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Quantifying Central Hypotheses on Environmental Kuznets Curves for a Rich Economy:
A Computable General Equilibrium Study

Abstract:
We investigate whether the future relationships between several pollutants and per capita income in rich countries may assume the inverted U-forms of Environmental Kuznets Curves (EKC). The emission-augmenting effect of scaling up aggregate economic activity may be counteracted by greener composition of production and consumption, technological progress, and increased demand for environmental quality and policy. To quantify the importance of these central hypotheses, we use a CGE model with endogenous policy for Norway. Our results suggest significant future effects of all these three counteracting mechanisms. For most local and regional pollutants, they may be strong enough to prolong the falling emission trends. However, we cannot rely on reductions in emissions of climate gases and some transport-related local pollutants. Our results also indicate that pollution leakages abroad are likely to find place.

Keywords: The Environmental Kuznets Curve; Endogenous Policy; Climate policy; Dynamic CGE Model.

JEL classification: D58; O11; Q25; Q28; Q48

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1 Introduction

Over the last decade, a long series of studies have investigated the relationship between pollution and economic growth per capita. Initial papers by Grossman and Krueger (1993, 1995), Shafik and Bandyopadhyay (1992) and Selden and Song (1994) presented evidence that some pollutants have historically followed an inverted U-curve with respect to per capita income. This relationship is usually referred to as the Environmental Kuznets Curves (EKC). The observations may lead to the conclusion that a more or less automatic link between income growth and environmental improvements may, in general, ensure environmental improvements also in the future. However, a range of underlying forces influences the environment in opposing directions. Thus, it is not possible to conclude whether the trend will continue or not, without further analyses of the driving forces and estimates on the future economic development.

Several theories for the observed EKCs have been proposed (see e.g. Borghesi, 1999, for a survey of the theories and empirical results from the literature). One branch of theories emphasises that changes in the *composition of consumption and production* reduce emissions per unit GDP when the economy is growing. Services and green-labelled products are relatively income-elastic, implying that their share of consumption and production may increase with income. Further, income growth may bring about a cleaner composition of available production factors. Rich economies tend to rely more on human capital and knowledge accumulation. Also, the environment, regarded as a production factor, becomes scarcer as the natural resource stock and the nature's restoration capacity gradually decline. A second branch claims *technological changes* as explanatory factors. Growth in factor productivity promotes more efficient use of resources and less pollution per produced unit. Increased factor mobility, international trade and widespread use of information and communication technology are characteristics of the growth process that contributes to an effective diffusion of innovations.

A third branch of explanations advocates *political economy* mechanisms (see e.g. Jones and Manuelli, 2001). Environmental goods are normal goods, and higher income increases the demand for a cleaner environment (Kristrøm and Riera, 1996). Agents influence the government through political economy mechanisms like lobbying, voting and other political activities (see Drazen, 2000, for a survey). A higher acceptance for environmental regulations and taxes reflects increased willingness to pay for the environment, and such policies also stimulate environmentally friendly technologies.

The crucial question within the EKC literature is whether positive environmental effects via compositional changes, technological progress, and political economy processes, are sufficient to counteract the negative environmental implications of scaling up aggregate economic activity. The predominant approach to the EKC has been to study historical data on the relationship between economic growth and some environmental indicators. Findings suggest that counteracting effects dominate for many emissions, especially for rich countries. Thus, it is of great interest to investigate whether this trend can be expected to continue. We supplement the econometric contributions by considering the EKC relationship for a rich country in a forward-looking perspective. Our tool is a complex computable general equilibrium (CGE) model that integrates economic and environmental mechanisms. A general framework enables us to take into account central assumptions and mechanisms of relevance to the environmental development, such as future changes in technology, factor endowment and energy markets for the next three decades.

Empirical contributions based on CGE models have been modest. Andersen and Cavendish (2001) shed some light on the EKC by studying exogenous environmental policy within a CGE model. In a CGE study of trade liberalisation, Jansen (2001) lets environmental regulations depend endogenously on income. Ansuatega and Escapa (2002) study policy effects on EKC by modelling governmental tax behaviour explicitly in an overlapping generation framework. Our contribution is to study all the hypotheses simultaneously in a consistent framework and to quantify their isolated contributions. The complexity of the model captures changes in composition, technology and policy on a detailed level. To single out the contributions of changes in (A) scale, (B) composition and (C) technique and (D) policy, we take advantage of combining two methods: CGE simulations and a decomposition procedure. The literature offers a wide range of similar decomposition analyses of pollution, also in an EKC context, see e.g. Grossman and Krueger (1993), Selden et al. (1999). Previous decomposition analyses applied on historical data for Norway show that technology effects as well as composition effects mainly explained the de-linking of a range of emissions and economic growth in Norway over the previous two decades (Bruvoll and Medin 2003, Bruvoll and Larsen 2003). By comparing our future projections with these analyses, we shed light on whether certain observed trends might be stable over time.

In our approach to the political economy hypothesis, we focus on CO_2 policy. The climate problem is considered to be one of the greatest challenges in rich countries' future environmental policy. Econometric analyses of EKC curves for CO_2 show mixed results. The turning points of the emission curves, if any, appear at very high income levels, varying from about the level of the Norwegian

GDP/capita today (40 000 € in 2000) to several millions € (see e.g. Holtz Eakin and Selden, 1995 and Lucas, 1996). Norway is the fourth richest country in the world (OECD 2001), and constitutes an interesting case, since she may be one of the leading countries when it comes to future CO_2 abatement policy.

As in Jansen (2001), we do not explicitly model the environment in the object functions, but link policy changes to income growth. We make use of regressions on long time series for Norwegian CO_2 emissions, to integrate a relationship between emissions and income into the CGE model.
One advantage of the model approach is the opportunity to include several indicators of the environmental development. Many partial studies have found substantial co-benefits of CO_2 abatement policies (see OECD, 2000, and Aunan et al., 2001). We define the environmental aspects of growth in general, and of CO_2 policy in particular, broadly by measuring the changes in emissions to air of six emissions with local or regional damaging effects: Sulphur Dioxide (SO_2), Nitrogen Oxides (NO_x), Non-Methane Volatile Organic Compounds (NMVOCs), Carbon Monoxide (CO), Suspended Particulates (PM) and Ammonia (NH_3). We also calculate the effects on emissions of all the six climate gases in the comprehensive approach of the Kyoto Protocol: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Perflourocarbons (PFCs), Sulphur Hexafluoroides (SF_6), and Hydrofluorocarbons (HFCs).

Finally, we discuss whether environmental improvements due to the composition of consumption and production stem from altered comparative advantages. Then, a downscaling of polluting industry in rich countries will partly be obtained by raising import shares of products that are dirty to produce, a process we will call *pollution leakage*. Typically, pollution-intensive production tends to be displaced to less developed countries, with lower preferences for a clean environment, and hence lower policy ambitions. Suri and Chapman (1998), Hettige et al. (1992) and Hettige et al. (1997) indicate empirical support for the theory that pollution leakage contributes to explain EKCs at a national level. It is an ethical question whether reduced domestic emissions should be credited as environmental improvements, if the counterpart is a degradation of the environment elsewhere. Also in a dynamic perspective, ethical concerns are relevant. Countries that lag behind in terms of welfare and abatement policy cannot to the same degree grow at the expense of the global environment, as the potential for exporting pollution problems will gradually diminish. This perspective is particularly relevant for climate gases, as no environmental benefit will be obtained by a pure relocation of the source. Several climate policy studies that quantify the extent of carbon leakage point out this problem (see e.g. Jacoby et al. 1997, Barker 1999).

The paper proceeds as follows; section 2 describes the method, section 3 presents the main set of results, while section 4 concludes the analysis.

2 Method

2.1 The design of the analysis

In order to study the isolated contributions of each of the hypotheses, we decompose simulated projections of emissions to air for the next 30 years into (A) scale, (B) composition, (C) technique, and (D) policy effects. We separate the analyses of the emissions from households and firms, respectively. To illustrate the decomposition procedure, we formulate total emissions of one pollutant, P, in a given year as the sum of emissions from firms and emissions from consumption (P^{CO}). Emissions from firms are subdivided into emissions from stationary and mobile energy (P^{SM}), emissions related to use of intermediates (P^{PR}), and emissions that are most adequately linked directly to the level of production (P^{X}):

(1) $P = P^{SM} + P^{PR} + P^{X} + P^{CO}$

Each of these elements may be factored as follows:

(2) $$P^{SM} \equiv \sum_i \sum_j \frac{P_{ij}^{SM}}{E_{ij}} \frac{E_{ij}}{E_j} \frac{E_j}{Y_j} \frac{Y_j}{Y} \frac{Y}{B} B ,$$

(3) $$P^{PR} \equiv \sum_j \frac{P_j^{PR}}{M_j} \frac{M_j}{Y_j} \frac{Y_j}{Y} \frac{Y}{B} B ,$$

(4) $$P^{X} \equiv \sum_j \frac{P_j^{X}}{Y_j} \frac{Y_j}{Y} \frac{Y}{B} B \text{ and}$$

(5) $$P^{CO} \equiv \sum_k \frac{P_k^{CO}}{C_k} \frac{C_k}{C} \frac{C}{B} B .$$

where B is population, Y is total output, Y_j is output in sector j, E_j is energy use in industry j, E_{ij} is use of energy type i in industry j, and M_j is the use of intermediates in industry j. For the emissions from households, C represents total consumption and C_k consumption of good k. We measure production, intermediate input and consumption in 1995 NOK and energy use in Joule. The respective contributions from the components are computed in terms of annual average growth rates, see Appendix 2 for a more detailed description of the procedure.

(A) *The scale effects* on emissions are separately calculated for the production (Y) and the consumption (C) side. They are further decomposed into the effect of population growth (*B*), and per capita growth in GDP (*Y/B*) and consumption (*C/B*), respectively.

(B) *The composition effects* on firms' and households' emissions arise from changes in the composition of industries (Y_j/Y) and consumption (C_k/C).

(C) *The technique effects* are the effects of the remaining factors in (2) - (5), i.e. changed production techniques, which change input intensity and shares (M_j/Y_j, E_j/Y_j and E_{ij}/E_j), and other technological adjustments, which change unit emissions P_{ij}^{SM}/E_{ij}, P_j^{PR}/M_j, P_j^X/Y_j and P_k^{CO}/C_k.

(D) *The policy effects* are inferred by simulating emission projections on two versions of the model, one with endogenous policy changes and one with exogenously set constant policy. The differences in emissions between the two projections constitute the isolated contributions of policy changes[1]. The two model versions are outlined in more detail below.
In addition, we address the *net* pollution leakage effects. We consider the simulated changes in import and export along the emission projection, and for most of the air pollutants included in the model we combine this information with data on emission coefficients that apply to our trade partners.

2.2 The model

We use a CGE model of the Norwegian economy, MSG6, which is a dynamic, integrated economy and emission model, designed for studies of economic and environmental impacts of climate policy. The model specifies 60 commodities and 40 industries, classified with particular respect to capture important substitution possibilities with environmental implications. We simulate two versions of the model, one with exogenous and constant CO_2 policy, *The Constant Policy Version*, and one with endogenously changing CO_2 policy, *The Endogenous Policy Version*. All other policy variables like other environmental policy, trade policy, subsidies, tax rates, and real government spending are exogenous in both versions. The exogenous public budget constraint is satisfied through lump-sum transfers. Since the Norwegian economy is small and the exchange rate is normalised to unity, all

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[1] The policy effects are the sum of changes in *policy-induced* scale, composition and technique effects.

agents face exogenous world market prices and real interest rates. Thus, financial capital is perfectly mobile across borders. Real capital and labour are domestically mobile. Parameters are estimated, or they are calibrated on the basis of the 1995 Norwegian National Accounts and relevant micro-econometric studies. Fæhn and Holmøy (2000) provide a more detailed description.

Household behaviour

Households are rational and forward-looking, and determine their consumption and savings by maximising welfare over an infinite horizon. The aggregate consumption profile, and thus the scale effect on emissions from households, results from the combination of consumption smoothing and consumption substitution across time according to the relative costs of living and intertemporal substitution[2]. The endogenous treatment of savings brings about interesting dynamics in the current account and trade balance, which is particularly important to conclusions concerning pollution leakages. The intratemporal utility function has a detailed nested CES structure, which reflects relevant price-induced substitution possibilities and distinguishes between activities with different pollution profiles (see Appendix 1, Figure A1). It forms the main basis for the potential composition effects on emissions from consumption. Aasness and Holtsmark (1995) document substitution and Engel elasticities. External effects, and in particular repercussions from the environment to the utility of the household, are not explicitly modelled.[3]

Market Structure and Producer Behaviour

Changes in emissions from firms in the private business sector are determined by firms' input and output decisions. Firms are run by rational, forward-looking managers who maximise the net present value of the cash-flow to owners. The commodities produced in primary industries are homogenous and traded in perfectly competitive markets. In the domestic markets for manufacturing goods and services, which constitute the main part of the economy, the firms face monopolistic competition. As in most models in the CGE tradition, all goods, services and factors are perfectly mobile across industries within the economy, and supply equals demand in all markets in every year. The demand for inputs is derived from industry-specific nested structures of linearly homogeneous CES-functions (see Appendix 1, Figure A2). Most elasticities of substitution are set in accordance with estimates presented in Alfsen, Bye and Holmøy (1996).

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[2] The intertemporal substitution elasticity is 0.3, which is in line with other studies, see Steigum (1993).

[3] Nevertheless, such reasoning forms the basis for the modelling of endogenous policy; increased income stimulates demand for environmental quality and thus policy. In the model, carbon policy only affects welfare through the costs of abating.

Trade

The determination of trade influences the composition effects on emissions from firms. Imported services and manufactured goods are close, but imperfect substitutes for the domestically supplied products. Both Norwegian and foreign consumers consider *Electricity*, *Crude Oil and Natural Gas*, as well as commodities produced by the primary industries *Agriculture*, *Forestry* and *Fisheries*, as homogenous, and net imports cover the gap between domestic production and demand.

Producers of manufactured goods and tradable services allocate their output between two segregated markets, the domestic and the foreign. It is costly to change this allocation, as output is a Constant-Elasticity-of-Transformation function of deliveries to the export market and deliveries to the domestic market. Prices of exports are exogenous, determined in the world markets.

Emissions

For all compounds, emission calculations are linked to each economic activity at a detailed level (Strøm, 2000). Table 1 provides an overview of the specified air pollutants, and their sources.

Table 1. Air pollutants and important sources in MSG-6

Pollutant	Important sources MSG-6 industry in parenthesis
Kyoto gases	
Carbon Dioxide (CO_2)	Combustion of fossil fuels (Several) Reducing agents (Manufacture of Metals) Gas power generation (Production of Electricity, Oil and Gas Extraction) Flaring (Oil and Gas Extraction)
Methane (CH_4)	Livestock, manure management (Agriculture) Landfills Production and use of fossil fuels and fuel wood (Several)
Nitrous Oxide (N_2O)	Fertilising (Agriculture), Fertiliser production (Manufacture of Industrial chemicals) Road traffic (Road Transport)
Perflourocarbons (PFCs)	Aluminium production (Manufacture of Metals)
Sulphur Hexafluoroides (SF_6)	Magnesium production (Manufacture of Metals)
Hydrofluorocarbons (HFCs)	Cooling fluids (Several)
Other pollutants	
Sulphur Dioxide (SO_2)	Combustion (Several) Process emissions (Manufacture of Metals)
Nitrogen Oxides (NO_x)	Combustion (Several)
Carbon Monoxide (CO)	Combustion (Several)
Non-Methane Volatile Organic Compounds (NMVOCs)	Oil and gas-related activities Road traffic Solvents (Oil Refining, Road Transport, Households)
Ammonia (NH_3)	Road traffic (several) Fertilising (Agriculture)
Suspended Particulates ($PM_{2,5}$ and PM_{10})	Road traffic (Households, Agriculture, Road Transport) Fuel wood (Households)

Energy combustion is the main polluting activity in firms and households. Both stationary and mobile combustion have imperfect substitutes (see Figure A1 and A2), some that do not pollute (hydropower electricity, rail and tramway transport), some that cause emissions abroad (imports) or in other sectors (gas power electricity, transport by road, sea and air). Firms and households contribute to *Methane* emissions through consumption of several material inputs that generates solid waste, which in turn emits from landfills. A major polluter is *Extraction and Transport of Crude Oil and Gas*. In 2000, it produced about 1/4 of the Norwegian calculated CO_2- emissions and 2/3 of the NMVOC-emissions. The sector is heavy regulated and treated exogenously in the model. Electricity supply is specified by three different, substitutable sources, and its composition is important to the determination of emissions. First, hydropower is produced domestically with virtually no emissions to air. Investments are large and irreversible, and sharply decreasing returns to scale limit capacity expansion. The production of hydropower is exogenously controlled in accordance with recent practice and intentions expressed by the government. Secondly, electricity may be imported from the Nordic market, causing pollution leakages in terms of emissions from thermal power plants abroad. Conditions in the Nordic electricity market determine the electricity price, and net imports equal the residual between domestic production and consumption[4]. Thirdly, the model specifies the technology of gas combustion, associated with substantial emissions, primarily of CO_2. Emissions from the public sector are low and disregarded in the model.

The CO_2 policy determination

In *The Constant Policy Version*, all emissions are recursively calculated, linked to economic activity as described above. We keep the CO_2 policy exogenous and constant. In *The Endogenous Policy Version*, we approach a scenario with endogenously determined CO_2 policy. An attractive approach for testing the isolated influence of policy could be to estimate the effect of CO_2 taxes directly. One obvious policy reform of the past is the introduction of Norwegian carbon taxes in 1991. However, the empirical data on CO_2 taxes is too limited to test empirically. Besides, in practice, concerns about the greenhouse effect are part of the foundation for the general energy taxes and car taxes. Other environmental taxes and regulations, such as taxes on lead and sulphur dioxide, may also function as substitutes to carbon taxes in the practical design of environmental policy. Thus, it is not straightforward to single out and test the *isolated* effect of climate policy.

As an approximation, we make use of historical data to extrapolate the future emissions of CO_2. We conduct an econometric analysis of the relation between *total* emissions and GDP/capita. This

[4] In order to get a satisfactory grip on Nordic market conditions, we have simulated a model for the Nordic electricity market (Johnsen, 1998) in iterations with our model.

historical relationship is partly influenced by climate policy. We include this relationship into the model. By doing so, the emission calculations from each single activity can no longer remain recursive, as in the constant policy version. Endogenous variation in the CO_2 tax closes the model. We choose this option, as it may be argued that in projections based on the constant policy version, this will be the main omitted effect that underlies the emission /GDP to capita- relation.[5] In accordance with standard optimality rules (Sandmo 1975), we assume a uniform tax on all emissions, irrespective of source.[6] Emissions of other compounds than CO_2 are determined as in the constant policy version.

Econometric representations are usually quadratic or cubic in GDP per capita, either linear or logarithmic, and with or without a trend term (see e.g. de Bruyn, 1997 or Agras and Chapman, 1999). Reduced-form models capture the structural model in which increased economic activity scales up emissions, while the related income rise influences the composition of consumption and production, as well as technological change and environmental policy. Changes in all these factors in turn influence emissions. We use a flexible third degree functional form model in the analysis of Norwegian time series data of CO_2 over the years 1949-2000:

(6) $$\ln CO_{2,t} = \alpha + \beta_1 \ln \bar{y}_t + \beta_2 \ln \bar{y}_t^2 + \beta_3 \ln \bar{y}_t^3 + \varepsilon_t ,$$

where $CO_{2,t}$ is CO_2 emissions in million tonnes in year t and y_t is income per capita. Income increased steadily over the period. We opt for a certain lag between income growth and the realisation of environmental policy. We further include the possibility that expectations about future income growth partly form the basis on which policy reforms evolve. A two years' lead and lag structure fits the data well. With a five-year moving income average of the per capita income (denoted $\bar{y}_t$), we obtain reasonably statistically significant estimates.[7]

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[5] An alternative could be technological changes other than those already accounted for in the projections. Though there still exist no feasible ways to treat CO_2-emissions, we do account for changes in factor productivity, including energy efficiency, only by exogenous and highly uncertain estimates.

[6] The welfare literature is differentiated at this point. The second-best theories show that a differentiated tax system may be optimal in particular distorted situations. Applying such alternative systems into this analysis would however complicate an endogenous policy determination. Another question is whether to expect that the policy outcome of political actions is welfare maximising. It will rely on factors like relative lobbying power, incentives to vote etc. Again, we disregard these complications in order to focus the analysis. It would require a complete structural model of the political economy of carbon policy.

[7] The results show the following relation: $\ln CO_{2,t} = 6.64 + 64.53 \ln \bar{y}_t + 2.39 \ln \bar{y}_t^2 + 0.46 \ln \bar{y}_t^3 + \varepsilon_t$. Note that $\ln CO_{2,t}$ >0, while $\ln \bar{y}_t$ <0. The coefficients are significant on a 0.00, 0.09, 0.05 and 0.01percent level, respectively. CO_2 emissions are measured in mill. tonnes, real income is measured in mill. NOK per capita.

3 Results

3.1 The underlying macroeconomic development

The projections are made for the period 2000 to 2030. The reported long-run estimates are the steady-state results based on the exogenous estimates in 2030. Most exogenous estimates are drawn from the reference scenario in the Long Term Programme for Norway (LTP), see Norwegian Ministry of Finance, 2001 for a detailed documentation.

Except for the CO_2 policy, we keep most policy variables constant at 1995 levels. The other main exception is public consumption, which we assume will increase by 1.0 percent annually, on average. This is higher than the LTP estimates, but still the public to private consumption ratio is low in a historical perspective. The assumptions on public consumption severely affect emission projections, as unit emissions from the public sector are low, and by assumption ruled out in the model. As for most European countries, the growth in total employment will be low the next 30 years compared to previous periods (on average 0.2 percent annually), due to an ageing population. In the last 10 years of the projection period the growth is negative. Total factor productivity growth rates in the private sector are exogenously set to 1.0 percent annually; the corresponding rates in the public sector are 0.5. The Norwegian income depends heavily on natural resources. The oil and gas exploitation is set exogenously, implying a fall from 14 percent of total GDP in 2000 to 3.6 percent in 2030. The expected oil and gas prices fall the first 6 years of the period. Later, the annual average growth rate is 1.5 percent, which is in line with the projected development in other international prices. The former natural resource wealth will to a large extent turn into financial assets, which ensures Norway a substantial currency income flow also in the future. The return flow is based on a 4.0 percent international real interest rate.

The constant policy scenario

In the constant policy scenario, the real CO_2 tax rates are kept constant at their factual 1999 levels. In principle, the system covers all use of fossil fuels, but with highly varying rates - see Table 2.

Table 2. Real CO_2 tax rates in the constant policy scenario, 1999, €[*] per tonne CO_2

	€ per tonne
Maximum taxes by fuels	
- Gasoline	48
- Coal for energy purposes	23
- Auto diesel and light fuel oils	21
- Heavy fuel oils	18
- Coke for energy purposes	17
Taxes by sectors and fuels	
North Sea petroleum extraction	
- Oil for burning	40
- Natural gas for burning	46
Pulp and paper industry, herring flour industry	
- Light fuel oils, transport oils (gasoline, diesel etc.)	10
- Heavy fuel oils	9
Ferro alloys-, carbide- and aluminium industry	
- Coal and coke for processing	0
- Land-based use of gas	0
Cement and leca production	0
Air transport	0
Foreign carriage, fishing and catching by sea	0
Domestic fishing and goods traffic by sea	0
Average tax for all sources	20

[*] 1 € ≅ 8.3 NOK

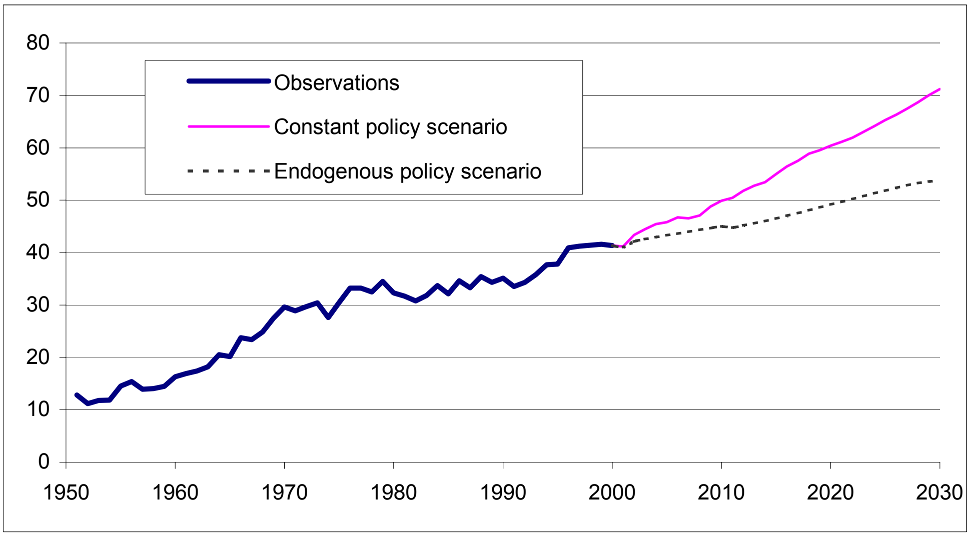
Source: Statistics Norway

In brief, two equilibrium conditions, the labour market balance and the intertemporal budget constraint that restricts the long-run current account, may represent the model. In spite of the downscaling of the offshore activities, the projected exogenous growth factors, *ceteris paribus*, stimulate the economy. As a response, the wage rates and the overall consumption level adjust, in order to ensure a re-fulfilment of the two balance criteria. In light of the low growth in the labour force, the effect in the labour market of stimulating the economy is to create excess labour demand. At the same time, domestic producers improve their competitive positions, and thus the national current account. As a counteracting reaction, wage rates rise. This helps restore labour market equilibrium as well as the long-run current account. The level of consumption may in principle respond in both directions: A consumption *fall* would, *ceteris paribus*, help to restore the labour market balance, while a consumption *rise* increases imports demand and would thus help to re-establish the long-term current account. The model simulations show that a combined rise in both consumption and wage rates takes place. Consumption rises at an annual average rate of 4.1 percent. This rather high growth rate relies highly on the relatively low annual growth in public consumption of 1.0 percent. Simultaneously, the average wage rates grow by 4.7 percent annually. The simulated growth in GDP over the next 30 years is 1.8 percent, in annual average terms. On the macro level, primary factor intensities change substantially. Accumulated capital endogenously increases by 1.4 percent yearly, as opposed to the low employment growth. This mirrors the relatively moderate increases in user costs of different capital goods, of between 2.0-2.9 percent. The GDP growth is substantially lower than consumption growth. This reflects the considerable and increasing financial wealth, as more and more of Norway's natural wealth turn into financial assets. By 2030, this financial capital amounts to 15 times the wealth in 2000. In *per capita* terms, GDP grows by 1.4 percent as a yearly average. The per capita growth in consumption averages 3.7 percent.

The endogenous policy scenario

The simulations indicate that an endogenously determined uniform carbon tax would amount to 13 € per tonne CO_2 in 2000. This is significantly lower than the average tax rate of about 20 € that applies in the constant policy scenario, and reflects that a uniform system is considerably more cost-effective. Within 2010, the uniform tax in our scenario almost doubles, to 24 €, while it ends up at 58€ in 2030. Compared to the constant policy scenario, the endogenous tax reduces carbon emissions by 5 million tonnes CO_2 in 2010 and by 18 million tonnes at the end of the scenario, see Figure 1.[8]

Figure 1. Historically observed CO_2 emissions, emissions in the constant policy scenario and in the CO_2 policy scenario, mill. tonnes



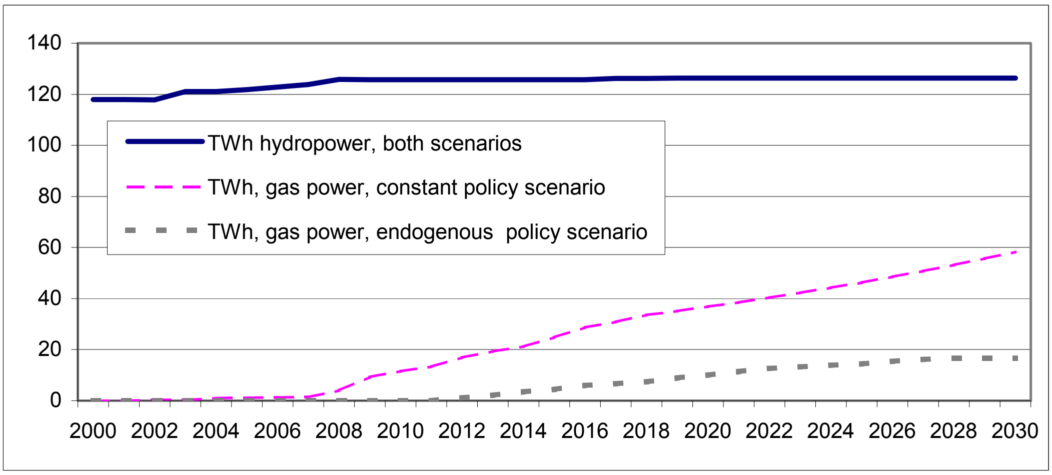
According to our projections, the endogenous CO_2 policy significantly reduces gas power production, see Figure 2. Today, Norway does not exploit gas for domestic power generation to any significant degree. There is an ongoing debate on what is the appropriate economic policy directed towards the gas power sector. The political pressure towards increased processing of natural gas is strong, given

[8] For a comparison, Norwegian Ministry of Environment (2001) estimates the necessary reductions in all Kyoto gases to 11 million tonnes in 2010, in order to fulfil the Kyoto commitments by means of domestic measures, only, i.e. without an international quota arrangement.

Norway's rich endowments.[9] The future exploitation and development of gas power technology will be of great importance to Norway's ability to abate carbon emissions, e.g. in accordance with international CO_2 gas agreements like the Kyoto Protocol.

Economic activity falls in the endogenous policy regime, compared to the constant policy scenario. The long run level of GDP falls by 0.5 percent, as does long-run aggregate consumption. However, the first part of the endogenous policy scenario deviates less from the constant policy scenario, and the average annual growth rates are not significantly affected. Less immediate stimulus to production and consumption relaxes the pressure on the labour market, and wage rates increase by 4.6 percent as a yearly average, i.e. 0.1 percentage points lower than in the constant policy scenario. CO_2 taxes also reduce competitiveness for Norwegian producers, which contributes to this fall.

Figure 2. Electricity production in the reference and the policy scenario (TWh)



[9] Sensitivity analyses made by exogenously adjusting the gas power production, i.e. changing the profitability requirements, indicate that the endogenous tax rate is highly responsive: A 10 percent increase (decrease) in gas power production increases (decreases) the tax rate by 20 percent in the long run.

3.2 Emission projections

Table 3 displays the results from the decomposition of different EKC effects on the emission changes.

Table 3. Average annual growth in emissions decomposed into (A) scale, (B) composition, (C) technology and (D) endogenous policy effects

Emissions*	CO_2	Other Kyoto gases	SO_2	NO_x	NMVOC	CO	PM	NH_3
Emission changes from firms, contribution from:								
(A) Scale effects	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
-population	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
-GDP per capita	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
(B) Composition effects	-0.9	-0.6	-0.1	-1.0	-2.9	-0.1	-0.4	-1.3
(C) Technique effects	0.4	-0.6	-1.8	-1.2	-0.6	-2.2	-2.5	-1.8
-energy intensity	-0.5	0.0	-0.2	-0.8	-0.1	-0.5	-1.2	0.0
-energy mix	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	0.0
-intermediate intensity	-0.7	-0.6	-1.6	-0.3	-0.5	-1.2	-0.1	-1.9
-other technological changes	1.6	0.0	0.0	0.0	0.1	-0.8	-1.2	0.1
(D) Policy effects	-1.3	-0.1	-0.4	-0.3	-0.2	-0.4	0.0	0.0
Total, firms	0.0	0.5	-0.5	-0.6	-1.9	-1.0	-1.2	-1.3
Emission changes from households, contribution from:								
(A) Scale effects	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
-population growth	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
-consumption per capita growth	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
(B) Composition effects	0.2	-0.5	-1.2	0.5	0.2	-0.1	-1.6	0.7
(C) Technique effects	0.0	0.9	0.0	-2.6	-1.5	-1.7	-0.1	1.9
(D) Policy effects	-0.1	-0.1	-0.2	-0.2	-0.1	-0.2	-0.3	-0.1
Total, households	4.2	4.5	2.7	1.7	2.6	2.0	2.0	6.7
Emission changes from firms and households:								
(A)-(C)	1.8	1.4	0.1	-0.1	-0.6	1.5	1.6	-0.1
(D) Policy effects	-0.9	-0.1	-0.4	-0.2	-0.1	-0.2	-0.2	0.0
Total	0.9	1.3	-0.3	-0.4	-0.7	1.3	1.4	-0.1

* See Table 1 for symbol list

(A) Scale effects

Emissions are, by assumption, generated according to constant returns to scale, and the scale effects correspond to the average annual growth in GDP and consumption, i.e. 1.8 percent in emissions from firms and 4.1 percent from households, see Table 3. Decomposing the scale effects reveals that annual average population growth explains 0.4 percent of the annual growth rate in emissions from both households and firms, while the remaining scale effects are due to per capita growth rates in GDP and consumption.

(B) Composition effects

We first turn to the composition effects that result from changes in the industrial structure. To understand the composition effects, Table 4 disaggregates the GDP growth. Structural effects mainly result from changes in comparative advantages during the period. In accordance with the composition argument explaining EKC, our computations show that structural changes contribute to reduce the future growth rates for all the emissions studied. One main explanation to the reductions, particularly in the emissions of NMVOC, CO_2 and NO_x, is that offshore activities fall by 2.9 percent in annual terms. Further, non-sheltered, manufacturing industries with high (input-output-corrected) labour-intensity tend to contract and thus contribute to CO_2reductions. *Manufacture of Chemical and Mineral Products, Manufacture of Hardware and Machinery*, and *Manufacture of Pulp and Paper* are the main examples. Finally, most of the primary industries are typically labour intensive and will face relatively unfavourable world market prices and/or reduced protection in the future. The relative contraction of *Agriculture* contributes to reductions in emissions of NH_3 and the Kyoto gases CH_4 and N_2O. Typically, the capital-intensive, import-intensive, fossil fuel-intensive, and/or sheltered industries expand in relative terms. These structural effects modify the emission reductions. *Oil refining* is a highly polluting industry. It increases its gross product by 5.3 percent as an annual average, as it is both capital-intensive and favoured by increased demand, especially in the first 6 years when electricity prices increase strongly relative to oil prices. This mainly affects the composition effects on the emissions of CO_2, NMVOC, and NO_x. Other capital-intensive industries with relative growth and high emissions, especially of Kyoto gases, are the export-oriented *Manufacture of Metals* and *Manufacture of Industrial Chemicals*. Finally, the sheltered service industries expand in relative terms. As services are typically low-polluting, this shift mainly benefit the environment, with one important exception: The sheltered transport sectors expand, as a combination of increased demand and a relative price decrease of capital. Particularly emissions from *Land Transport* and *Air Transport* contribute to increase the composition effects for several gases.

The shifts in the composition of consumption reflect relative price changes, substitution possibilities and differences in income elasticities. As shown in Table 5, two main changes dominate. First, the use of petrol and diesel increases in relative terms. Lower import prices and high-income elasticities stimulate purchases and use of cars. This, in combination with relative reductions in petrol prices, increases own transport. Thus, emissions of CO_2, NO_x, NH_3 and NMVOC all increase due to changes in the consumption pattern. This increase in private transport comes at the expense of public supply - first of all of *local* transportation, by road or tramway, as they are relatively income inelastic. The second important composition effect origins from a long-term substitution of electricity for fossil fuels for heating. This explains the reductions in SO_2, CO and PM.

Table 4. Gross Product in the constant policy scenario; level in 2000 (mill. NOK[*]) and average annual growth rate 2000-2030 (percent)[**]

	Level 2000 (mill. NOK)	Av. Annual growth (%)
Agriculture	12867	0.4
Forestry	4250	-3.9
Fisheries and Fish Farming	8613	0.8
Manufacture of Food	22046	2.8
Textile and Clothing Industry	2376	0.1
Manufacture of Wood and Wood Products	4998	0.3
Manufacture of Chemical and Mineral Products	16522	-1.2
Printing and publishing	12618	1.4
Manufacture of Pulp and Paper	9330	-1.2
Manufacture of Industrial Chemicals	9370	1.8
Oil refining	994	5.3
Manufacture of Metals	13850	2.2
Production of Hardware and Machinery	27960	-0.9
Shipbuilding	5012	0.9
Manufacture of Oil Platforms	7483	-0.2
Ocean Transport	19148	2.7
Extraction and Transport of Crude Oil and Gas	148494	-2.9
Oil and Gas Exploration	3077	-1.2
Production of Electricity	24248	1.2
Construction	41893	1.4
Wholesale and Retail Trade	92473	2.2
Land Transport	26805	2.2
Air Transport	8340	2.8
Railway and Tramway transport	2140	2.5
Coastal and Inland Water Transport	6737	1.4
Post and Telecommunications	18752	1.1
Finance and Insurance	39934	1.6
Dwelling Services	75524	4.5
Other Private Services	119698	1.9
Public Sector	178639	1.4
Weighted average		1.8

[*] 100 NOK=12€

[**] The table is somewhat more aggregated than the model structure, for presentation purposes.

Services, in particular the two dominating *Housing*[10] and *Other Services*, tend to increase their share of consumption. Both are luxury goods that are relatively stimulated by the income increase. *Housing* is also affected by the relatively favourable capital price development. The material luxury goods *Furniture and Durables*, *Clothes and Footwear*, *Equipment for Recreation Activities* all contribute to increase the composition effects on emissions of Other Kyoto Gases, as they imply CH_4 emissions from organic waste on landfills. However, the relative reduction we find in the income *in*elastic consumption of *Food*, contributes to more than offset this increase, so that the overall composition effect on Other Kyoto Gases is to reduce the emissions. It is also interesting to note that the share of *Purchases Abroad* increases. This activity is income elastic and stimulated by relatively low foreign prices. Consumption abroad implies emission leakages.

Table 5. Consumption in the constant policy scenario; level in 2000 (mill. NOK*) and average annual growth rate 2000-2030 (percent)**

	Level 2000	Average Annual Growth
Food	60880	2.1
Beverages and Tobacco	32716	3.7
Electricity	17021	2.3
Fuel	2158	2.0
Petrol/Diesel and Maintenance	28855	4.8
Clothes and Footwear	29053	4.3
Leisure equipment	14402	4.1
Furniture and Durables	15613	4.8
Electric Goods	7303	3.7
Health Services	7026	3.8
Medicines and Medical Goods	4534	2.8
Housing	95954	4.5
Cars etc.	15021	4.8
Road Transport	5426	3.1
Air Transport	9852	4.1
Railway and Tramway Transport	2430	4.4
Sea Transport	2008	4.1
Post and Telecommunications	6866	2.1
Other Goods	26329	3.7
Other Services	61653	4.2
Purchases Abroad	18925	5.6
Purchases by non-residents	-16942	2.5
Weighted average		4.1

* 100 NOK=12€

** The table is somewhat more aggregated than the model structure, for presentation purposes.

[10] *Housing* is the value of the flow of services resulting from investments in houses.

(C) Technique effects

For emissions from firms, the technique effects consist of changes in energy and intermediate intensity, energy mix, and other technological effects. As seen from Table 3, this component contributes to reduce average annual growth rates for all emissions except CO_2. Changes in *intermediate intensity* are the most important contribution. On average, the use of intermediates per produced unit decreases at a rate of -1.4 percent. This is due to the steady increase in exogenous total factor productivity, in combination with substitution for intermediates of other input factors. In particular, reduced intermediate shares in *Manufacture of metals, Manufacture of industrial chemicals*, *Construction* and *Agriculture* dominate the strong technique effects for NH_3, SO_2, CO and CO_2. Also, *energy intensities* fall, by an annual average rate of -1.1 percent. For most of the polluting gases, the factor substitution effect partly counteracts the exogenous productivity growth. The overall decrease in energy use per unit contributes to lower growth in virtually all emissions, and for PM and NO_x in particular. The relative changes in the *energy mix*, i.e. the relative use of electricity, transport oils and fuel oils, are minor when averaged across the period and across industries. In total, this effect on the emission growth is negligible.

CO_2 emissions increase due to *other technological changes*, which comprise the increasing reliance on gas power in *Production of electricity* (see Figure 2). This is an endogenous technology effect in the analysis, in the sense that we have iterated between the model and a model for the Nordic electricity market to determine the capacity of hydropower and gas power. For other gases, *other technological changes* that affect emissions from firms are primarily due to exogenous reductions in the technical emission coefficients, based on information from the Norwegian Pollution Control Authority and Statistics Norway. First, we account for a gradual market entrance of new car vintages with catalytic converters that imply lower emissions from transportation, particularly of CO. However, as a side effect of catalytic converters, the emissions of N_2O (in *other Kyoto-gases)* and NH_3 increase. Secondly, we account for some commitments made by large companies within *Manufacture of metals*, *Manufacture of industrial chemicals* and *Manufacture of chemical and mineral products* to implement cleaner technological solutions.

For households, the technique effects reduce emissions of NO_x, NMVOC, CO and PM. The introduction of new car vintages explains this, as well as the increases in NH_3 and Other Kyoto gas emissions.

(D) Endogenous CO_2 policy effects

Although the aggregate macroeconomic effects of introducing endogenous CO_2 policy are small, the policy-induced composition and technique effects give rise to significant emission changes[11]. The firms most seriously hit by the computed CO_2 policy changes belong to the heavily CO_2-emitting industries that today face no or low CO_2 taxes (see Table 2), such as *Production of Electricity* (the sub-sector based on gas power)*, Manufacture of Metals*, *Manufacture of Industrial Chemicals* and *Manufacture of Chemical and Mineral Products*.

An important secondary effect of the policy changes is lower wage rates, implying that the relatively more labour-intensive and heavily taxed *Manufacture of Pulp and Paper* suffers less. The policy directed towards CO_2 emissions contributes to reductions in virtually all gases, as the most affected economic activities emit several polluters simultaneously. Except for the transport sector, the service sectors in general increase their share of production slightly compared to the constant policy scenario. For households, the major consequence of the computed CO_2 policy is a relative decrease in the consumption of fossil fuels for heating, as well as petrol and diesel. Consumption tends to shift towards labour intensive services, as a result of lower wage increases. The endogenous policy effects on emissions are significantly smaller than for firms, due to the differentiated system in the constant policy scenario, implying that the endogenous tax rate does not exceed the real levels of the current rates facing the households before the last 10 years.

Leakage effects

We find that international trade changes considerably the next 30 years. In the nearest future, export surpluses will be high, while the situation turns to import surpluses that steadily increase from 2018 until the end of the period. There are two main explanations. First, this reflects the gradual downscaling of oil production and thus export, and the related increased reliance on income flows of foreign currency from financial assets. While gross oil export slowly increases in the first five years, it falls by an average rate of 0.8 percent yearly over the entire period. Secondly, domestic prices increase substantially along with wages and greenhouse gas taxes, and we project a gradual price decrease in prices of imports relative to domestic goods. As a result, the growth rate of import increased from 0.6 percent annually the first five years to an average rate of 2.8 percent the following 25 years.

[11] We do not account for innovations in environmental technology induced by policy changes.

Along with increased import, the net pollution leakages increase markedly over the years. Unit emissions in Norwegian production are significantly lower than for our trade partners for most gases, due to technological and compositional differences. In Table 6, we have calculated weighted emission factors for our trade partners; i.e. unit emissions for our trade partners relative to unit emissions in Norway. The factors for each emission, *zz*, *FACTORzz*, are calculated as:

$$(7)\ \ FACTORzz = \sum_i \frac{IMP_i}{IMP} \frac{Ezz_i}{GDP_i} / \frac{Ezz^{Norway}}{GDP^{Norway}}$$

where IMP_i is Norwegian import from country *i*, *IMP* is total Norwegian import, Ezz_s is emission of pollution *zz* and GDP_i is gross domestic product in country *i*. The computations are made for 1995. The emission database is UNFCCC (2002) and the data source for GDP is United Nations (2002).

Table 6. Macro emission factors for Norwegian trade partners

Emission (*zz*)	*FACTORzz*
CO_2	2.2
CH_4	2.2
N_2O	1.7
CO	1.6
SO_2	9.8
NO_x	1.0
NMVOC	0.7

The emissions per GDP unit are significantly higher for our trade partners than in Norway for almost all gases. For SO_2, the emissions per unit GDP for our trade partners are almost 10 times higher. Due to the Norwegian sulphur taxes and other political regulations, SO_2 emissions have decreased by 80 percent over the two last decades. Due to extensive hydro-based energy production, the pollution intensity in Norwegian energy production is relatively low compared to our trade partners. This partly explains why the macro emission factors for the climate gases CO_2, CH_4 and N_2O are about the double for our trade partners. NMVOC emissions, however, are lower than in Norway, because of substantial Norwegian oil loading activities.

These factors indicate that the global emission abatements are generally lower than if we restrict the analysis to domestic effects, only. This relates both to local pollutants and climate gas emissions. However, to draw sharp conclusions, we would need to account for compositional changes in imports and exports. Such calculations require, *inter alia*, a detailed account of emission intensities per imported unit specified on industries and countries. Furthermore, due to changes in energy use and technological progress, foreign unit emissions may also change over time. The conclusion above relies on the assumption that progress abroad in environmental technology will not be (much) faster than in Norway. If the EKC relationship holds, each country and pollutant will follow its own emission abatement path, depending on the welfare development.

4 Conclusions

An important implication from this analysis is that we cannot rely on the EKC mechanisms alone to solve the future environmental problems. Particularly, this is relevant to climate policy. However, our forecasting model predicts a decoupling between growth in GDP for most local and regional pollutants, even if we assume business as usual, i.e. no changes in the environmental policy compared to present tax system. When we also account for endogenous CO_2 policy effects, the growth rate for CO_2 emissions is bisected.

In line with the EKC hypothesis, the technique effects generally reduce the emission growth for all emissions except for CO_2. This is mainly due to the anticipated increase in total factor productivity and new car vintages. Also, low-polluting consumption and production increase at the expense of material- and energy-intensive activities, and the total composition effects reduce all gases. The emission-reducing composition effects stem from relatively high income elasticities for low-polluting services, a downscaling of the oil industry, and reduced agricultural production due to lower anticipated protection in the future. When it comes to the composition of consumption, the effect is ambiguous, due to a relatively high growth in petrol consumption.

A comparison of our model simulations with a decomposition of historical emissions (Bruvoll and Medin, 2003) shows that the relative roles of the driving forces may continue into the future much in line with the historical trends. Our projections indicate that technological changes may be the main emission-reducing factors counteracting economic growth in the future. This is in line with the historical data for the years 1980 - 1996. Also, the composition effects we find tend to prolong the observed pattern over the previous decades.

Our decomposition also reveals that consumers increase their share of pollution relative to the production sectors. This is first of all explained by the strong scale effect in consumption, combined with relatively modest policy effects. Due to the uniform CO_2 policy, the consumers pay *lower* CO_2 taxes in the first 20 years, as compared to a prolonging of the current differentiated carbon tax system. However, consumption falls despite the relatively low tax burden in the nearest future. Thus, the environmental policy involves welfare costs in terms of reduced utility from material consumption.

This reflects that the endogenously determined tax system represents a higher willingness to pay for a cleaner environment than the current tax system requires.

The analysis supports the need for broadening the perspective in studies of climate policy in two respects: First, we find strong environmental co-benefits of climate policy in terms of reduced emissions of local and regional pollutants. This emphasises the need for an integrated approach in the assessment of climate policy that takes into account the overall environmental benefits. Secondly, this study points to the need for including counteracting, as well as reinforcing, leakage effects in the overall assessment. Although we cannot conclude sharply on the basis of our aggregate approach, our computations indicate that not only will the local environment improve at the expense of other countries, but the emissions abroad will increase more than the domestic reduction given that domestic production is fully substituted by increased import.

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Appendix A

Figures

Figure A1. The preference structure of the household in MSG-6

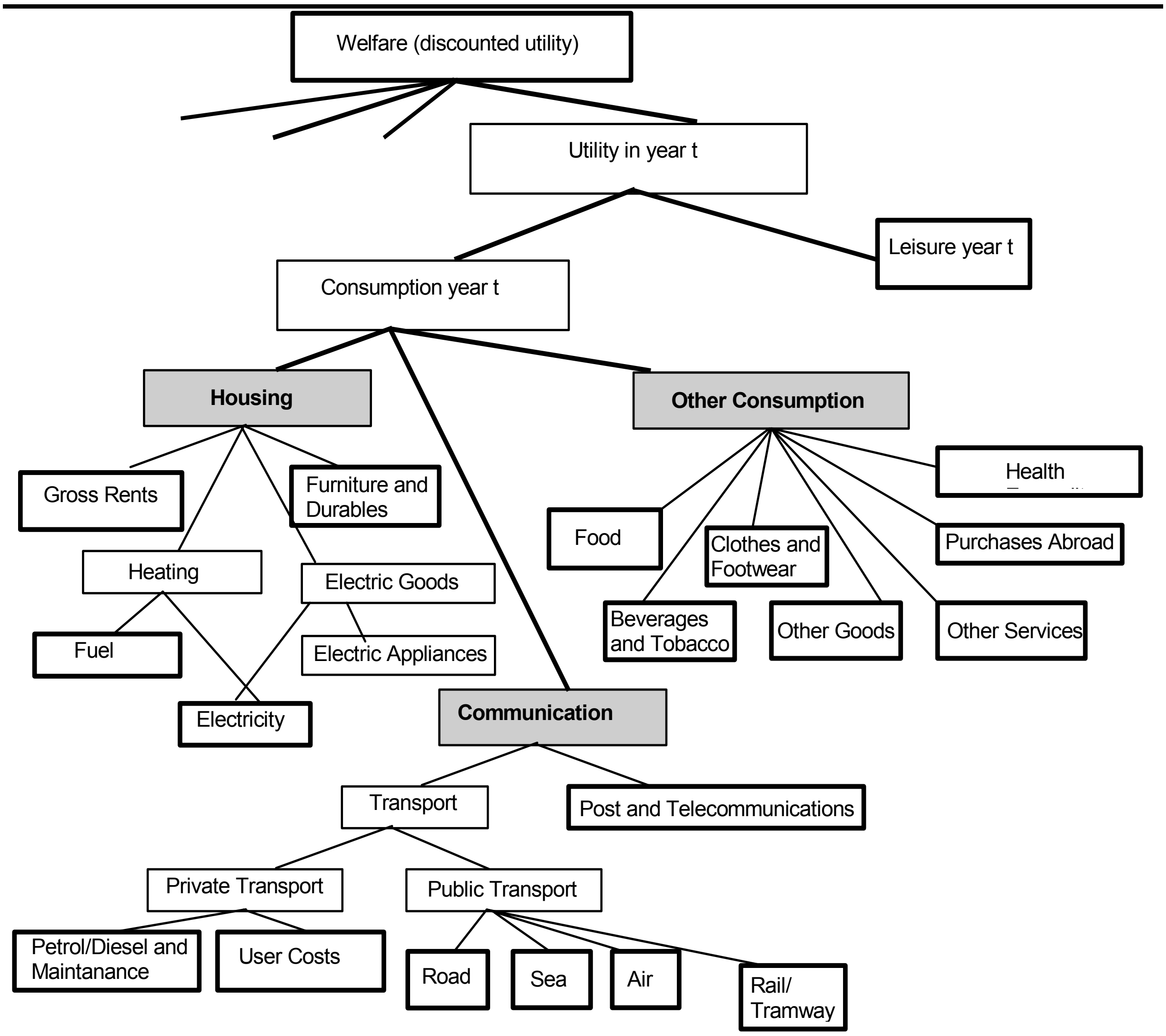
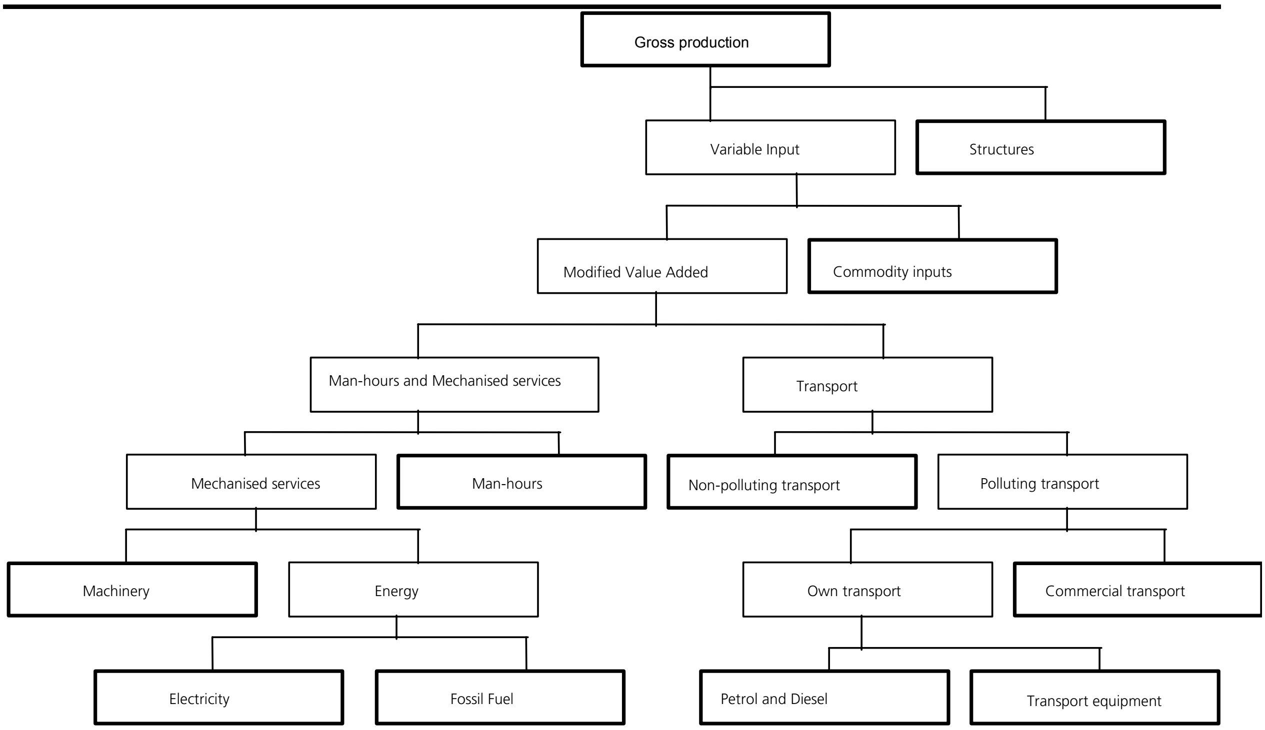


Figure A2. The separable structure of production structure of the firms in MSG-6



Decomposition of the emission changes in the constant policy scenario

Emissions from firms:

The population component:

(8) $$N = P_0\left[\frac{B_1}{B_0} - 1\right]$$ where $P_0 = P_0^{SM} + P_0^{PR} + P_0^{X}$

The GDP per capita component:

(9) $$S = P_0\left[\frac{Y_1}{Y_0} - \frac{B_1}{B_0}\right]$$

The composition component:

(10) $$C = \sum_j P_{j0}\left[\frac{Y_{j1}}{Y_{j0}} - \frac{Y_1}{Y_0}\right]$$ where $P_{j0} = P_{j0}^{SM} + P_{j0}^{PR} + P_{j0}^{X}$

Energy related emissions from firms:

The energy intensity component:

(11) $$H = \sum_j P_{j0}^{SM}\left[\frac{E_{j1}}{E_{j0}} - \frac{Y_{j1}}{Y_{j0}}\right]$$

The energy mix component:

(12) $$Z = \sum_j \sum_i P_{ij0}^{SM}\left[\frac{E_{ij1}}{E_{ij0}} - \frac{E_{j1}}{E_{j0}}\right]$$

The other technological changes component for combustion related emissions:

(13) $$T^{SM} = \sum_j \sum_i P_{ij0}{}^{SM} \left[\frac{P_{ij1}{}^{SM}}{P_{ij0}{}^{SM}} - \frac{E_{ij1}}{E_{ij0}} \right]$$

Material related emissions from firms:

The material intensity component:

(14) $$K = \sum_j P_{j0}{}^{PR} \left[\frac{M_{j1}}{M_{j0}} - \frac{Y_{j1}}{Y_{j0}} \right]$$

The other technological changes component for material related emissions:

(15) $$T^{PR} = \sum_j P_{j0}{}^{PR} \left[\frac{P_{j1}{}^{PR}}{P_{j0}{}^{PR}} - \frac{M_{j1}}{M_{j0}} \right]$$

Emissions related directly to production:

(16) $$T^{X} = \sum_j P_{j0}{}^{X} \left[\frac{P_{j1}{}^{X}}{P_{j0}{}^{X}} - \frac{Y_{j1}}{Y_{j0}} \right]$$

Emissions from households:

The population component

(17) $$N^{CO} = P_0^{CO} \left[\frac{B_1}{B_0} - 1 \right]$$

The scale component

(18) $$S^{CO} = P_0^{CO} \left[\frac{C_1}{C_0} - \frac{B_1}{B_0} \right]$$

The composition component for consumption emissions:

(19) $$W^{CO} = \sum_k P_{k0}^{CO} \left[\frac{C_{k1}}{C_{k0}} - \frac{C_1}{C_0} \right]$$

The technique component for consumption emissions:

(20) $$T^{CO} = \sum_k P_{k0}^{CO} \left[\frac{P_{k1}^{CO}}{P_{k0}^{CO}} - \frac{C_{k1}}{C_{k0}} \right]$$

Symbols

B:	population
P:	emissions
Y:	production
E:	energy use
M:	intermediates
C:	consumption
SM:	stationary and mobile combustion
PR:	process
X:	gross production
j:	sectors
i:	energy commodities
k:	consumption goods
0:	estimate in 2000
1:	estimate in 2030

The decomposition is complete. All components in (8) to (20) summarise to the total changes in emissions.

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