are limited in the long run by natural resource scarcities. We treat these scarcities as different from an environmental drag, since energy can be imported at a given price.

In the steady state long run, growth converges to 2 percent annually, which is the rate of exogenous labour saving technical change. It takes the economy of the traditional model around 35 years to reach an approximate steady state. It takes longer for the economy of the feedback model. For more detail on the baseline input, see Olsen and Vennemo (1994).

## 3 Main results

### 3.1 An outline

To outline the impacts of the environment on the productive economy, consider table 2. It shows the production structure of a simple general equilibrium model on a log-differentiated form, and is designed to give information on the difference between the traditional model in a given year and the feedback model in the same year. We may think of the feedback model as a perturbed version of the traditional model.

**Table 2.** Log-differential small model

| | |
|---|---|
| $p_l = -\frac{\theta_k}{\theta_l} p_k$ (1) | **Variables (log differentiated):**<br>*h:* *productivity index*<br>*l:* *labour supply*<br>*n:* *labour supply in efficiency units*<br>$p_k$: *user cost of capital*<br>$p_l$: *costs of labour in efficiency units*<br>*w:* *wage rate*<br>*y:* *output*<br><br>**Parameters:**<br>$\varepsilon$: labour supply elasticity<br>$\eta$: change in output coefficient of labour<br>$\theta_k$: cost share of capital<br>$\theta_l$: cost share of labour |
| $w = p_l + h$ (2) | |
| $l = \varepsilon w$ (3) | |
| $n = h + l$ (4) | |
| $y = n + \eta$ (5) | |

Equation (1) says that any increase in the user cost of capital will transmit into a lower wage rate. The reason is the small open economy assumption. Overall unit costs are therefore fixed, and labour costs must be flexible in order to accommodate that. How strongly wages respond to an increase in the user cost of capital depends on the cost shares of labour and capital.

The primary reason for an increase in the user cost of capital in the feedback model is that corrosion increases depreciation rates. More maintenance and repair makes capital more expensive to use. A secondary reason is that the economy that is influenced by the environment is on a different dynamic path with a different set of asset prices, affecting the investment good price and its rate of change.

Equation (2) shows the change in the hourly wage rate to be the change in the labour cost of producers derived from equation (1), plus the change in productivity or "efficiency". The price producers pay for labour, which is the focus of equation (1), is denoted in efficiency units. Consumers are however interested in the hourly wage. To find the change in that variable, we must add the change in efficiency to the change in pay per unit of efficiency.

The change in efficiency is the other channel of influence from the environment to the productive economy. The environment imposes a decrease in efficiency, which reinforces the decrease in the wage.

Equation (3) shows the change in labour supply to be the change in the wage times the labour supply elasticity. Since the wage falls, labour supply will fall as well. For simplicity we ignore the wealth effect on labour supply in this equation. The wealth effect, which of course is present in the full dynamic model, modifies the fall in the labour supply: with environmental drags we must expect the households of the economy to be poorer than if there were no drags. This lower wealth calls for reduced consumption of leisure, and a higher labour supply cet.par. We conjecture, however, that the effect of reduced wages is the stronger.

Equation (4) shows the change in labour supply measured in efficiency units. This variable is determined by the change in labour supply measured in natural units from equation (3), plus the change in efficiency or productivity per natural unit. The fall in labour supply measured in efficiency units will be larger than the fall measured in natural units, as efficiency goes down.

Equation (5) shows the change in GDP. Like in other growth models, the limiting factor on GDP growth in this model is the availability of labour in efficiency units. The fall in GDP will equal the fall in labour supply measured in efficiency units plus the change in the output coefficient of labour. Since the user cost of capital increases and the producer price of labour falls, we should expect the output coefficient of labour to fall (more labour per unit of output). The fall in the output coefficient of labour will contribute to the fall in GDP. The response of the output coefficient of labour to given price changes depends on the substitution possibilities in production.

From the fall in GDP follows a fall in consumption. The time path of consumption is however different from that of production, as the current account is endogenous at any point in time. Using the current account as a buffer, households are able to smooth the effect of environmental drags.

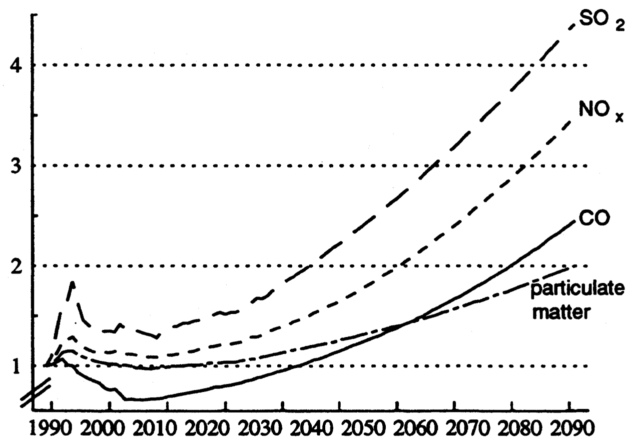
We now turn to the quantification of the effects that we have mentioned. We discuss emissions and fuel consumption first to indicate implications from the economy to the environment. We then discuss the impact on depreciation, productivity, wages and labour supply. Thereafter we turn to GDP and some other macroeconomic impacts. Finally we discuss welfare issues. The simulations are run for 101 years from 1989 to 2090. By 2090 the economy is approximated by a steady state path that continues into infinity. We will mainly treat the period from base year 1989 until 2030, but will also comment on some interesting steady state results.

## 3.2 Emissions and fuel consumption

The activity level increases over time in both the feedback and the traditional model. Figure 2 shows a 101 year time path for the pollutants that cause feedbacks in the model: $SO_2$, $NO_x$, CO and particulates. The increased activity level doubles gasoline and diesel consumption from 1989 to 2030 as the demand for transportation increases with income. Consumption of heating oil also doubles in this period.

We see that emissions grow fast the very first years, and are then reduced towards 2010, to increase in the long run. Although all emissions more or less are tied to the same emission carriers, figure 2 shows that they grow at very different speeds in the first years. CO and particulates fall, or grow very slow. $SO_2$ and $NO_x$ grow between 30 and 80 percent until 2030. All pollutants grow less than fossil fuel consumption. The differences are smaller in a 100-year perspective. Pollution growth is lower than fossil fuel growth because of abatement measures and because pollution from some specific sources diminishes over time. Abatement of transportation fuels will reduce the growth in $NO_x$ and CO emissions. Abatement in industries and cleaner, less sulphur-intensive fuel-oils will reduce the growth in $SO_2$ emissions. Some pollutants have particular explanatory variables. A large share of emissions of particulates and CO is tied to exogenous use of fire-wood stoves. This use is projected to be constant over time.

**Figure 2.** Time path of $SO_2$, $NO_X$, CO and particulates, 1989 = 1.00.




The reason for the long run exponential path is that in the steady state, all emission carriers approach a growth rate equal to the 2 percent rate of technical progress. Emissions will also grow by this rate unless there is steady state increases in abatement.

## 3.3 Depreciation, productivity and wages

Table 3 shows the difference in depreciation, user cost of capital, price of effective labour, productivity and wages in feedback model compared with traditional model for the years 2030 and 2090.

**Table 3.** Percentage difference between the feedback model and the traditional model in the years 2030 and 2090

| | 2030 | 2090 |
|---|---|---|
| Depreciation of buildings in tradables industry | 0.15 | 1.54 |
| Depreciation of roads | 55.80 | 58.04 |
| User cost of capital in tradables industry | 0.02 | 0.21 |
| Price of effective labour | -0.01 | -0.13 |
| Productivity | -0.76 | -5.20 |
| Wage | -0.77 | -5.32 |

Corrosion is estimated to increase the depreciation rate of buildings (in the feedback model compared with the traditional model) by 0.15 percent until 2030. This is an empirically moderate figure. Depreciation of public capital (roads) increases 56 percent to 2030, from a low base-value.

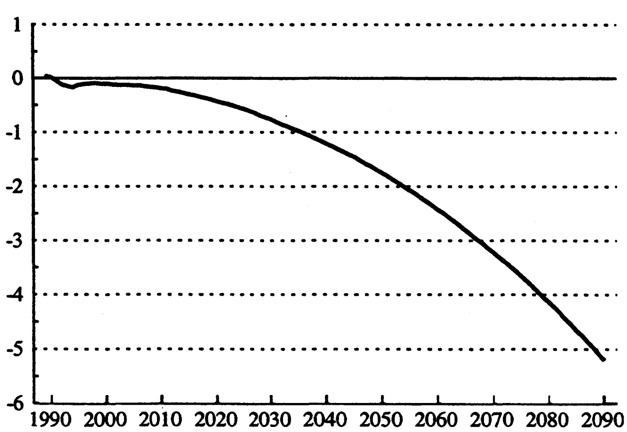
The increase in the depreciation of private capital, i.e. buildings and structures influence wages through the requirement that price equals cost, c.f. equation (1) above. Depreciation of public capital increases public consumption, which crowds out private consumption.

The increase in the private user cost of capital in the competitive industry is 0.02 percent by 2030. This figure is lower than the change in depreciation of buildings and structures because depreciation is only one aspect of the user cost of capital.

The increase in the cost of capital depresses the producer price of effective labour by 0.01 percent in order to keep overall costs constant. That is less than the increase in the cost of capital because the cost share of labour is larger than that of capital. Intuitively, the fall in the wage can be spread thinner than the corresponding increase in the user cost of capital.

To arrive at the change in wages we need an impact of efficiency, c.f. equation (2) above. Figure 3 shows the time path of the difference in labour productivity between models over 101 years.

**Figure 3.** Percentage difference in productivity between traditional model and feedback model. 1989-2090.




In 2030, the difference is 0.8 percent, but growing exponentially. By 2090 the difference in productivity is 5.2 percent. The reason for the exponential growth is that emissions, gasoline, diesel consumption and traffic all grow exponentially in the steady state. For practical purposes it seems that there is a linear relation between productivity and its environmental determinants, which also grow exponentially, over the next century. The imposed maximum productivity loss is not binding, nor is the second order term in the polynomial relation between productivity and its determinants important. Depreciation shows a similar pattern.

## 3.4 Labour and capital

Table 4 indicates the impact of the environmental drags on labour and capital input. In the year 2030 labour supply is 0.3 percent lower in the feedback scenario, c.f. equation (3). By 2090 it is 3.1 percent lower. The world with environmental drags is one where we work less than we would have done otherwise.

| | 1989-2030 | 1989-2090 |
|---|---|---|
| Labour supply | -0.3 | -3.1 |
| Effective labour input | -1.2 | -9.2 |
| Capital input | -1.3 | -8.0 |
| Investment | -0.2 | -12.0 |

**Table 4.** Environmental drags on labour and capital input. Percentage difference between feedback model and traditional model

When measured in effective units, c.f. equation (4), which is what matters for production, labour input is 1.2 percent lower in year 2030.

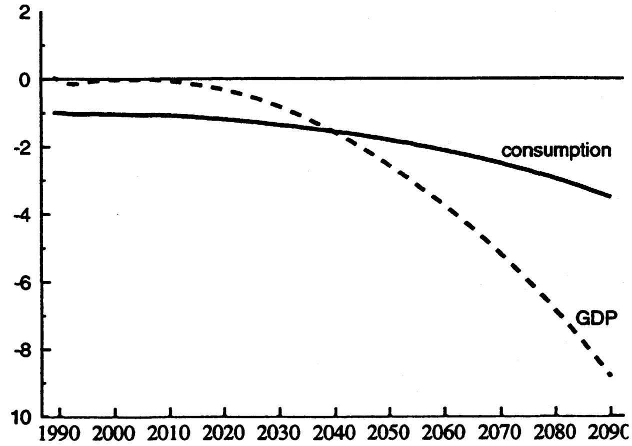
Capital input falls 1.3 percent by 2030. This is a combination of two effects: One is a substitution effect away from more expensive capital into cheaper labour: the fact that capital gets more expensive to maintain and repair encourages firms to hire more labour and reduce their demand for capital. The substitution effect occurs per unit of output. The other, and quantitatively more important effect is that the scale of production goes down, which decreases the demand for real capital at given prices. The reason the scale of production goes down is that labour input goes down in macro.

Gross investments are affected in two ways as well: first by the need to replace, maintain and repair a greater share of capital as corrosion sets in, and second by the economy's response to environmental feedbacks in the form of lower demand for capital. Most of the period before 2030 gross investment increases as the replacement effect is the most important. Later on, gross investment decreases heavily because of the general equilibrium response.

## 3.5 GDP and consumption

The fall in labour supply and capital contribute to a lower activity level in the feedback scenario, c.f. equation (5). GDP of 2030 is 0.82 percent lower. The GDP gap grows over time because of the exponential decline in productivity compared with the traditional model. The decline is actually stronger than exponential, because the growth rate of emission picks up after 2030 when there is no extra abatement. The difference reaches 8.8 percent by 2090, see figure 4. There is no immediate effect on GDP.

**Figure 4.** Time paths for GDP and consumption. Percentage difference traditional model and feedback model.




The lower GDP level of the feedback scenario yields less income and less consumption. The 2030 value of private consumption in the model with environmental feedbacks is 1.4 percent lower than in the traditional model. Consumers act as if they spread the fall in income over the entire period, and consume less in each period. The immediate fall in consumption is 1.0 percent compared with the traditional model, while the long run fall towards the end of the next century is 3.5 percent. The reductions in GDP and consumption reduce consumption of fossil fuels, which reduces emissions. That induces positive second order effects on the environment: The environmental costs are dampened.

| | 1988-2030 | 1988-2090 |
|---|---|---|
| GDP | 0.020 | 0.092 |
| Consumption | 0.033 | 0.036 |

**Table 5.** Environmental drags on GDP and consumption. Difference in annual growth between traditional model and feedback model. Percent

Table 5 shows that environmental feedbacks reduce annual growth in GDP by 0.02 percent until 2030. Since the growth of the GDP gap is increasing, the reduction in the growth rate is larger in the long run. The consumption growth rate is reduced by 0.03 percent until 2030. This reduction is not significantly more pronounced in the long run.

It is clear from looking at figure 4 above that the measured reduction in the consumption growth rate would have been larger if we examined a shorter period (i.e. 1988 until 2000) since there would have been fewer years by which to spread the reduction in the level.

## 3.6 Trade balance

Consumers' long term adjustment to a lower activity level opens a gap between production and consumption the first years, see figure 4. Consumers spend less, but produce the same. In these years the economy runs a trade balance surplus compared to the traditional model. In the long run this trade balance surplus increases interest income from abroad.

Larger foreign income opens for a larger long term deficit in the trade balance. It is possible for consumers to maintain a relatively higher consumption level in the long run, since it is "paid for" in the beginning of the period. We see how the change in the trade balance is a consequence of the producer and consumer adjustments to environmental feedbacks.

## 3.7 Welfare

Recall that the arguments of our money metric welfare function are consumption of goods and services, leisure and environmental services. We measure equivalent variation divided by initial wealth and call the result percent welfare change. Welfare is intertemporal, i.e. it is a statistic of consumption of goods/services, leisure and environmental services over the entire infinite time-span.

If consumption of goods and services was the only argument of the welfare function, we would expect a welfare loss from environmental feedbacks in the region of 2-3 percent, which is the average decrease in consumption in the feedback scenario. For instance, if consumption was 2 percent lower each and every year, the percent welfare change would also be 2 percent if consumption was the only argument. But part of the reason consumption and production is lower in the feedback scenario is, as we have seen, that labour supply decreases. That is to say that people have more leisure in the feedback world. The partial effect of this increase in leisure is higher welfare.

There is a welfare loss from consumption of goods/services and leisure taken together, which is to be expected. The net effect of accounting for the environment in the production process is after all to impose additional costs on the economy. It would be strange if those did not imply a net loss in welfare. The net welfare loss from full consumption is 0.8 percent. That is to say that the welfare effect of the environmental feedbacks into production; corrosion, road depreciation and productivity is a 0.8 percent intertemporal loss.

To get the full picture we must however add disutility from lower environmental services. It turns out to be significantly more important than welfare from full consumption, and amounts to 9.2 percent of total wealth. That means that to have zero pollution, noise etc. would be equivalent for consumers to a 9.2 percent increase in wealth. Such an increase in wealth could finance a 9.2 percent higher annual level of full consumption. If we transform this into annual growth, otherwise known as environmental drag, the annual growth rate required to reach a 9.2 percent higher level by 2030 is 0.22 percent.

A break-down of welfare from environmental services shows $NO_x$ emissions, congestion, traffic accidents and noise to cause the greatest harm, see table 6.

**Table 6.** Percentage distribution of disutility from lower environmental services in 2030

| | |
|---|---|
| Health damage from emissions of $NO_x$ | 35 |
| Costs of congestion | 31 |
| Costs of traffic accidents | 23 |
| Disutility of noise | 7 |

The cost of $NO_x$ emissions is significantly higher than the cost of other emissions. One reason may be that $O_3$ (ozone) formation is not significantly high enough to limit $NO_x$ concentrations. Second, $NO_x$ emissions are high to begin with, implying that a certain percentage increase in emissions equals a high increase in concentration levels in densely populated areas.

The other main cost components are congestion and traffic accidents. Traffic related costs contribute around one half of the total estimate (the number fluctuates over the years). By contrast, domestic contribution to acidification of lakes and forests contribute insignificantly to the total estimate.

The full welfare difference between the traditional and feedback worlds is 9.95 percent of welfare, or 716 billion NOK. The annual growth rate of wealth required to reach 9.95 percent by 2030 is 0.23 percent.

Our welfare indicator is of course not meant to include everything that gives welfare to members of the economy. The model includes a limited number of arguments, and the measurement of their impact is a difficult and controversial matter.

Of the seven pollutants projected by the model, $CO_2$, $CH_4$ and NMVOC do not have any formal welfare impact in the model. One might nevertheless find it significant that $CO_2$ increases around 80 percent until 2030 in the feedback model. Emissions of $CH_4$, another greenhouse gas, also increase. In the steady state, all three emissions grow.

Premature deaths in traffic accidents is another variable of relevance to welfare. Accumulated traffic deaths reduces the population of 2030 by 7700. Injuries rise from 33000 in 1989 to 67000 in 2030. These numbers hide suffering and grief of great welfare importance. Recall that our model by contrast treats accidents and injuries as an issue of resource costs only, while a death to one of n members of the population is simply the removal of 1/n of total utility.

# 4 Sensitivity

The important parameters of the model are the parameters reflecting environmental damage for the feedback model, and the substitution parameters in production and consumption. This section explores the sensitivity of model results with respect to these parameters. The focus is on welfare change. See table 7.

| Alternative | Total welfare | Welfare from consumption | Welfare from environment |
|---|---|---|---|
| 1 Base-case | **9.95** | **0.76** | **9.19** |
| 2 Damage parameters halved | 5.36 | 0.77 | 4.60 |
| 3 Damage parameters doubled | 19.15 | 0.76 | 18.38 |
| 4 Productivity reducing parameters halved | 9.31 | 0.02 | 9.28 |
| 5 Productivity reducing parameters doubled | 11.20 | 2.19 | 9.01 |
| 6 Depreciation rates halved | 9.49 | 0.36 | 9.13 |
| 7 Depreciation rates doubled | 11.25 | 1.94 | 9.31 |
| 8 Inelastic labour supply | 9.89 | 0.64 | 9.25 |
| 9 Elastic labour supply | 9.97 | 1.03 | 8.94 |
| 10 Inelastic substitution in production | 10.11 | 0.78 | 9.33 |
| 11 Elastic substitution in production | 9.85 | 0.75 | 9.10 |

**Table 7.** Welfare loss under different parameter assumptions. 2030. Percent

Alternative 1 is the "base-case" discussed in section 3.

## 4.1 Environmental feedbacks

### *4.1.1 Marginal disutilities*

In alternatives 2 and 3 the marginal disutilities of emissions and traffic accidents are reduced by 50 percent and doubled respectively. Since consumer demand and producer behaviour are unaffected by the strength of welfare from environmental services, variations in these parameters only affect the environmentally generated utility loss.

To double the monetary value of environmental quality implies that disutility from a polluted environment doubles, and the estimated welfare loss almost doubles. The underlying point is that welfare from the environment is homogenous of degree one in the value coefficients[2].

[2] Brendemoen, Glomsrød and Aaserud (1992) ascribe a larger confidence interval than 1:4 (one half versus double) to most of their value coefficients. On the other hand, if the value coefficients vary independently, which seems a reasonable prior, one will expect some to be larger than their expected values, and some to be smaller. The full multivariate distribution will then tend to be more collected than an examination of each parameter would suggest. This point is pursued in Brendemoen and Vennemo (1993).

#### *4.1.2 Labour productivity*

In alternatives 4 and 5 a similar exercise is carried out for the parameters that describe the impact on labour productivity. Recall table 2. When productivity lowering coefficients are doubled, we expect output and consumption to decline: wages fall because workers are rewarded according to their provision of labour efficiency units (equation 2). Labour supply therefore falls, and effective labour supply falls even more. Substitution of leisure for work dampens the welfare loss, and it is fair to say that the impact of doubling the productivity lowering coefficients is not dramatic. Disutility from environmental services is also somewhat reduced, which dampens the welfare loss further, but the feedback via environmental welfare is all in all relatively unaffected.

#### *4.1.3 Depreciation*

The next scenarios (6,7) illustrate the impact of assumptions about environmentally induced rates of depreciation. We return to table 2: Higher depreciation rates increase the user cost of capital (equation 1), which lowers wages, labour supply, output and consumption. Consumption of leisure increases, but the overall effect on utility from full consumption is to increase the loss in welfare. The explanation is that a steeper increase in depreciation rates imposes an additional cost on the economy.

Disutility from environmental services actually increases when depreciation rates go up. That is somewhat surprising given that the economy contracts as explained above. One would expect fossil fuel use and with that environmental problems to contract as well.

What this argument overlooks is substitution possibilities in production. It is true that household consumption of fossil fuels goes down (because their consumption expenditure goes down), but on the production side, higher capital prices lead to substitution away from capital and into for example energy. The economy switches to a more energy-intensive mode which in equilibrium increases consumption of fossil fuels and the environmental problems that go with it. It is fair to say however, that the increase in disutility from environmental services is quite small.

We offer the following conclusion from this section of the sensitivity analysis: Our results are quite robust to the parameters affecting the production side of the economy, that is the parameters of productivity loss and the parameters of depreciation. Thus the welfare loss from consumption is robust to alternative specifications. The results are not equally robust to a proportional change in all parameters describing disutility from the environment.

## 4.2 Substitution parameters

#### *4.2.1 Labour supply elasticity*

The reaction of labour supply to wage changes is focused in alternatives 8 and 9. From table 2 (equation 3) we recall that a small labour supply elasticity (inelastic supply) transforms a given wage rate change into a relatively small change in labour supply, while a large labour supply elasticity (elastic supply) does the opposite. The outcome in the inelastic case is a smaller loss in consumption of goods and services and a smaller loss in traditional welfare.

There is a danger here of explaining the smaller loss in traditional welfare only in terms of the smaller loss in consumption of goods and services. In that case, the smaller loss in traditional welfare would be self evident. But the story is more complicated. In the inelastic alternative, the smaller loss in consumption (which contributes to a smaller welfare loss) is accompanied by a smaller increase in leisure consumption (which contributes to a larger welfare loss). The reason for the overall smaller loss is taxation.

From the consumer's partial point of view, the utility effect of exchanging one unit of consumption for one unit of leisure is zero as the price ratio she faces equals her marginal rate of substitution. But because of taxation the value to society of her working exceeds the value she puts on it herself. The marginal productivity of labour exceeds the net real wage rate. Some of the rewards from working goes to society as taxes. From society's point of view therefore, her working one hour extra more than pays for itself since it produces the amount of consumption goods she demands in order to work one hour extra, plus it leaves something to pick up since the marginal productivity is higher than the wage. This "profit" is handed back to the consumer (formally in the form of lump sum tax refunds) and constitutes the source of the smaller loss.

While implying a smaller loss in traditional welfare, an inelastic labour supply on the other hand increases the disutility from environmental services. That is because it is labour supply that limits production. Inelastic labour supply implies a smaller reduction in labour supply and the scale of production, and induces a relatively higher burden on the environment. Hardly anything happens to production intensities, since factor prices (to the first order) are unaffected by the labour supply elasticity. (There are second order effects from depreciation and productivity.) The case can be contrasted with scenarios 6 and 7 above where the scale effect on the environment was dominated by the effect of changing factor intensities. We see that the outcome is as ordinary intuition would suggest with only the scale effect at work.

With inelastic labour supply, the improvement in traditional welfare (i.e. the decrease in the loss) is larger than the deterioration in environmental welfare. We understand from the above that this has as much to do with the tax wedge on labour as with the valuation of environmental services.

#### *4.2.2 Production elasticities*

When we view changes in the elasticities of substitution in production (alternatives 10 and 11), the story is similar to that of labour supply. Larger elasticities of substitution induce producers to change more of one factor for another, but the extra profit from that is zero at going producer prices. Consumer welfare is affected to the extent that producer prices of factors and output are different from the "shadow" prices that properly reflect marginal trade off in the economy.

For instance, higher elasticities of substitution will induce producers to use more labour (the cheaper input) and less capital (the more expensive input). This has two effects on welfare: Production falls since the output coefficient of labour goes down. Investment demand on the other hand goes down as well, which at constant production leaves more room for consumption and welfare. If producers had faced shadow prices, these two effects would cancel. The resources saved on investment and capital would equal the reduction in output. An inspection of alternatives 10 and 11 shows that this is approximately what happens. Traditional welfare is relatively unaffected by the elasticities of substitution.

Fuel demand is relatively lower in the elastic case. The primary reason is that producers shift out of e.g., fuel into (cheaper) labour in this case. They also shift from (more expensive) capital into e.g., fuel, but the former effect is empirically stronger. That is why we see somewhat lower disutility from the environment in this scenario.

The conclusion we draw from examining the effects of changing labour supply and elasticities of production is the following: neither of these parameters seem to have significant effects on the outcome. Our results are quite robust to changes in their values.

# 5 Exploratory sources of drag

This section investigates some sources of environmental drag that some (especially environmentalists) would claim were important, while others would claim that they were not important, or (in some cases) had nothing to do with the environment as such. The sources are: Whether conventional economic analysis uses a too high discount rate, whether the assumed rate of technical progress is too high, and whether energy prices will increase more than projected at the moment. It is interesting to check their implications for the results. Table 8 summarises the results.

**Table 8.** Welfare loss given exploratory sources of drags. 2030. Percent

| Alternative | Total welfare | Welfare from consumption | Welfare from environment |
|---|---|---|---|
| 1 Base-case | **9.95** | **0.76** | **9.19** |
| 12 Rate of time preference 0 pct. | 11.33 | 1.46 | 9.87 |
| 13 Rate of time preference 3 pct. | 8.77 | 0.26 | 8.52 |
| 14 Planner's rate of time preference 0 pct. | 13.93 | 0.70 | 13.23 |
| 15 Planner's rate of time preference 3 pct. | 6.65 | 0.86 | 5.79 |
| 16 Technical progress 3 pct. | 9.75 | 0.57 | 9.19 |
| 17 Technical progress 1 pct. | 9.79 | 0.76 | 9.03 |
| 18 Techn. progr. 1 pct. in feedback model | 37.10 | 30.80 | 6.30 |
| 19 Low fossil fuel price | 10.16 | 0.79 | 9.38 |
| 20 High fossil fuel price | 9.49 | 0.70 | 8.79 |
| 21 High fossil fuel price in feedback model | 6.32 | -2.78 | 9.10 |

## 5.1 A lower discount rate?

Environmentalists sometimes claim that the discount rate is, or should be lower than assumed in traditional economic analysis. The idea is that when all plans, investment decisions etc. take a lower discount rate as a premise, the environmental drag will decrease because what happens far into the future carries more weight. A too high discount rate therefore accentuates environmental drags. We take up this issue in two ways.

First, we investigate the consequence of decreasing (and increasing) the subjective rate of time preference in the model (alternatives 12 and 13). This has as one of its consequences to decrease (increase) the discount rate. (The discount rate is of course higher than the rate of time preference because consumption increases over time.) The base-case subjective rate of time preference is 1 percent. We explore the consequences of 0 and 3 percent instead.

Our analysis finds that contrary to popular opinion, the environmental drag increases with a low discount rate. The reasoning behind our result is the following:

A lower discount rate has no particular effect on how an environmental feedback *of a given size* affects prices, labour supply or GDP, i.e. the variables of table 2. It is true that a lower discount rate reduces the user cost of capital, but that happens both in the traditional model and in the feedback model.

The main impact of a lower discount rate is to change the consumer's trade-off between consumption now and in the future. That too is the case for both scenarios, but it has a greater impact in the feedback scenario: Recall that the consumer of the feedback scenario hedged against the future impact of production drags by saving some of his early income. The reward to this action is reduced by a lower discount rate, because interest rates fall as the lower discounting penetrates the market. A lower interest rate means that consumers must save more early on in order to enjoy the same steady state consumption level later on. This constitutes a welfare loss (traditional welfare) for them. To put it differently, a lower discount rate strains the current account and the original consumption path cannot be sustained. This bites more in the feedback scenario.

Consumers partly respond to the strain on the current account by working more, which increases production and modifies the fall in intertemporal consumption. The increase in production however harms the environment, and disutility from lower environmental services rises. (There is an opposite effect on the environment: A lower interest rate reduces the user cost of capital, which leads to more capital intensive, and less energy intensive production. The scale effect on production is obviously larger.)

To summarise: A lower discount rate does not induce producers to prevent long-term environmental effects of their actions, which would be too much to ask for anyway given that the effects are external. A lower discount rate strains the current account, pushes the intertemporal trade frontier inwards (for savers), increases production and reduces consumption of goods/services, leisure and environmental services.

The next argument regarding the discount rate that we take up is the following: When society evaluates the result of an economic process, it may be desirable or reasonable to employ a lower discount rate than the members of society do as economic agents. To put it differently, the market rate is distorted for some reason. One reason that has been advanced is that individual agents do not care enough for their descendants. Another says that one should employ a lower interest rate in the lack of first best instrument to combat environmental problems. The idea that one should not discount utility in welfare evaluations goes back a long way, see e.g., Ramsey (1928).

Alternatives 14 and 15 look at the impact of evaluating the economic outcome by means of a 0 or 3 percent rate of time preference, respectively (the base case is 1 percent). The impact on welfare from full consumption is small because of consumption smoothing. Consumption smoothing implies that the largest losses in full consumption do not necessarily come last. The largest impact is on welfare from the environment. A low planner's rate of time preference puts more emphasis on damages far into the future, and these damages are the largest (in current value) since pollution is the largest far into the future. Disutility from lower environmental quality increases 45 percent (4 percentage points). By contrast, a high planners' rate of time preference discounts high future damages more, reducing the impact on intertemporal utility. Disutility from lower environmental quality decreases 37 percent.

## 5.2 Lower technological progress?

Environmentalists sometimes accuse the standard economic analysis of assuming too high future technological progress. Alternatives 16 and 17 evaluate how technological progress affects welfare losses. Reducing technical progress is similar to reducing the rate of discount, but in addition it has scale effects on production and consumption. Reducing the rate of technical progress will reduce the steady state interest rate, since the interest rate from the Euler-equation is linked to steady state consumption growth. This contributes to a higher loss in welfare from consumption, similarly to the higher loss of a low rate of time preference.

A low rate of technical progress over time implies a smaller scale of production. A smaller scale of production implies lower pollution and smaller environmental feedbacks. This contributes to a lower loss in welfare from consumption. All in all reducing the rate of technical progress has two opposing effects on welfare from consumption: the interest rate effect increases the loss, and the scale effect decreases it. The strengths of these effects are non-symmetric around the base-case.

In terms of welfare from the environment, reduced technical progress implies lower growth in emissions, and lower disutility from reduced environmental services. The effect on intertemporal disutility from reduced environmental services is modified by the increased work effort that is part of the answer to lower interest rates.

Alternative 18 takes a different approach to technological progress. It shows the effects of assuming lower technological progress in the feedback scenario only. One possible explanation for confining lower technological progress to this scenario is that economic development over time reduces the biodiversity that is the source of some technological progress like new inventions in medicine. This argument is less compelling in a national model of Norway. But there may also be other reasons why technical progress should be lower in the feedback scenario, and in any case it is of interest to review the effects of changing this parameter. For illustration we have made the difference one of 1 versus 2 percent.

The outcome of a low rate is an overwhelming increase in the welfare loss from full consumption, as could be expected. Lower technical progress makes the economy a lot worse off in terms of income opportunities. In particular there is a striking difference from changing the productivity *level* (scenarios 2 and 3). The conclusion is that feedbacks on technical progress will create large environmental drags.

While loosing more traditional welfare, the quality of the environment improves. The reason is, again, that lower technical progress expands the economy more slowly, leading to lower emissions.

## 5.3 Increasing energy prices?

Environmentalists sometimes claim that energy prices in the long run will increase more than assumed by the standard analysis. The baseline input assumes a 14 percent growth in real fossil fuel prices by 2030, which amounts to a 0.32 percent annual growth. What is the impact on the environmental drag of assuming higher (and lower, for comparison) fossil fuel prices? That is the topic of alternatives 19, 20 and 21. By "higher" we mean 2.5 percent annual growth. "Lower" means zero growth.

Higher prices of fossil fuels imply that producers move away from energy as an input to production into a more energy efficient mode of production. Emissions per unit of output fall. In addition the level of output falls because lower labour supply means a contraction of the economy. All in all emissions fall, which reduces the disutility from pollution.

Alternative 21 assume that prices in the model without environmental feedbacks increase according to the baseline input, while only the prices in the feedback model rise more. This scenario confirms Norway's benefits from higher energy prices. The effect on welfare from consumption is positive. A more energy efficient technology contributes to a better environment, while higher consumption works in the opposite direction. The total effect is a slight improvement in welfare from environment.

A conclusion to the analysis of exploratory sources of environmental drags is the following: The results are robust with respect to a lower market rate of time preference. The effect of a lower planner's rate of time preference is significant, but not dramatic. The results are robust to energy prices and technical progress as long as both the traditional and feedback scenarios are affected. Assuming lower technical progress in the feedback model only creates a big impact. Some of the effects that we do detect run against popular wisdom. For instance, endowing agents with a lower rate of time preference will increase the impact of environmental drags.

# 6 Conclusions

We started this paper by asking the question of whether the economy can -- or should -- grow in the long run in the face of ecological constraints. Our analysis indicates that the answer to the "can" part is affirmative so far, on the background of the limited number of feedback mechanisms included in this study. Integrating the environment into the analysis does not imply that production cannot increase. On the contrary, the impact of economic constraints on production is probably quite modest over most of the next century. The impact on welfare from consumption of goods/services and leisure is even less. This conclusion is robust to a number of alternative specifications of parameters and exogenous variables. In fact, the welfare cost of consumption shows a rather remarkable stability across different assumption.

The answer to the "should" part is also affirmative, but maybe to a smaller degree. The welfare cost of ignoring the environment is significant. This conclusion is also robust to a number of alternative specifications of parameters, with the notable (and obvious) exception of the parameters that attribute welfare to environmental services. In particular, a lower valuation of environmental services might render the welfare cost of lower environmental quality insignificant.

These are the main conclusions of this study. It indicates that the environmental drag on production will reduce economic growth rates by less than a tenth of a percentage point. Growth in wealth, including environmental wealth, is reduced by 0.23 percent, which, although also a small number, is 11 times larger than the effect of production growth over the same time period.

Our results can be used as indicators of the benefits of abatement and related activities. If all the specified sources of environmental problems were eliminated by the year 2030, the GDP of that year would be 11 billion NOK higher (ignoring intertemporal reallocations). If all environmental problems were eliminated today, the total intertemporal welfare gain would amount to 716 billion NOK. As we have seen, these are small sums in percentage terms, but they are pretty large sums in the context of abatement. Full abatement or elimination of all environmental problems will obviously not be cost effective, but a large number of abatement measures could probably pass the cost-benefit test.

As always, the results of this paper are subject to a number of qualifications. For one thing, global environmental linkages like the greenhouse effect are absent from the study, since these will affect both the traditional and feedback scenarios equally much. They cannot be internalised by the Norwegian economy. It may be that global environmental linkages are more important than the local linkages that we focus on.

Regarding the effects we find on production growth, there may be interactions between the environment and the economy that we have not accounted for. We have shown in section 5.2 that anything that reduces the rate of technical progress will have a lasting effect on production growth, and a large effect on welfare. An environmental linkage to that effect (for instance reduce bio-diversity) would therefore overturn our results on production growth.

Our assumption that the unit value of environmental damage is constant is certainly doubtful. It may in reality change with the level of damage as well as with income or just with time. Even if interpreted as an average value, we know that the estimation of non-market environmental goods is riddled by all sorts of theoretical and practical difficulties.

Overall, our estimate of the environmental drag is uncertain and based on a number of underlying assumptions that some readers may find unconvincing. But that might be constructive. One of the advantages of an applied general equilibrium analysis like ours is that the underlying assumptions are brought into the open for discussion. Future research will no doubt improve our understanding of the relation between economy and ecology, and thereby refine and improve the estimates of the environmental drag.

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