

ANALYSIS

Environmental drag: evidence from Norway

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Abstract

Economic growth affects the environment negatively. A polluted environment and other environmental constraints reduce economic output and the well-being of consumers. The cost to society of environmental constraints may be called the environmental drag. The traditional economic analysis of growth neglects the environmental drag, while this paper attempts to measure it empirically. We employ a dynamic general equilibrium model of the Norwegian economy, extended to include some important environmental linkages, which feed back to the productivity of labor and capital from damages to health, materials and nature. The environment also directly affects the consumers' well-being. Using this model, we are able to estimate the environmental drag, measured as reduced welfare from consumption and environmental services. We present macroeconomic effects in terms of reduced production and consumption, and calculate the overall welfare effects. We find that the environmental constraints incorporated in the model probably have a modest effect on production over the next century. The direct welfare loss from a degraded environmental quality, however, is significant. A lower rate of technological growth and a lower discount rate both increase the drag. © 1999 Elsevier Science B.V. All rights reserved.

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Nothing really matters much,
it's doom alone that counts.

Bob Dylan, 'Shelter from the Storm'

1. Introduction

It is becoming increasingly appropriate to view the economic system as a growing subsystem within the ecological system, rather than an independent system with more or less infinite access to input and output. The need for a change of focus to a growing interdependence on the surrounding

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nature was pointed out by Ayres and Kneese (1969), who argued that the production of residuals (disposals from the consumption and production process) is an inherent and general part of the production and consumption process, and that partial equilibrium approaches may lead to serious errors.

The cost of environmental constraints on welfare is labeled the *environmental drag*.¹ The overall environmental drag can affect economic growth and total welfare in different proportions. It surfaces as negative effects on health, vegetation, materials and consequently productivity, and implies a reduction in welfare from both the consumption of material goods and environmental services. The traditional economic analysis of growth neglects the environmental drag.

This paper addresses empirically the size of the drag on the Norwegian economy. The size of the environmental drag will be measured in terms of changes in welfare as well as effects on growth rates.

Earlier economic studies have provided valuable theoretical contributions to the understanding of how the environment constrains economic development. For instance, Dasgupta and Heal (1974) show that when taking account of a drag from non-renewable resources, a steady state growth path only exists if the non-renewable resources are inessential in production. Tahvonen and Kuuluvainen (1993) show that a steady state path of an economy with pollution only is possible in the case of a relatively low discount rate. For a more policy oriented discussion of the same issues, see Nordhaus (1992).

To estimate the environmental drag we employ a computable dynamic general equilibrium (CGE) model for Norway called DREAM (dynamic resource/environment applied model). DREAM treats the economy and the environment as a simultaneous, extended dynamic general equilibrium system. There are linkages, in the form of environmental externalities, back and forth be-

tween the economy and the environment. The model integrates externalities associated with local air pollution and road traffic. Damages to health, materials, nature and congestion feed back to material welfare by reducing productivity of labor and capital. In addition, the environment matters directly to consumers as a good or service of its own, providing non-economic welfare to the society through opportunities for recreation, esthetic pleasure and personal well-being.

We compare two simulations. In the baseline scenario, we assume that there are no linkages between the environment and the economy. In the feedback scenario, based on the feedback model, we introduce the mutual dependence between the economy and the environment as an additional constraint on economic development. By comparing the difference in the outcome in the two scenarios, we are able to estimate the environmental drag. Within our empirical feedback model framework, we also question the role of discounting, technical progress and energy prices in relation to the environmental drag.

Stringent future regulation of environmental externalities can change the estimated environmental drag. At this stage we aim at estimating the worst case, given that no further political actions are taken. Thus our estimate of the drag is to be considered as a starting point with respect to further policy formation and decision making.

As a disaggregated and general equilibrium model, DREAM reveals benefits and costs from reallocation of resources as a response to environmental damage or implementation of control measures. The dynamic feature further brings in the importance of consumers and producers looking forward, choosing between actions now or in the future.

To motivate our choice of model further we note that the relationship between the environment and the economy is fundamentally about interdependency and economywide linkages, i.e. it has a general equilibrium nature. Experiences with incorporating environmental costs in static CGE models suggest that the general equilibrium effects of environmental impacts can be significant compared with the estimated direct out-of-pocket expenditures (Alfsen, 1994). In some cases those general equilibrium effects are not as important,

¹ In some contexts environmental drag refers to the effect of environmental *regulation*. This must not be confused with our definition, which refers to the effects of environmental *constraints*.

but that is difficult to tell at the outset and in our case not necessary to accept by assumption. Discussing this issue, Jorgenson and Wilcoxon (1993) recognize that the dynamic CGE model is a powerful tool for conducting medium to long-run applied economic analysis of energy and the environment. Predecessors in the related field of global models include the DICE model of Nordhaus (1993) and the model of Kverndokk (1993), both focusing the interdependence between economic activity and carbon dioxide emissions.

The paper proceeds as follows; Section 2 describes our model, including the environmental linkages, and Section 3 presents the main set of results. Section 4 indicates effects of introducing some channels of interdependence of a more exploratory nature, while Section 5 concludes and summarizes the analysis.

2. The model

DREAM is a computable dynamic general equilibrium model of Norway. (See Vennemo (1997) for a complete technical documentation). DREAM has earlier been used in cost-benefit analyses of emissions reductions (Olsen, 1995), tax reform implications (Vennemo, 1995) and to estimate the effects of green throughput taxation (Bruvoll and Ibenholt, 1998). The economic core model is a growth model of Cass–Koopmans type. The economy of Norway is reasonably close to a small, open economy, facing an exogenous interest rate and exogenous prices on competitive products. The model treats the economy and the ecology as a simultaneous system and thus opens for analysis of the environmental effects, in addition to baseline economic effects. The model also computes the welfare effects of environmental quality and leisure time in addition to the welfare from baseline material consumption.

The annual trade balance reflects intertemporal optimization by consumers and producers. The trade balance changes temporarily with underlying economic conditions, but must comply with a financial restriction in the long term. This treatment is similar to current work in trade theory, see Obstfeld (1982) for an early contribution. All

agents have perfect foresight. We impose annual governmental budget balance, while a lump sum tax clears the budget. The transversality condition is a ‘non-Ponzi Game’, which implies that the stock of net foreign claim cannot grow at a rate higher than the interest rate as time goes to infinity, thereby limiting the consumers’ consumption possibilities.²

2.1. Production structure

The model includes six endogenous industries with competitive producers.³ The model also includes two exogenous industries⁴ in addition to the public sector, all heavily regulated. Factors are mobile between sectors. Capital is internationally mobile, while labor is assumed immobile between Norway and other countries.

The manufacturing industry produces tradables. Equality between price and unit cost in this industry determines the equilibrium wage rate in all sectors. This wage level in combination with the exogenous interest rate and self-fulfilling expectations of the future prices of capital goods, determines the output prices of non-tradables.

Labor demand is determined such that the value of the marginal product of labor equals the price of effective labor input. An exogenous trend increases labor productivity, while production is adversely affected by the environmental impacts.

Output is produced in multi-level CES production functions. At the top level, material input and a capital-energy-labor composite combine into gross production. The elasticity of substitution is zero; material input (including transport oils) is a fixed factor.⁵

² The model assumes that Ricardian equivalence holds, stating that total savings will be unaffected by changes in government spending, since the household sector will change its savings correspondingly. In this case it is less interesting to focus on the state of public finances.

³ Manufacturing goods, petroleum refining, construction, services, wholesale and retail trade, and housing.

⁴ The production of crude oil and gas, and production of hydro-power.

⁵ Although this is a standard assumption in CGE models, it is not satisfactory in a long-term environmental context. A more flexible approach will be useful in future analyses.

Subsequent composites aggregate labor, capital and energy, while energy is a CES aggregate of fuel oil and electricity. The substitution elasticities, which differ among the 'endogenous' industries of the model, are derived from Alfsen et al. (1996). Elasticities of substitution are generally below unity, indicating an inelastic production structure.

2.2. Consumption

The consumers are represented by an infinitely lived consumer who maximizes utility from full consumption (i.e. consumption of goods and leisure). Distributional issues are ignored. Preferences are assumed to have a multi-level CES structure. Parameters are estimated on time series data for the Norwegian economy. The intertemporal rate of substitution is 0.5, a value broadly consistent with econometric evidence in Norway (Biørn and Jansen 1982; Steffensen, 1989).

The consumers' choice between labor and leisure is a function of the real wage. The income effect on labor supply is rather low, in accordance with empirical evidence for Norway (Dagsvik and Strøm, 1992). The uncompensated elasticity is 0.3 and the compensated 0.4.

A Cobb Douglas system spreads consumer expenditure on housing, tourism abroad and a manufacturing good, which includes gasoline and diesel associated with household transport, and captures the rest of commodities. With a given interest rate, consumption growth is determined.

2.3. Environmental feedbacks

The model tracks traffic volumes and emissions of seven pollutants to air. SO₂ (sulfur dioxide) and NO_x (nitrogen oxides) cause local pollution and contribute to the formation of acid rain, CO (carbon monoxide) and PM₁₀ (particulate matter) cause local pollution problems, NMVOC (non-methane volatile organic compounds) generate ground level O₃ (ozone), with local, regional and global environmental effects, while CO₂ (carbon dioxide), N₂O (nitrous oxide), NH₃ (ammonia) and CH₄ (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 input respectively. Emissions from private consumption are proportional to households' gasoline and fuels consumption.

Three links from the environment to the economy are identified. The first link concerns labor supply and labor productivity. Air pollution from SO₂, NO_x, CO and PM₁₀ and traffic noise damage health and leave people unable to work for a short or long spell, which together with a large number of traffic casualties, add up to a decrease in labor productivity in macro.

The second link concerns material damage; SO₂ induces corrosion on capital equipment, and traffic wears down roads and increases road depreciation and thus depreciation of public capital. This increased burden on public expenditures eventually crowds out private activity.

The third link concerns welfare. Consumers receive direct utility from environmental services, like recreational values. NO_x and SO₂ contribute to acidification of lakes and forests, exposure to NO_x, SO₂, CO and PM₁₀ results in health-related suffering, and traffic involves annoyance from congestion, noise and traffic accidents. The consumers treat this utility component as a datum (external effect).

Marginal damage estimates refer to the base year. In the model, feedbacks from the environment to the productive sphere are characterized by decreasing marginal damage, while the marginal welfare effect to consumers is assumed to be constant. Pollution and traffic loads rise above the base year level in all growth scenarios. This might lead us to underestimate the drag associated with economic growth. On the other hand, constant marginal welfare effects might overstate the benefit of reaching zero pollution.

The incorporation of environmental pollution feedbacks in this model is limited to include elements which originally were assessed by the Norwegian Pollution Control Authorities for the City of Oslo (Statens forurensningstilsyn, 1987), and generalized to other cities in Norway. Expert panel contributions were a significant element of the assessment. Roughly, the environmental and

road traffic costs added up to around US\$ 1.2 per liter of gasoline and 1.5 per liter of diesel. See Table 1 and Brendemoen et al. (1992) for further details.

Since the effect of Norwegian economic activity on global environmental changes are rather negligible, the model does not include feedback from the global environment. Also, it is assumed that economic actions in Norway do not influence trans-national pollution. Trans-national pollution is implemented as a constant in the utility function.

In Appendix A we outline the detailed incorporation of the various environmental links in the core model and the underlying sources.

2.4. Welfare indicators

The welfare function is additive in welfare from full consumption (goods and leisure) and welfare from environmental services. Due to this specification, consumers' trade-offs between leisure and work, and consumption versus saving, are not directly affected by environmental feedbacks. However, the feedbacks affect the prices facing consumers. The consumers respond by adjusting demand for consumption, leisure and savings.

Changes in welfare are 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 equivalent variation method in a dynamic context. To arrive at a unit free measure of welfare

change, we divide equivalent variation by the baseline scenario wealth.

2.5. Baseline input

The baseline input is used by the Ministry of Finance for the most recent long-term projection of the Norwegian economy (Ministry of Finance, 1993). From 2030 on, the exogenous values are assumed to be consistent with a steady state. See Olsen and Vennemo (1994) for more details on the baseline input.

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 mainly discuss the period from base year 1989 until 2030, but we will also comment on some interesting steady state results. The reason for focusing on 2030 is that this period corresponds to the time horizon frequently used in medium- and long-term analyses of the Norwegian economy. In steady state, long-run growth converges to 2% annually, which is the rate of exogenous labor saving technical change. It takes the economy of the baseline model around 35 years to reach an approximate steady state, while it takes longer time in the feedback model.

3. Comparing the models: main results

We now compare the outcome of the feedback model with the baseline model. Total welfare, including welfare from the environment, is reduced by 9.95%, mainly due to less welfare from the environment. The overall *environmental drag*, defined as the annual reduction in welfare growth, is estimated to 0.23%. Due to environmental feedbacks, annual production growth in the period 1988–2030 is reduced by 0.02 percentage points and consumption growth by 0.03 percentage points. The rest of the reduction in welfare growth is due to welfare from environmental services.

We now turn to a more detailed description of the main results, before we turn to the underlying effects explaining the difference between the feedback model and the baseline model.

Table 1
Marginal pollution and traffic-related costs in Norway (1994—US\$ per liter)

	Heavy fuel oil	Gasoline	Diesel
Health	0.06	0.33	0.57
Traffic accidents	0.00	0.21	0.24
Traffic noise	0.00	0.09	0.10
Congestion	0.00	0.23	0.24
Road damage	0.00	0.29	0.32
Corrosion	0.01	0.00	0.00
Total	0.08	1.15	1.47

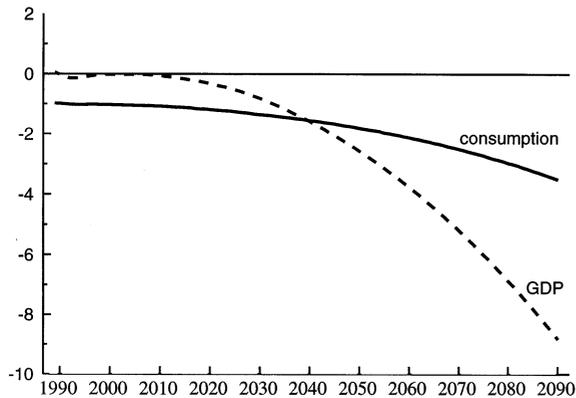


Fig. 1. Time paths for GDP and consumption. Percentage difference between baseline model and feedback model.

3.1. Welfare

Recall that the arguments of our money metric welfare function are a linear combination of full consumption (consumption of baseline goods and services and leisure) and environmental services. 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 range of 2–3%, which is the average consumption decrease (Fig. 1). But part of the reason why consumption and production are reduced in the feedback scenario is that labor supply decreases. That is to say that people purchase more leisure time in the feedback world, of which the partial effect is higher welfare. The total effect on full consumption (goods/services and leisure taken together) is a welfare loss, 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. The intertemporal net welfare loss from full consumption, due to the effect of the environmental feedbacks into production, is 0.76%.

To get the full picture, we must however add the welfare loss from lower environmental services, which is far more important than welfare loss from full consumption, and amounts to

9.19% of total intertemporal wealth. That means that to have zero pollution, noise etc. would be equivalent for the consumers to a 9.19% increase in wealth, which could finance a 9.19% annual increase in the level of full consumption. Transformed into annual growth reductions required to reach 9.19% by 2030, the drag from environmental services is 0.22%.

Table 2 provides a break-down of welfare loss from environmental services due to health damages, congestion, traffic accidents and noise.

The health damages increase by 28% from 1989 up to 2030, while the other damage factors, congestion, traffic accidents and noise, increase by 92%. Health damages from emissions are the most important damage factor, and contribute to 39% of the total disutility from environmental services in 2030. The other main cost components are congestion and traffic accidents. Traffic related costs contribute to about one-half of the total estimate. By contrast, domestic contributions to acidification of lakes and forests are insignificant in the total estimate.

The intertemporal full welfare difference (discounted over the infinite time horizon) between the baseline and feedback worlds is 9.95% of welfare, or 110 billion US\$. The annual growth rate of wealth required to reach 9.95% by 2030 is 0.23%, indicating the overall *environmental drag*.

Our welfare indicator does not of course include every subject that contributes to a society's welfare. Of the seven emission components projected by the model, CO₂, CH₄ and NMVOC do not have any formal welfare impact in the model. One might nevertheless find that the 80% increase in CO₂ emissions until 2030 adds to the environmental drag. Emissions of CH₄, another green-

Table 2
Percentage distribution of disutility from lower environmental services in 2030

	%
Health damages	39
Costs of congestion	31
Costs of traffic accidents	23
Disutility of noise	7

house gas, also increase. Premature deaths in traffic accidents is another variable relevant to welfare. According to the model, accumulated traffic deaths reduce the population of 2030 by 7700, while the number of person injuries rise from 33 000 in 1989 to 67 000 in 2030. These numbers hide suffering and grief of great welfare importance. Our model by contrast treats non-fatal accidents and injuries as an issue of resource costs only, while a fatal injury to one of n members of the population is represented in the model as the removal of $1/n$ of total utility.

3.2. GDP and consumption

The fall in labor supply and capital contributes to a lower GDP level in the feedback scenario. In 2030 GDP is 0.82% lower than in the baseline scenario. The GDP gap grows over time because productivity gradually declines compared with the baseline scenario. The difference reaches 8.8% by 2090 (Fig. 1).

The lower GDP level of the feed-back scenario lowers income and consumption possibilities. In 2030, the value of private consumption in the feedback scenario is 1.4% lower than in the baseline scenario. This is larger than the corresponding loss in GDP because the consumers spread the income fall over the entire period. The timing of the production drag is not important because of perfect foresight and arguments equivalent to Richardian Equivalence. The immediate (base year + 1) fall in consumption is 1.0%, while the long-run fall towards the end of the next century is 3.5%.

The GDP and consumption reductions also reduce fossil fuels consumption, which again lowers emissions. This induces positive second order environmental effects, which reduce the environmental costs. Table 3 verifies that environmental feedbacks reduce annual growth in GDP by 0.02 percentage points in 2030. Since the growth of the GDP gap increases, the growth rate reduction is larger in the long run.

The consumption growth rate is reduced by 0.03 percentage points in 2030. This reduction is not, however, significantly more pronounced in the long run. It is clear from looking at Fig. 1 that

Table 3
Environmental drag on GDP and consumption^a

	1988–2030	1988–2090
GDP	0.020	0.092
Consumption	0.033	0.036

^a Difference in annual growth between baseline scenario and feedback scenario. Percentage points.

the measured drag on consumption 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 reduced consumption.

3.3. Trade balance

The trade balance changes as a consequence of the adjustments to environmental feedbacks. In the first years, when consumption is decreased relative to production, the economy runs a trade balance surplus compared with the solution of the baseline scenario. Over time this trade balance surplus increases interest income from abroad, which opens the way for a long-term trade balance deficit. Thus it is possible for consumers to maintain a relatively higher consumption level in the long run, ‘paid for’ in earlier years.

3.4. Emissions and fuel consumption

Fig. 2 shows a 101-year time path for the pollutants that cause welfare loss and feedbacks in the model: SO₂, NO_x, CO and PM₁₀. An increased activity level over time doubles gasoline and diesel consumption from 1989 to 2030, as transportation demand increases with income. The growth in transportation helps to explain the welfare loss from environmental services. Consumption of heating fuel oil also doubles in this period.

As seen in Fig. 2, the emissions grow at very different speeds in the first years. CO and PM₁₀ fall, or grow very slowly. NO_x and SO₂ grow with 30 and 80%, respectively, until 2030. Pollution growth is lower than fossil fuel growth because of abatement measures and because pollution from

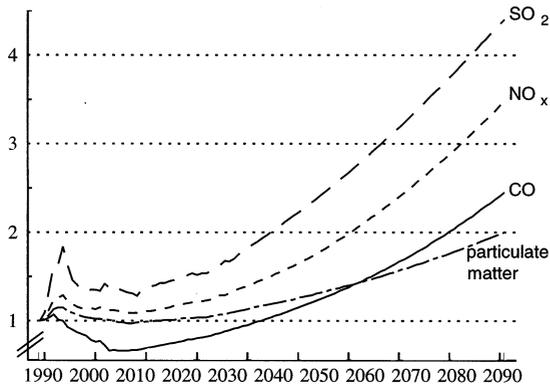


Fig. 2. Time path of SO_2 , NO_x , CO and particulate matter, 1989 = 100.

some specific sources diminishes over time. Abatement in transportation lowers the NO_x and CO emissions growth. Abatement in industries together with the introduction of cleaner, less sulfur-intensive fuel-oils contribute to a lower SO_2 emission growth. A large share of PM_{10} and CO emissions is tied to exogenous and constant use of fire-wood.

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% rate of labor saving technical progress. Emissions also grow by this rate, as there is no increase in abatement beyond current plans. In other words, we do not impose the inverted U-shape between emissions and growth that has been detected in historical data in some recent studies, e.g. Grossman and Krueger (1995). The increase in emissions explains part of the welfare loss of environmental services. It also explains the increase in depreciation and fall in labor productivity.

3.5. Depreciation, productivity and wages

Table 4 shows the difference in depreciation, user cost of capital, price of effective labor, productivity and wages in the feedback scenario compared with the baseline scenario for the years 2030 and 2090.

Corrosion is estimated to increase the depreciation rate of buildings (in the feedback scenario

compared with the baseline scenario) by 0.15% in 2030. Depreciation of public capital (roads) has increased 56% by then, from a low base-value of about 0.75% annually. The increase in the depreciation of private capital, i.e. buildings and structures, influences wages through the requirement that price equals cost. Depreciation of public capital increases public consumption, which crowds out private consumption.

The increase in the user cost of capital in the competitive industry is 0.02% by 2030. The change in user cost is smaller than the change in depreciation of buildings and structures since depreciation is only one aspect of the user cost of capital. The increased capital cost depresses the price of effective labor by 0.01% in order to keep overall costs constant in the competitive sector. This is less than capital costs increase, since the cost share of labor is larger than the cost share of capital. Intuitively, the fall in the wage can be spread thinner than the corresponding increase in the user cost of capital.

Fig. 3 shows the time path of the difference in labor productivity between scenarios over 101 years. In 2030, the difference is 0.8%, and growing exponentially to 5.2% by 2090. The reason for the exponential growth is that emissions, consumption of gasoline and diesel and road traffic all grow exponentially in steady state. Over the relevant range, there is an almost linear relation between productivity and its environmental determinants over the next century.

Table 4

Percentage difference between the feedback scenario and the baseline scenario, 2030 and 2090

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

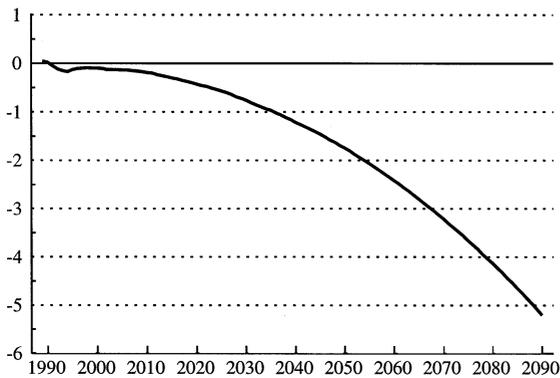


Fig. 3. Percentage difference in productivity between baseline model and feedback model, 1989–2090.

3.6. Labor and capital

Table 5 indicates the impact on labor and capital input. In 2030, labor supply is 0.3% lower in the feedback scenario, while it is 3.1% lower by 2090. The world with environmental drag is one where we work less than we would have done otherwise, since we receive a lower wage per hour. When measured in effective units, which is what matters for production, labor input is 1.2% lower in year 2030.

Capital input is lowered by 1.3% in 2030, due to a combination of two effects: One is a substitution effect from more expensive capital into cheaper labor: the fact that capital becomes more expensive relatively to labor encourages firms to hire more labor 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.

Table 5
Environmental drag on labor and capital input^a

	1989–2030	1989–2090
Labor supply	–0.3	–3.1
Effective labor input	–1.2	–9.2
Capital input	–1.3	–8.0
Investment	–0.2	–12.0

^a Percentage difference between feedback scenario and baseline scenario.

Gross investments are affected in two ways as well: first by the corrosion-induced 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. In most of the period before 2030, gross investment increases as the replacement effect is the most important. Later on, gross investment decreases markedly because of the general equilibrium response.

By describing the effect on factor supplies, we have come full circle, as we started this story by explaining how lower factor supplies lowered consumption and GDP.

4. Sensitivity analysis

This section investigates some sources of environmental drag which are especially relevant from an environmental point of view. Crucial questions in the environmental debate 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. Table 6 summarizes the results of the sensitivity analysis.

4.1. A lower discount rate?

Environmentalists sometimes claim that a high social discount rate is unfavorable to environmental concerns by ignoring the future damage to the ecosystem associated with investment projects. However, the role of the discount rate in addressing the environmental costs is ambiguous when the effect of discounting on capital accumulation is taken into account. As pointed out by Krautkraemer (1988), a low discount rate encourages conservation of nature, but at the same time stimulates accumulation of production capital, which indirectly demands increasing amounts of natural resources. The trade off between welfare from these two types of wealth (capital and nature) must be assessed empirically. We take up this issue in two ways.

Table 6
Welfare loss by exploratory sources of drag (percent)

Alternative	Total welfare	Welfare from consumption	Welfare from environment
1 Base-case	9.95	0.76	9.19
2 Rate of time preference 0 pct.	11.3	1.5	9.9
3 Rate of time preference 3 pct.	8.8	0.3	8.5
4 Planner's rate of time preference 0 pct.	13.9	0.7	13.2
5 Planner's rate of time preference 3 pct.	6.7	0.9	5.8
6 Technical progress 3 pct.	9.8	0.6	9.2
7 Technical progress 1 pct.	9.8	0.8	9.0
8 Low fossil fuel price	10.2	0.8	9.4
9 High fossil fuel price	9.5	0.7	8.8

In alternatives 2 and 3, we investigate the consequence of changing the subjective rate of time preference in the model to 0 and 3%, which changes the world discount rate. The discount rate is of course higher than the rate of time preference, since consumption increases over time. The base-case subjective rate of time preference is 1%.

In our case the environmental drag increases with a low discount rate. This is not a simple story of valuing more highly a given amount of future environmental damage. Future environmental damage is not given, it is lower when the discount rate is lower. In fact, as Table 6 shows, welfare loss from the environment is not significantly different from the base-case, and the difference that is observed may be related to the welfare loss to consumption, which we now proceed to explain: The main impact of a lower discount rate is to change the consumers' trade-off between consumption now and in the future. That is the case for both scenarios, but the impact is greater in the feedback scenario: recall that the consumer of the feedback scenario hedged against the future impact of production drag by saving some of the early income. The reward to this action is reduced by a lower discount rate, thus the consumers must save more early on in order to enjoy the same steady state consumption level later. Thus to mobilize savings in order to meet the drag is more costly under a lower discount rate, increasing the welfare loss from consumption.

Consumers partly respond to the strain on the current account by working more, which increases

production and modifies the fall in intertemporal consumption. This increase in production, however, harms the environment, increasing the environmental drag and the welfare loss from environment. On the other hand, a lower interest rate reduces the user cost of capital, and leads to more capital intensive and less energy intensive production, which modifies the scale effect on the environment. Hence, in our case, the more costly saving together with the production scale effects dominate the drag modification obtained through less energy and emission intensive production.

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 single economic agents. One reason that has been advanced is that individual agents do not care enough for their descendants, while another point of view is that society should employ a lower interest rate in the lack of first best instrument to combat environmental problems. The idea that utility should not be discounted in welfare evaluations goes back a long way (see e.g. Ramsey (1928)).

Alternatives 4 and 5 concern the impact of evaluating the economic outcome from a planner's point of view by 0 or 3% rate of time preference.⁶ This is a simple story of valuing the future more highly. The impact on welfare from

⁶ Optimal government reactions to 0 or 3% are not accounted for.

full consumption is small because of consumption smoothing which 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 the long-run damages than the consumers do themselves. Disutility from lower environmental quality increases 45% (4 percentage points) according to the preferences of the planner. In the same way, a high planner's rate of time preference discounts high future damages more, reducing the impact on intertemporal utility.

4.2. Lower technological progress?

Environmentalists sometimes accuse the standard economic analysis of assuming too high future technological progress and consequently an easy way out of many environmental problems. Alternatives 6 and 7 evaluate how technological progress affects welfare losses. Reducing the rate of technical progress will reduce the steady state interest rate, since the interest rate is linked to steady state consumption growth from the Euler-equation. This contributes to an increased welfare loss from consumption, similar to the higher loss of a low rate of time preference.

A low rate of technical progress over time also implies a smaller production scale, which in turn implies lower energy consumption and lower pollution, which in turn contributes to a lower loss in welfare from consumption in the feedback scenario. Thus reducing the rate of technical progress has two opposing effects on welfare from consumption: the interest rate effect increases, while the scale effect decreases the loss. The strengths of these effects are non-symmetric around the base-case.

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

4.3. Increasing energy prices?

Environmentalists are concerned that energy prices in the long run will increase more than assumed by the standard analysis. The baseline input assumes a 14% growth in real fossil fuel prices by 2030. What is the impact on the environmental drag of assuming higher (and lower, for comparison) fossil fuel prices? That is the topic of alternatives 8 and 9. By 'higher' we mean 2.5% annual growth. 'Lower' means zero growth.

Higher prices of fossil fuels imply that producers move into a more energy efficient mode of production. Emissions per unit of output fall. In addition the level of output falls because lower wages (remember they adjust to keep overall costs down) and labor supply means a contraction of the economy. All in all, emissions fall, which reduces the disutility from pollution.

A conclusion to the sensitivity analyses 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. Some of the effects that we do detect run against popular wisdom. For instance, endowing agents with a lower rate of time preference increases the environmental drag through its effect on labor supply.

4.4. Robustness

To further check the robustness of the model, several other important parameters are tested for alternative specifications (see Bruvold et al. (1995)). This test shows that 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. Damage parameters that characterize disutility from the environment have a first order impact on utility, and thus matter a great deal more. Changing labor supply elasticities and elasticities of production do not seem to have significant effects on the outcome.

5. Conclusions

This analysis shows that environmental constraints so far incorporated into production probably have a modest effect over most of the next century. This conclusion is robust to a number of alternative specifications of parameters and exogenous variables. In fact, the welfare cost of full consumption (consumption of goods and leisure) shows a rather remarkable stability across different assumptions. However, the direct loss of welfare from the environment is significant. This conclusion is also robust to a number of alternative specifications of parameters, with the exception of the parameters that attribute welfare to environmental services.

The study indicates that the environmental drag on production reduces annual economic growth rates by about 0.1 percentage point. Annual growth in wealth, including environmental wealth, is reduced by 0.23 percentage points until 2030.

Our results can be compared to those of Nordhaus (1992). Nordhaus estimates the drag from non-availability of cheap resources and from local pollutants. Our estimate for Norway only covers a limited number of acknowledged feedbacks from local pollution, but still comes out with twice the Nordhaus drag on economic growth. Costs related to road traffic volume that are included in our study, but not among local pollutants considered by Nordhaus, can partly explain the difference.

Our results can be used to indicate the benefits of abatement and related activities. If all the specified sources of environmental problems were eliminated by year 2030, GDP in that year would be 1.7 billion US\$ higher (ignoring intertemporal reallocations). If all environmental problems were eliminated today, the total intertemporal welfare gain would amount to 110 billion US\$. 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 would probably pass the cost-benefit test. In a study of the US, Jorgenson and Wilcoxon (1990) find that environmental regula-

tion reduced the annual economic growth by 0.2 percentage points over the period 1974–1985, and the long-run reduction in growth significantly lower. Assuming a rational political process, one can interpret this as an estimate of the willingness to pay for avoiding environmental drag. Willingness to pay (for environmental improvements) of this magnitude would roughly match the level of environmental costs estimated in this paper so far in Norway.

The results of this paper are subject to a number of qualifications. The global environmental linkages might be more important than the local linkages. Global environmental problems like the greenhouse effect are external to the Norwegian economy, and thus these are absent from the study, since they would affect both the baseline and feedback scenarios equally. Regarding the effects we find on production growth, there may be crucial interactions between the environment and the economy that we have not accounted for. Health impacts of current chemical flows are not yet fully understood or recognized. Relevant subjects of serious concern are carcinogens, hormone-mimicking compounds and anti-bacterial agents. Also, long term effects on productivity of land and marine environment are potential sources of drag that are not accounted for in our analysis.

We have assumed that the unit value of environmental damage is constant. This is doubtful, as the value may change with the level of damage as well as with income or just with time, and the estimation of non-market environmental goods is also riddled by a range of theoretical and practical problems. In addition we assume no technical improvement in abatement technology, which might contribute to overstating the environmental drag.

Overall, our estimate of the environmental drag is uncertain and based on a number of underlying assumptions that some readers may find unconvincing. These assumptions notwithstanding we think our numerical results are indicative of the size of the drag, and that the mechanisms we have described are important determinants of the environmental drag.

It is a general experience that environmental assessments must be rooted in the ministries of

finance to generate efficient environmental and economic policy options. To bridge a gap between environmental and financial policy spheres, an integrated assessment of the environmental drag is clearly useful.

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Appendix A. Environmental feedbacks

We summarize the main principles and sources behind the incorporation of the environmental links into the core model. 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. Further details and actual equations are documented in Vennemo (1997).

A.1. Emissions and traffic

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. The reduction in emission coefficients due to exogenous abatement is projected according to estimates from the Norwegian Pollution Control Agency. We use gasoline and auto-diesel consumption to proxy traffic volume. The argument is that efficiency, demographic variables and security measures being constant, the change in gasoline and auto-diesel consumption captures the change in traffic-related externalities reasonably well. Traffic costs include accidents, congestion and noise and rise proportionally to traffic volume. About half of external cost associated with gasoline and diesel consumption originate from traffic, not pollution per se.

The level of environmental and traffic-related costs included in this study can be illustrated as

marginal costs of using various fuels. The externalities per liter of diesel and gasoline amount for about US\$ 1.5 and US\$ 1, respectively. Light and heavy fuel oil incur external costs of about US\$ 0.02 and US\$ 0.8 per liter, respectively (see Brendemoen et al. (1992)).

A brief presentation of an updated version is provided by Alfsen and Rosendahl (1996), while a comprehensive documentation can be found in Rosendahl (1998).

A.2. Depreciation and productivity

Brendemoen et al. (1992) provide data on the relation between SO₂ and corrosion costs associated with buildings and similar capital assets. Cost estimates are based on dose-response functions and material inventories as documented in Glomsrød (1990). Pollution included corrosion also harms buildings and monuments of cultural value. This effect, while probably important, is not included in the model for data reasons. We assume that the amount of traffic is a reasonable proxy for the determinants of road depreciation.

Brendemoen et al. (1992) provide data on the environmental effects on labor productivity. 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 SO₂, NO_x, CO and PM₁₀, respectively. 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 above the base year level. Only urban emissions are assumed to do harm.

We model traffic casualties along the lines of Glomsrød et al. (1998). We assume the number of traffic casualties with person injuries to be proportional to vehicle kilometers, and inversely related to congestion. We estimate the reduction in the labor force to be a fraction of casualties ‘this year’ that accounts for short-term injuries and injuries to dependents, 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 labor and capital grow without bounds. The model imposes upper bounds on the emissions' impacts, which for capital depreciation is assumed to be 7.5%, three times the actual base-year rate of depreciation (of buildings and roads). For labor productivity loss, the maximum is assumed to be 3% for NO_x and PM₁₀, and 1.5% for SO₂ and CO, while the upper boundary for productivity loss from traffic noise is set to 1%. None of the maxima are binding within the first 101 years of the feedback scenario.

A.3. *Welfare from environmental services*

The monetary cost estimates from Brendemoen et al. (1992) can be directly compared with monetary gains in consumption or wealth. We assume constant marginal costs of degradation as a first approximation, as the data quality at the moment precludes any sophisticated modeling. Our cost estimates are uncertain even as marginal cost approximations, but they do indicate a likely magnitude. Somewhat arbitrarily we claim the welfare cost of air pollution to be one-half the productivity cost, which may well be an underestimate.

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% of traffic causes congestion costs, corresponding to the ten largest Norwegian cities' share of total diesel and gasoline consumption in the model base year. Traffic accidents 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.

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