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International climate policy – consequences for shipping

by

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PREFACE

This report summarises the main results from the project "Norwegian and international climate policy – consequences for shipping". The aim of the project has been to shed light on how climate policies might affect shipping, both from the cost side and from the demand side. The project has been divided into three sub-projects, investigating the consequences of climate policies for

1. Optimal shipping operations and management
2. The competitiveness of shipping relative to land transport
3. The transport demand from the steel industry

So far, four publications have resulted from the project:

"Tilpasninger til CO2 avgift i skipsfartsnæringen", SNF-working paper 29/2000.

"Klimapolitikkens betydning for konkurransen mellom sjø- og landtransport", SNF-working paper 06/2000.

"A Steel Industry Model", SNF-report 81/2000.

"Data for a Steel Industry Model", SNF-working paper 86/2000.

This report represents a synthesis of the main results in these publications. In addition, it reports the results from the simulations of the consequences for seaborne transport of climate policies in the steel industry.

A number of people have generously assisted our work on this project. In particular, we are grateful to Bjørn von Hafenbraedl for his contributions about structural and economic aspects of the steel industry.

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Bergen, February 2001

Ottar Mæstad

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EXECUTIVE SUMMARY

Shipping may be affected by future climate policies both directly through changes in operating costs and indirectly through changes in transport demand from customers who themselves are affected by climate policies. The results from this study suggest that the indirect effects may in turn be more important than the direct ones.

The combustion of marine bunkers causes annual emissions of some 440 million tons CO2, which is about 2% of global emissions. Due to the inherent difficulties in allocating emissions from the combustion of bunkers in international shipping to any particular nation, these emissions are not included in the emission targets defined by the Kyoto Protocol. However, the Protocol requests initiatives from the International Maritime Organisation (IMO) that will ensure that the shipping sector contributes to solving the climate problem.

Various measures that may reduce greenhouse gas emissions from shipping are conceivable; a tax on the use of bunkers, a system of tradable emission quotas, subsidies on abatement efforts, technical standards on energy consumption etc. Although a system of tradable emission quotas is unlikely in the short run, this might well be the solution that wins out in a longer time perspective. There are at least three reasons for this: First, the idea of using tradable emission quotas in order to reach the emission target defined by the Kyoto Protocol is gaining increasing political support throughout the world. Secondly, as more and more nations are included in a binding climate agreement, there will no longer be any reason to treat international shipping differently from other sectors. And finally, the shipping sector itself might be better off with a solution where it can be included in a trading scheme with other sectors, rather than to have its own abatement targets. The reason is that substantial emission reductions are likely

to be more costly in the transport sector than in many other sectors of the economy.

Climate policy and optimal shipping operations and management

An immediate effect of including the shipping sector in a system of tradable emission permits is that the costs of bunkers will increase. This may lead to changes in the optimal operation of existing vessels and to changes in the design of new ones. We have analysed how a quota price of 200 NOK/ton CO2 will affect bunkers costs and thereby

(1) the optimal speed of existing vessels
(2) the optimal design speed of new vessels, and
(3) the profitability of investing in more fuel efficient technology.

A quota price of 200 NOK per ton CO2 – which we consider to be a somewhat high but not unreasonably high quota price – will imply an additional cost of about 630 NOK per ton fuel. This represents a price increase of 31% for marine diesel oil and 62% for heavy fuel oil. Without any abatement efforts, we estimate that transport costs in short sea shipping will increase by 3-15%, depending on vessel type, fuel type and average sailing distances.

A cost increase of this magnitude is unlikely to reduce the optimal speed of existing vessels in short sea shipping. The savings that can be reaped by slow steaming will not be large enough to outweigh the costs of reducing the number of trips per period, due to relatively favourable freight rates.

Speed reductions are more likely for new vessels than for old ones, because a lower design speed of a new vessel will save capital costs. In the case that we have studied, we find that climate policies will reduce the optimal design speed, but with no more than 0.5 knots.

There is a fuel saving potential of at least 5-7% by rebuilding engines in existing ships. Without emission quotas in the shipping sector, these investments are only marginally profitable, even at the presently high fuel prices. But if the shipowners have to buy emission quotas at 200 NOK per ton CO2, they will probably have sufficient incentive to realise this fuel saving potential.

Climate policy and competition between sea and land transport

Increased bunkers costs will to some extent – depending on the market situation – be shifted on to the customers through higher freight rates. It is unlikely that higher freight rates will have a significant negative impact on transport demand. The share of transport costs in *cif*-prices is so small in most cases that even if transport costs rise by 3-15%, as they do in our cases, the price increase for final consumers will be negligible.

Even though climate policies are unlikely to reduce total transport demand significantly, the demand for sea transport might still change since climate policies affect the competitiveness of sea transport relative to other transport modes. We have therefore analysed how a non-discriminating climate policy will influence the competitiveness of sea transport relative to land transport (truck) in two specific cases:

(1) Transport of containers between Oslo and Rotterdam

(2) Transport of frozen fish between Ålesund and Bologna

The effect of a non-discriminating climate policy on relative competitiveness of transport modes depends on

- The price of CO2 emission quotas
- The relative emission level per unit of transport work

- How much of the cost increase that is shifted on to the freight rates
- Whether there are any discriminating climate policies in place at the outset

We find that emissions of CO2 per unit of transport work are lower in sea transport than in land transport. Nevertheless, it is unlikely that a non-discriminating climate policy will increase the market share of sea transport. The reasons are:

(1) At realistic price levels for CO2 quotas, the increase in freight rates will be very small (<3% in our cases).

(2) In some countries (e.g., Norway and the Netherlands), CO2 taxes are levied on land transport already. Implementation of a non-discriminating climate policy therefore implies a disadvantage for sea transport.

(3) In cases where freight rates in sea transport are lower than in land transport, a smaller *absolute* cost increase in sea transport does not necessarily imply that the *relative* freight rates will change to the advantage of sea transport.

In sum, our analysis suggests that to include shipping in an international system of emission trading will only have moderate consequences for the sector as long as the quota price is no higher than 200 NOK/ton CO2. In interpreting these results, the fact that this quota price is a rather high one compared to the predictions of most international studies, should be taken into account.

Climate policy and transport demand from the steel industry

Irrespective of which climate policies that are implemented in the shipping sector, climate policies will have an indirect impact on shipping by influencing the structure of the global economy. Reduced emissions of climate gases must imply higher energy efficiency and substitution towards goods and production processes with relatively low emissions of greenhouse gases. Such structural changes may have a significant impact on transport demand.

Section 3 of this report discusses the consequences for transport demand of climate policies in the steel industry. The steel industry is a vital customer for the shipping sector. The transport of iron ore and coking coal represents about ??? % of world bulk trade (REFERANSE). In addition comes the transport of steel products and scrap. The steel industry is at the same time a major source of greenhouse gas emissions; almost 10% of global emissions of carbon dioxide are attributable to this industry. Therefore, climate policies in the steel industry might lead to substantial structural changes with implications for transport demand.

We have analysed the consequences of implementing a system of tradable emission quotas in the Annex I countries, encompassing the steel industry and the power production industry, but not international shipping. The quota price is set to 25 USD per ton CO_2.

The consequences of climate policies vary between production technologies and between countries due to differences in the input combinations used.

Emissions of CO_2 per ton crude steel, 1995. Ton.

	Basic Oxygen Furnace	*Standard Electric Arc Furnace*	*Electric Arc Furnace based on directly reduced iron*
EU13	2.1	0.5	1.0
RoWEur	2.0	0.2	-
EeoFSU	2.4	0.8	1.6
NorthAm	2.0	0.6	1.0
SouthAm	2.5	0.3	1.1
Japan	2.5	0.4	-
China	3.9	0.9	-
RoAsia	2.4	0.7	1.3
Austral	2.5	0.7	-
RoW	2.8	0.6	1.5

The Basic Oxygen Furnace (BOF) is the most polluting process and will experience the largest increase in production costs. This is bad news for the shipping sector, because it is the BOF that is the main user of iron ore and coking coal.

We find that climate policies will reduce transport demand by some 5.3%. This is to be compared with a fall in total steel production of 2.8% and a fall in BOF steel production of 4.3%. BOF steel production is reduced more than total steel production because there is substitution towards steel that is produced by less polluting processes. There are two reasons why transport demand for iron ore and coal declines more than for BOF steel production. First, producers of BOF steel in the Annex I countries reduce their use of pig iron per ton steel by 3-7% (which is compensated by increased scrap consumption). Secondly, the average transport distances decrease slightly in the iron ore transport due to reallocation of production to non-Annex I countries.

Change in transport demand (%).

Steel	-4.5
Ore	-5.5
Coal	-5.6
Total	**-5.3**

The main reduction in steel transport comes from a reduction in the transport between Eastern Europe & the Former Soviet Union and Asia. This decrease is partly offset by higher steel exports from South America, China and other Asian countries to North America and Europe.

When it comes to iron ore, it is the transport to Japan that is most badly hurt, followed by the transport to Europe. This decrease is partly offset by more transport to Rest of Asia. It is worth noticing that the high degree of self-sufficiency of iron ore in Eastern Europe and China implies that big changes in production volumes in these regions do not have a great impact on transport demand.

A very similar pattern is observed in the coal trade. Again, it is the transport to Japan and Europe that declines most, while production changes in China and Eastern Europe have a negligible impact on transport demand due to a high degree of self-sufficiency.

Sensitivity analysis shows that:

- Transport volumes are not particularly sensitive to the price elasticity of steel demand, because much of the change in transport demand is due to a change in the input mix in the BOF process and not to a decline in the production volume as such.

- The transport of iron ore and coal is somewhat sensitive to the substitutability between BOF steel and EAF steel, because larger substitution possibilities will imply a stronger structural shift away from BOF steel production.

- The transport of steel is sensitive to the substitutability between steel from different regions. If the substitution possibilities are large enough, climate policies might cause a marked increased in steel transport, partly due to relocation of steel production away from the main consumer regions, but mainly because of a general tendency towards less production for the home markets.

1 INTRODUCTION

The problem of global warming is among the most important environmental challenges of our time. Most political leaders seem to agree that some kind of action is needed in order to address the problem. However, there is deep disagreement about *what* should be done, and *by whom*.

The Kyoto Protocol, negotiated in 1997, defines binding emission limits for all industrialised countries; emissions are going to be reduced by an average of 5% compared to 1990 levels by 2008-12. The emission target covers six greenhouse gases, among which carbon dioxide (CO2) is by far the most important one.

It is highly uncertain which climate policies that will be implemented in coming years. In the short run, it is uncertain whether the Kyoto Protocol will be ratified and enter into force. If it does, it is uncertain which kind of policies that will be implemented in order to reach the agreed emission targets. In the longer run, there is uncertainty about what the follow up agreement to the Kyoto Protocol will look like; to which extent will developing countries take on binding emission limits, and how far beyond the Kyoto target of 5% abatement will the countries be willing to go?

Shipping is likely to be affected by future climate policies both through changes in the operating costs and through changes in demand for shipping services. The combustion of marine bunkers causes annual CO2 emissions of some 440 Mt CO2 (IMO, 2000), which is about 2% of global emissions. Due to the inherent difficulties in allocating emissions from the combustion of bunkers in international shipping to any particular nation, these emissions are not included in the emission targets defined by the Kyoto Protocol. However, the Protocol requests initiatives from the International Maritime Organisation

(IMO) which will ensure that shipping in the future contributes to solving the climate problem.

Various measures that may contribute to reduced greenhouse gas emissions from shipping are conceivable; a tax on the use of bunkers, a system of tradable emission quotas, subsidies to abatement efforts, technical standards on energy consumption etc. Although a system of tradable emission quotas is unlikely in the short run, this may well be the solution that wins out in a longer time perspective. There are at least three reasons for this: First, the idea of using tradable emission quotas in order to reach the emission target defined by the Kyoto Protocol is gaining increasing political support throughout the world. Secondly, as more and more nations are included in a binding climate agreement, there will no longer be any reason to treat international shipping differently from other sectors. And finally, the shipping sector itself might be better off with a solution where it can be included in a trading scheme with other sectors, rather than to have its own abatement targets. The reason is that marginal costs of abatement probably are lower in many other sectors than in the transport sector. It will therefore be cheaper for the shipping sector to buy emission permits in the market than to reduce own emissions.

In Sections 4 and 5 of this report we study the consequences for shipping of being included in a system of tradable emission quotas. The immediate implication of such a policy is that the costs of bunkers will increase. This may lead to changes in the optimal operation of existing vessels as well as to changes in the design of new ones. In Section 4, we analyse how a quota price of 200 NOK/ton CO2 will affect bunkers costs and thereby

(1) the optimal speed of existing vessels

(2) the optimal design speed of new vessels, and

(3) the profitability of investing in more fuel efficient technology.

Increased bunkers costs will to some extent – depending on the market situation – be shifted on to the customers through higher freight rates. Section 5 discusses the consequences of higher freight rates for the demand for shipping services. Particular emphasis is placed on the effect of climate policies on the competitiveness of sea transport relative to land transport. Two cases are analysed in detail:

(1) Transport of containers between Oslo and Rotterdam
(2) Transport of frozen fish between Ålesund and Bologna

Our analysis suggests that including shipping in an international system of emission trading will only have moderate consequences for the sector when the quota price is not higher than 200 NOK/ton CO2. This quota price is a rather high one compared to the predictions of most international studies.

Irrespective of which climate policies that are implemented in the shipping sector, climate policies will have an indirect impact on shipping by influencing the structure of the global economy. Reduced emissions of climate gases must imply higher energy efficiency and substitution towards goods and production processes with relatively low emissions of greenhouse gases. Such structural changes may have a significant impact on transport demand.

Section 3 of this report discusses the consequences for transport demand of climate policies in the steel industry. The steel industry is a vital customer for the shipping sector. The transport of iron ore and coking coal represents about ??? % of world bulk trade (REFERANSE). In addition comes the transport of steel products and scrap. At the same time, the steel industry is a major source of greenhouse gas emissions; almost 10% of global emission of carbon dioxide is attributable to this industry. Therefore, climate policies in this industry might lead to substantial structural changes with implications for transport demand.

2 INTERNATIONAL CLIMATE POLICY AND SHIPPING

Warnings from scientists that high concentrations of greenhouse gases in the atmosphere might lead to climate change beyond natural variations have led politicians all over the world to ratify the United Nations Framework Convention on Climate Change. The ultimate objective of the Convention is to stabilize atmospheric concentrations of greenhouse gases at "safe levels".

In 1997 the Kyoto Protocol was adopted as an attempt to put stronger obligations on the signatories of the Convention through legally binding emission targets. The Protocol commits some of the Parties to the Convention – the so-called Annex I Parties – to individual targets for their greenhouse gas emissions by the period 2008-12. The total emission reductions add up to 5% compared to 1990 levels. The emission targets cover six main greenhouse gases, of which carbon dioxide (CO2) is by far the most important one.

In order to enter into force, the Protocol must be ratified by 55 Parties to the Convention, including Annex I Parties accounting for 55% of carbon dioxide emissions from this group in 1990. Only a few small countries have ratified yet. The failure of the Hague conference in November 2000 has made it highly uncertain whether the Protocol will enter into force in sufficient time to make the countries able to fulfil their commitments. One important unresolved question is whether free international emission trading should be allowed or limits on trading should be defined in order to ensure a minimum level of domestic abatement. Another major issue is how carbon sequestration in forests should be accounted for.

If the Kyoto Protocol enters into force, policies that reduce the emission of greenhouse gases will be implemented. Each country is free to choose its own policies (e.g., carbon taxes, tradable emission quotas, or voluntary agreements). Most likely, some kind of mix between policies will be observed. But it is quite likely that most countries will implement some system of tradable emission quotas. There are several reasons for this. First, by using quotas, one can be more confident that the emission target is achieved than if other measures are being used. Secondly, international trading of emission quotas is part of the Kyoto Protocol. Thus, if a system of tradable emission permits is implemented within each country, it becomes possible to integrate the national quota markets with the international quota market. Indeed, with free emission trading, there will only be one big quota market. And with perfect competition, there will be a single quota price throughout. Agents with lower marginal abatement costs than the quota price will then reduce their emission, while those with marginal abatement costs above the quota price will buy emission permits and thus increase their emission. In equilibrium, marginal abatement costs will be equal across all emission sources. This implies that abatement costs cannot be further reduced by a different allocation of abatement efforts. In other words, such a policy will minimise abatement costs.

Since emissions from the combustion of international bunkers are not included in the emission targets defined by the Kyoto Protocol, none of the Parties will have incentives to make the shipping sector obliged to buy quotas for its emissions. In the short run, international shipping is therefore likely to be exempted from the quota system. It is however not obvious that this solution will be in the best interest of the shipping sector in the long run. In order to remain outside the quota system, the shipping sector may have to be able to demonstrate significant abatement efforts on their own. This might become quite expensive. As the analysis in Sections 4 and 5 suggests, the quota prices that are expected in the international market for emission quotas will induce very little abatement in the shipping sector. The reason is that the marginal costs of abatement in shipping will exceed the price of emission permits in the ordinary quota market. If this is true, the shipping sector may be better off by taking part in the ordinary quota system than by committing to a separate emission reduction target for the shipping sector, at least if emission quotas allocated to the shipping sector are not too different from historical emissions. The point is illustrated in the figure below:

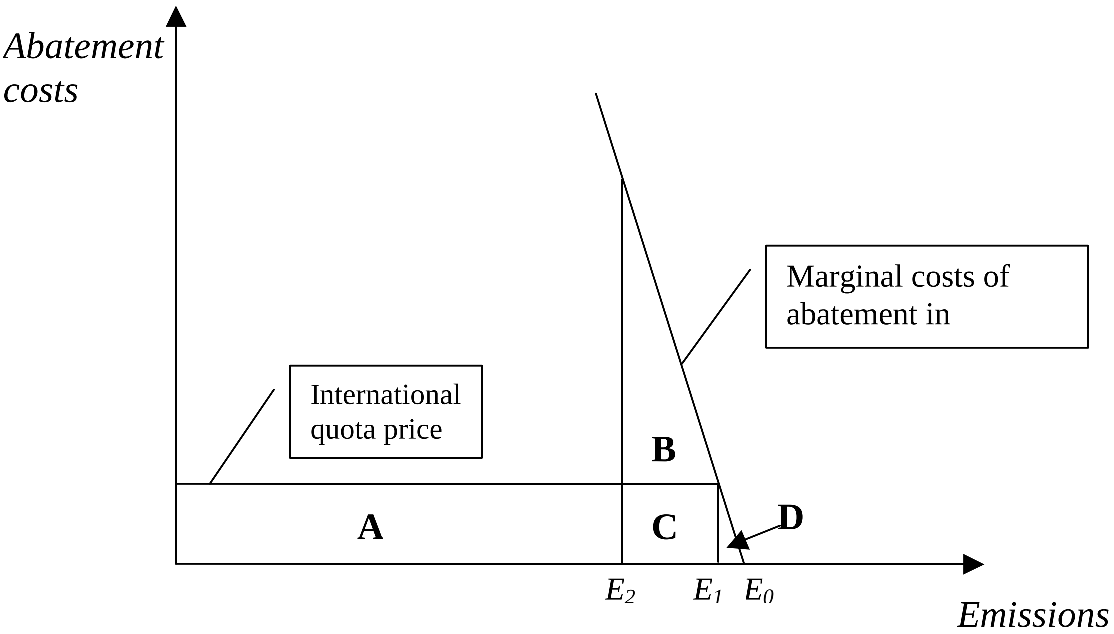


Figure 2.1. Emission standards vs. emission quotas

E_0 denotes the baseline emission level in the shipping sector. If the sector participates in the international quota system, it will be optimal to abate as long as marginal abatement costs are lower than the international quota price. Hence, the optimal emission level will be E_1. The level of abatement will be small (E0-E_1), and the total costs of abatement will equal the area D (i.e., the sum of marginal abatement costs between E_0 and E_1).

Now, if the shipping sector has to obtain significant emission reductions on its own, they may have to reduce emissions below E_1, to E_2 say. The total costs of abatement will in this case be the area B+C+D.

Which of these policies that will be preferred by the shipping sector depends on:

(1) The difference between E_1 and E_2, i.e., how stringent will the emissions standard be in a regime where the shipping sector has to show up with significant emission reductions on its own, compared to the emission level that will result from participation in the ordinary quota system.

(2) The extent to which the shipping sector has to pay market price for all its emission quotas. In other words, how a large share of the area A will be granted for free?

The costs of participating in the quota system are highest when the shipping sector receives no emission quotas free of charge and thus has to buy emission quotas corresponding to E_1 at the international quota price. The total costs are then A+C+D. Hence, the quota scheme is always better for the shipping sector if B is greater than A. But even in the opposite case (A>B), the quota solution may be preferable if some emission quotas are allocated free of charge.

If the shipping sector is included in regular international emission trading, the consequences for the shipping sector will depend on the level of the quota price. Most models predict that if the Kyoto Protocol is implemented, permit prices in the range of 10-30 USD/tCO_2 are likely (see the Energy Journal (1999) for details). It is important to note, however, that these models do not take into account carbon sequestration in forests and the potential of emission reductions in developing countries through the Clean Development Mechanism (CDM). If CDM measures are included, the quota price might well fall below

10 USD/tCO2. It is also of importance that restrictions of international emission trading might drive the quota price upwards. Mæstad and Holtsmark (2000) have compared free emission trading with the EU proposal about restrictions on emission trading. They find that the EU proposal will raise the international price of emission permits from 15 USD to 23 USD per ton CO2.

In this project, we have used a quota price of 25 USD per ton CO2 as our baseline. This is in the high end of the probable interval of quota prices. By using a relatively high quota price, we run the risk of overestimating the consequences of climate policies for firms' costs. This should be taken into account in the interpretation of our results. On the other hand, it is important to note that the Kyoto Protocol should be seen as only a first step towards a solution to the global climate problem. In order to stabilise the concentration of greenhouse gases in the atmosphere, quite drastic emission reductions are required in the future. Much higher quota prices must then be expected.

3 CLIMATE POLICY AND TRANSPORT DEMAND – THE CASE OF THE STEEL INDUSTRY

This section reports the results from our study of how climate policies in the steel industry will affect transport demand. Background information about the model that has been applied and the data that we were using can be found in Mathiesen (2000) and Mæstad (2000).

3.1 Background

Our study of the consequences for transport demand of climate policies in the steel industry is motivated by two observations. First, the steel industry is a heavy source of emissions of greenhouse gases. In a recent report prepared for the IEA Greenhouse Gas R&D Programme (ECOFYS, 2000)), it is concluded that the annual CO2 emissions from the steel industry are between 1400 and 1500 million tons per year. This is roughly 7% of global anthropogenic emissions of carbon dioxide. When mining and transportation are included the share is expected to be close to 10% of global emissions. If the steel industry becomes obliged to buy emission quotas, this is likely to have substantial cost effects, leading to structural changes in the industry.

Secondly, the steel industry generates large volumes of transport demand. Iron ore is the main transport commodity, accounting for some 2 200 billion tonne-miles a year. The transport of steel and metallurgical coal amounts to some 1 800 billion tonne-miles annually. Hence, at least 4 000 billion tonne-miles, out of a total seaborne transport in the world of about 20 000 billion tonne-miles, can be traced to the steel industry (Mæstad (2000), Fearnleys (1996)). Structural changes in the steel industry might therefore have large impacts on seaborne transport.

3.2 Steel production

Iron and steel are produced in a number of different production processes. The dominating steel processes are the Basic Oxygen Furnace (BOF) and the Electric Arc Furnace (EAF). The Open Hearth Furnace (OHF) has until recently also enjoyed a sizeable market share, but it has by now been phased completely out in most countries, except in China and the Former Soviet Union.

Table 3.1. Steel production by process, 1995.

Steel processes	*Share of world production (%)*
Basic Oxygen Furnace (BOF)	57.7
Electric Arc Furnace (EAF)	32.7
Open Hearth Furnace (OHF)	7.3
Other processes	2.4

Source: IISI (1997).

In the BOF process, pig iron and scrap are converted to steel in an oxygen blown converter. The share of scrap in the metal input usually varies between 10 and 30 per cent, depending *inter alia* on the scrap prices, which exhibit substantial volatility over time. Pig iron, which accounts for the rest of the metal input, is produced in the blast furnace process, where coke is used in order to reduce iron ore to liquid crude iron.

In the EAF process, electricity is used to produce steel from scrap. Small amounts of pig iron may be used as inputs as well, but scrap usually accounts for more than 90% of the metal input. However, there are also some EAF processes where the share of scrap may be below 50%. Directly reduced iron (DRI) then typically accounts for the rest of the metal input. DRI based processes account for 15-20 % of total EAF steelmaking.

There are more than one hundred known technologies for production of DRI. The dominating commercial processes are based on reduction of iron ore by natural gas. Due to the large gas volumes needed, DRI production principally takes place where a cheap supply of gas is available. The use of natural gas in DRI production implies that DRI based processes have a different carbon emission profile than the standard EAF process. DRI based steel making is therefore singled out as a distinct process in our analysis.

The steel products from the EAF and BOF processes are not homogenous. First, the steel quality may differ, in particular when scrap quality is low. Secondly, the products themselves are different, which has to do with the fact that the BOF process more easily can produce steel in large units. EAF therefore typically produces smaller steel products. The range of products where real competition between EAF and BOF steel takes place is in fact quite narrow. However, this may change in response to changes in market conditions.

3.3 Emissions of carbon dioxide in steel production

Our estimate of carbon emissions from the steel industry is based on input data at the plant level for about 70 steel mills, representing about 10% of world steel production. The advantage of using such a bottom-up approach is that we are confident that we are not operating with unfeasible or unrealistic input combinations. The disadvantage is that the sample may be biased and that the aggregate data therefore may be misleading.

When measuring emissions from a single industry, it is always a challenge to draw the system boundaries appropriately. In this study, we have used emissions that take place at the steel mill as our point of departure. This implies that in addition to the very process of steel making, we have included processes such as ore preparation (sintering), coke making, blast furnace iron making, direct reduction of iron, casting, and rolling and finishing. Thus, emissions related to the mining of ore and coal are not counted. However, the emissions from electricity production have been included even though these emissions are generated outside the steel mill. The reason is that if the steel industry is obliged to buy emission quotas, we expect that the electricity companies will have to buy quotas as well. Since large amounts of electricity are consumed in steel mills, regulations in the power production sector may have a substantial impact on the costs of steel production. Finally, we also report emissions related to the transport of iron ore, coal, and semi-finished and finished steel products.

3.3.1 Emissions by process

We have estimated the total emissions from the steel industry to 1462 million tons CO2 in 1995 (excluding transport).[1] As table 3.2 shows, emissions differ substantially between processes. The BOF process, which accounts for 2/3 of world steel production, is the most polluting process with an emission factor of 2.5. The standard EAF process, based on 100% scrap is the least polluting one with an emission factor of 0.6, while the DRI based EAF process with an emission factor of 1.2 comes in a middle position. Two things should be noted. First, the Open Hearth Furnace (OHF) has not been singled out as a separate process in our calculations but has been included in the BOF sector. According to ECOFYS (2000), the emissions from the OHF process may be about 50% higher than from the standard BOF process. Secondly, the DRI based EAF process is not a process where DRI accounts for 100% of the metal input. Rather, the process should be seen as representative of actual production processes where both DRI and scrap are used together. The emission factor in a pure DRI based process would have been substantially higher.

[1] ECOFYS (2000) has estimated the CO2-emissions to 1442 Mt using a methodology based on national data rather than on a site-by-site approach. This seems to suggest that our sample is quite representative of the steel industry.

Table 3.2. Emissions of CO2 in the steel industry, 1995. Million tons.

	Iron and steel production				*Rolling and finishing*		**Total**	***CO2 (t) Per ton steel***
	Coal	*Power*	*Natural gas*	*Fuel oil*	*Power*	*Fossil fuels*		
Basic Oxygen Furnace	1115	18	12	16	44	87	**1292**	***2.5***
Standard EAF	9	59	0	0	17	35	**120**	***0.6***
DRI based EAF	2	16	21	0	3	7	**50**	***1.2***
Total	**1126**	**94**	**33**	**16**	**64**	**129**	**1462**	***1.9***

Source: Mæstad (2000)

About 75% of the CO2 emissions from the steel industry are related to the combustion of coal in primary integrated steel mills. Coal is used both in the preparation of ore (sintering) and in the production of coke, which again is used to reduce iron ore to pig iron in the blast furnace. Pulverised coal may also be injected directly into the blast furnace. A minor share of the carbon content of the coal is bound in steel products, but most of it is released to the atmosphere as CO2.

In EAF processes, a substantial share of emissions is due to consumption of electric power in the steel making process. In the production of directly reduced iron (DRI), substantial emissions are generated through the combustion of natural gas.

Rolling and finishing of steel products are energy intensive processes that also cause large emissions of carbon dioxide. We do not have plant level data on energy consumption in rolling and finishing. We have adopted a similar procedure as in ECOFYS (2000) by assuming a uniform energy requirement of 3 GJ per ton finished steel across all processes and assuming that 20% of the energy is from electricity and that the rest is from a mix of fossil fuels. Therefore, the emission factor for rolling and finishing does not vary between processes. However, since the "carbon content" of electricity differs across regions, and since the various processes are not uniformly distributed across regions, the emissions related to power consumption in rolling and finishing are not strictly proportional to the level of production.

3.3.2 Emissions by region

As shown in Table 3.3, emissions per ton steel vary substantially across regions.

Table 3.3. Emissions of CO2 per ton crude steel, 1995. Ton.

	Basic Oxygen Furnace	*Standard EAF*	*DRI based EAF*
EU13	2.1	0.5	1.0
RoWEur	2.0	0.2	-
EeoFSU	2.4	0.8	1.6
NorthAm	2.0	0.6	1.0
SouthAm	2.5	0.3	1.1
Japan	2.5	0.4	-
China	3.9	0.9	-
RoAsia	2.4	0.7	1.3
Austral	2.5	0.7	-
RoW	2.8	0.6	1.5

Differences among regions partly reflect differences in energy efficiency. Most of the variation in the Basic Oxygen Furnace process can be explained by variations in the amount of coal used. We notice that steel production in China is extremely energy demanding.

Some of the variation, particularly in the EAF processes, is explained by varying emission rates in power production. In regions where hydro power is widely used (e.g., Rest of Western Europe and South America) emission rates are typically lower than in regions where coal fired power plants are more common.

3.3.3 Emissions from transport

We have not been able to calculate the total emissions from the transport activities related to the steel industry since we have no data on land transport. When it comes to sea transport, we use an average energy consumption for bulk transport in open sea of 0.2 MJ/tonne km (ECOFYS, 2000). Using the IPCC guidelines for emissions per energy unit of oil, this implies an emission factor of 0.0269 million ton CO2 per billion tonne-miles. With the transport volumes reported below, emissions from seaborne trade of iron ore, coal and steel products then amount to 100-110 million tons CO2 a year, or 0.14 ton CO2 per ton steel. The transport work related to the steel industry is thus far less polluting than the production of steel itself.

3.4 Transport demand from the steel industry

In terms of transport work carried out, iron ore and coal are the two most important dry bulk commodities in the world. Practically 100% of the transport of iron ore and nearly 50% of the transport of coal are for the steel industry. In addition, the transport of steel and steel products generates quite significant amounts of transport work. According to our estimates, total seaborne transport of steel, iron ore and metallurgical coal for the steel industry amounted to some 4000 billion tonne-miles in 1995. This is about 20% of world seaborne trade and XX% of dry bulk shipping. The development of the steel industry therefore plays a crucial role for the development of dry bulk shipping.

As shown in Table 3.4, the transport of iron ore is the most important trade related to the steel industry. Note that our estimate of ore transport volumes is about 5% lower than the figures from Fearnleys (1996).

Table 3.4. Main transport commodities in the steel industry, 1995.

	Billion tonne-miles
Iron ore	2162
Metallurgical coal	922
Steel	825
Total	**3909**

Figures 3.1 and 3.2 show how these transport flows are distributed on various regions of origin and destination. South America and Australia are the dominating exporters of iron ore, while Europe and Japan are the main importing regions. Europe and Japan are the main destinations in the coal trade as well, while North America and Australia are the main exporters. The steel trade is more evenly distributed across regions, but we notice the large export of steel from Eastern Europe and Former Soviet Union to Asian countries.

Figure 3.1. Transport work by origin

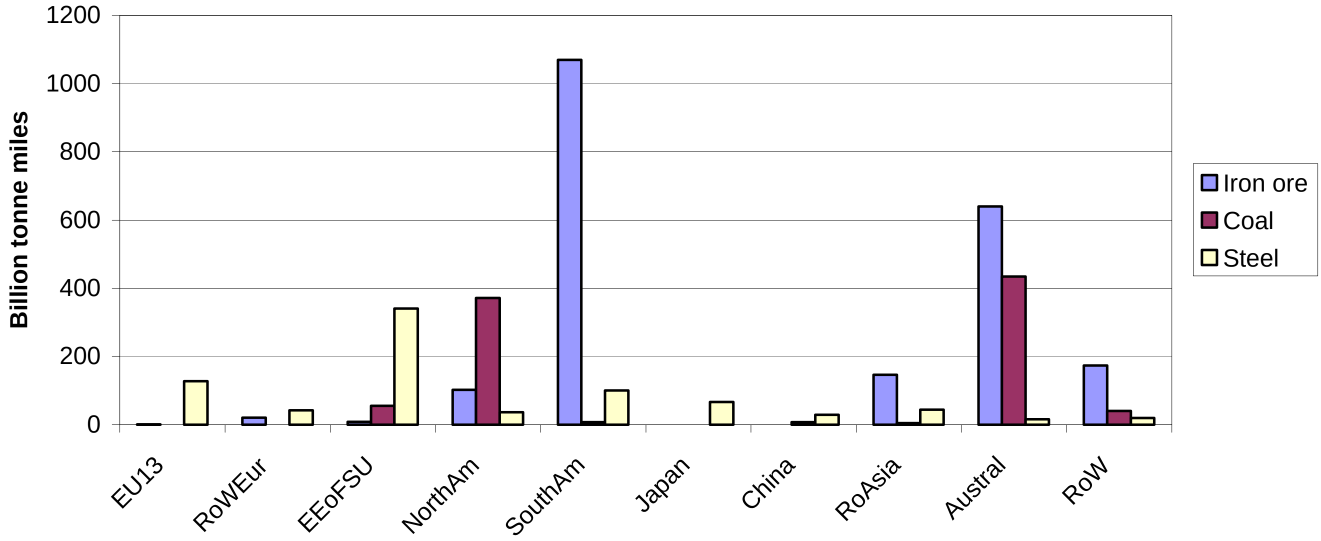
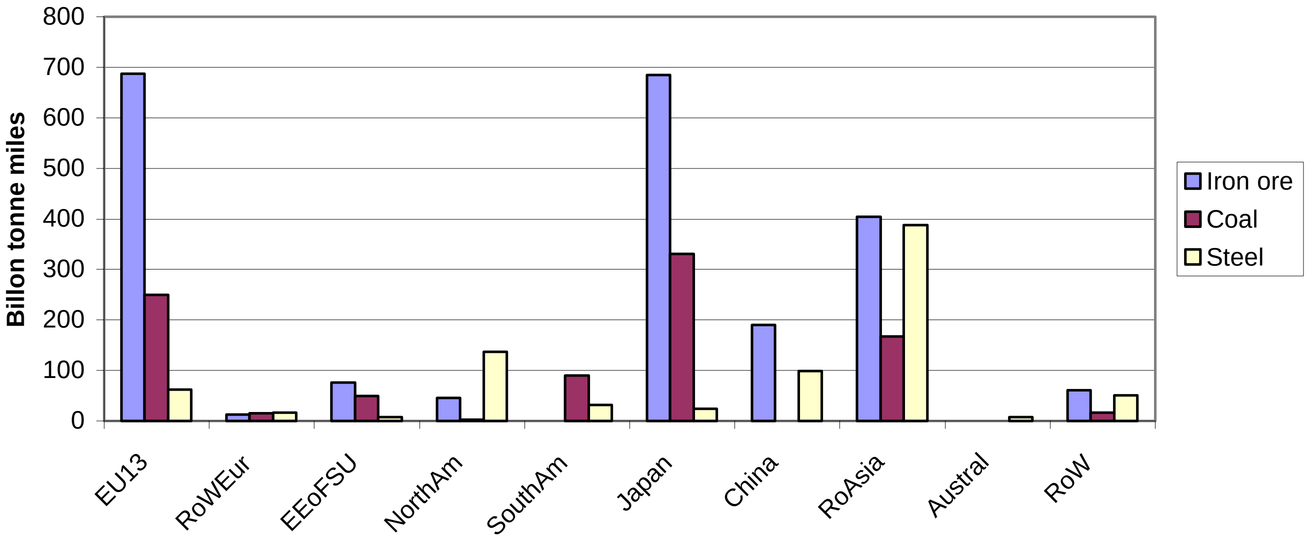


Figure 3.2. Transport work by destination



Among the most important determinants for the transport demand from the steel industry are (1) steel production volumes, (2) the share of iron ore relative to scrap as a source of metal input, (3) the location of steel production relative to the ore and coal mines, and (4) the location of steel production relative to the location of final consumers of steel. Climate policies in the steel industry are likely to affect a number of these factors and are therefore of potential importance for transport demand.

3.5 Modelling steel production and transport

We have analysed the consequences of climate policies for steel production and transport demand in a numerical model which incorporates essential aspects of the steel industry and the related factor markets and transport markets. A full description of the model and the data is given in Mathiesen (2000) and Mæstad (2000). Some crucial aspects of the model are summarised here:

- The model has 10 regions:

  Rest of Western Europe
  Eastern Europe and Former Soviet Union (including Turkey)
  North America (USA, Canada, Mexico)
  South America (Rest of America)
  Japan
  China
  Rest of Asia
  Australia (Australia and New Zealand)
  Rest of world (Africa and Middle East)

- Two types of steel are consumed in each region; oxygen blown steel and electric arc steel. These are imperfect substitutes because both the steel quality and the product mix differ between integrated steel mills and minimills.

- Steel is traded between regions, and steel from different regions is treated as imperfect substitutes (the Armington assumption). The price of steel from a given region is the sum of the marginal production costs, transport costs, and export and import taxes.

- In each region, steel may be produced by three technologies

  Basic Oxygen Furnace (based on a mix of pig iron and scrap)
  Standard Electric Arc Furnace (based on scrap)
  DRI based Electric Arc Furnace (based on a mix of directly reduced iron and scrap).

  The outputs from the two EAF processes are perfect substitutes.

- The model allows for a certain degree of substitutability between pig iron and scrap in the Basic Oxygen Furnace. All other inputs are used in fixed proportions (Leontief technology).

- There are global markets for iron ore, coal and scrap. The world prices of these factors are determined by supply and demand. The local factor prices vary due to differences in factor qualities and transport costs.

- There are local markets for natural gas and electricity. The prices of these factors are assumed to be exogenous to the steel industry.

- Production costs vary between regions due to differences in input mix and differences in factor prices. Production costs also vary within each region due to variations in productivity across plants. The profile of production costs for a given technology within a region is described by an industry cost curve. The production volume is determined so that the marginal costs of production equal the steel price.

- The model describes a short run equilibrium in the steel market. We therefore assume that all changes in production volumes take place within the limits of existing capacities.

- The regional pattern of steel consumption and production determines the steel transport volumes. The transport of iron ore and coal is determined by steel production volumes, the input mix in steel production, and the location of steel production. The share of each exporting region in the trade of ore and coal to a given importing region is assumed to be fixed. Changes in aggregate transport demand from the steel industry will affect freight rates and thereby the costs of transportation.

3.6 The climate policy regime

We study the consequences of implementing a climate policy based on tradable emission quotas in the countries that have signed the Kyoto Protocol (i.e., the so-called Annex I countries). Thus, there will be no climate regulations in China, Rest of Asia, South America and Rest of the World.

Implementation of climate policies implies that the steel industry and the power producing sectors will become obliged to buy emission quotas for their emissions of carbon dioxide. By including the producers of electricity, we take into account that climate policies will have implications for the price of electricity that is produced by fossil fuels. The transport sectors are not included in the quota system. This is due to the fact that most of the transport work related to the steel industry goes by ship, and emissions from international shipping are not included in the Kyoto Protocol.

We suppose that international emission trading takes place and that the quota price therefore is uniform across all Annex I regions. The quota price is set to

25 USD per ton CO2, which most likely is in the higher end of the range of probable quota prices.

We do not model any particular allocation rule for the emission quotas. Steel producers might have to buy all emissions quotas at the market price, or some quotas may be "grandfathered", based on historical emissions. In the short run, as long as production capacities are fixed, the allocation rule does not matter for the equilibrium. Independently of the allocation procedure, the quota system will increase the marginal cost of inputs that generate CO2 emissions, inducing steel producers to change their input mix and their level of production.

The allocation rule for emission quotas might be important for investment decisions and therefore affect the long run equilibrium. In particular, if emission quotas are grandfathered on the premise that the producers do not close down domestic production, the relocation of steel production to non-Annex I countries is likely to be smaller than if there is no grandfathering at all. Therefore, our model simulations will probably have more predictive power for the long run equilibrium if emission quotas are grandfathered so as to prevent relocation to non-Annex I countries than if the steel producers have to buy all emission quotas at the market price.

3.7 Impact on steel production

The consequences of climate policy for steel production depend on several parameters that are difficult to determine with accuracy. Among these are the sensitivity of steel demand to changes in steel prices, the degree of substitutability between steel types (BOF and EAF steel) and the degree of substitutability between steel from different regions.

None of these parameters have been estimated empirically in this study. Our estimates are based on discussions with industry experts and on other external sources. The steel demand is known to be rather inelastic. It is also the case that there are rather limited opportunities to substitute between BOF and EAF steel, at least in the short run. The degree of substitutability between steel from different regions is however quite good. In our base scenario, the following parameter values are used:

Table 3.4. Parameter values in base scenario

Parameters[2]	*Value*
Price elasticity of steel demand	-0.3
Elasticity of substitution between BOF and EAF steel	0.5
Elasticity of substitution between steel from different regions (Armington elasticity)	5.0

3.7.1 The base scenario

Table 3.6 and Figure 3.3 summarise the consequences of the climate policy for steel production. World steel production is reduced by 21 million tons (-2.8 %). There are only small changes in the total production of EAF steel, but quite significant changes in the production of BOF steel. The production of BOF steel declines by almost 31 million tons in the Annex I countries (-8.8%). Part of this reduction is compensated by an increase in BOF steel production in non-Annex I countries of 9 million tons (+5.4%). The non-Annex I countries benefit from improved competitiveness as production costs increase in the Annex I region. Moreover, costs are reduced in the non-Annex I countries since the prices of coal and iron ore decline when the production of pig iron and directly reduced iron falls in the Annex I countries.

[2] Definitions: The price elasticity of demand is the percentage change in demand for a commodity in response to a one per cent increase in the price of that commodity. The elasticity of substitution is the percentage change in the relative demand for two commodities as the relative price between the commodities is increased by one percent.

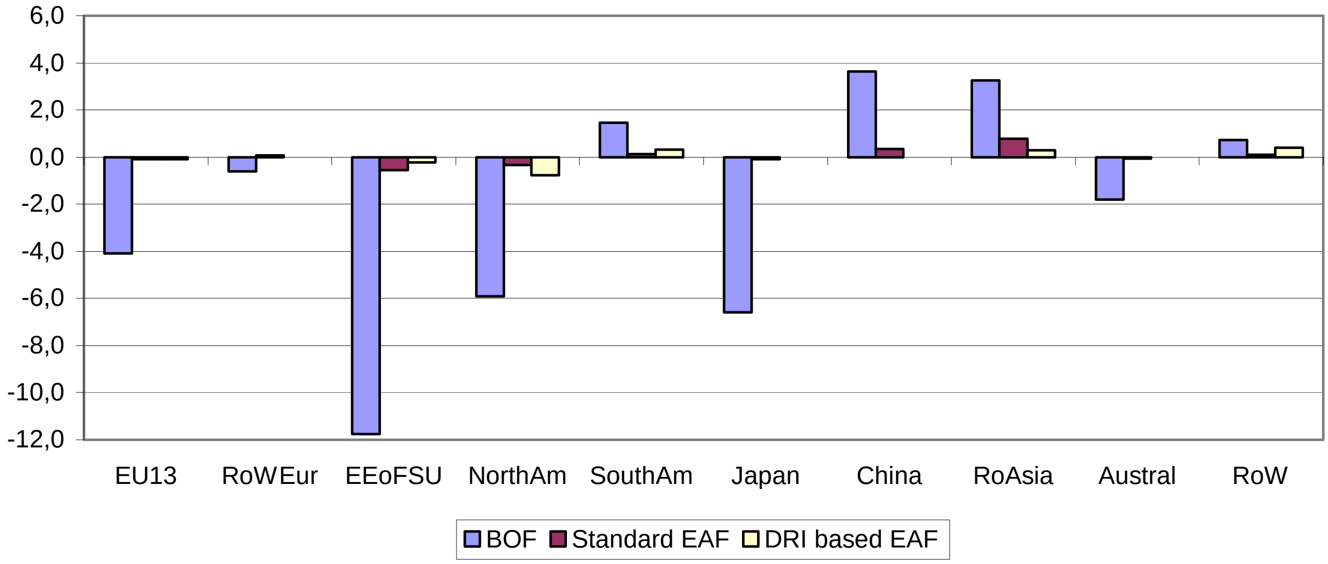
Climate regulations induce a certain shift away from BOF steel towards EAF steel. Without such a structural shift, climate policies would have a marked negative impact on EAF production in Annex I countries. It should be noted that the production volumes of EAF processes typically are more responsive to price and cost changes than the production in integrated steel mills. In our model, the price elasticity of supply is set to 0.7 in the BOF process and 1.2 in the EAF processes. Even though climate regulations lead to a relatively small increase in the costs of EAF production, the negative effect on output is therefore not negligible. In fact, without substitution from BOF steel towards EAF steel, the production of standard EAF steel and DRI based steel would have been reduced by 3-4% and 14-15%, respectively.

The relative reduction in BOF steel production across Annex I regions is determined by a number of factors, such as relative emissions per ton steel, relative production costs at the outset, and the shape of the industry cost curve. Relatively high emissions of carbon dioxide per ton steel in Australia, Japan and Eastern Europe contribute to large reductions there. But the relative fall in production is smaller in Japan than in Eastern Europe because Japan has much higher production costs at the outset. The climate policy therefore induces a smaller percentage increase in the marginal costs of production in Japan. While production in most Annex I regions is reduced by 8-12%, the production in EU13 falls less (only 4%). This happens even though emissions are higher in Europe than for instance in North America, where BOF steel production is reduced by 8%. The shape of the industry cost curves can explain this pattern; European producers seem to enjoy a competitive edge over their competitors in North America at the margin.

Table 3.5. Change in steel production (%)

	BOF	Standard EAF	DRI based EAF	**Total**
Annex I	-8.8	-0.7	-7.8	**-6.4**
Non Annex I	5.7	2.5	3.9	**4.8**
Total	**-4.3**	**0.2**	**-0.2**	**-2.8**

Figure 3.3. Change in production (mill. tonne)



3.7.2 Sensitivity analysis

We want to investigate the robustness of our conclusions with respect to some core parameters of the model. Consider fist the price elasticity of demand. It can be argued that the price elasticity of demand is too high because climate policies will not only affect the price of steel but also the price of some of the products that compete with steel, for instance cement. We therefore investigate the consequences of lowering the elasticity from –0.3 to –0.15. Table 3.7 summarises the results.

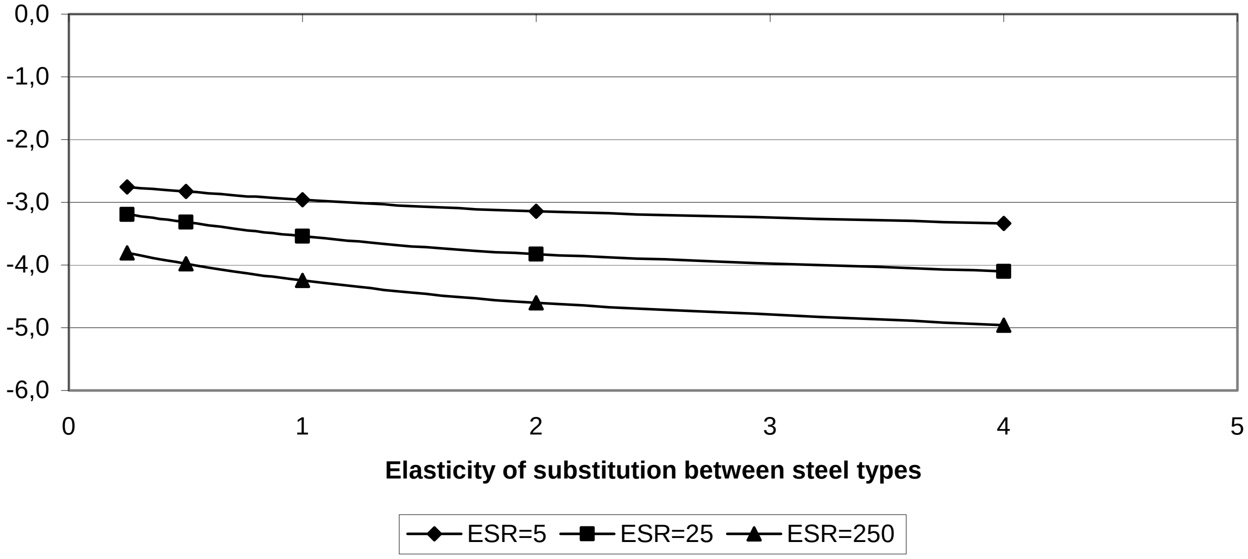
Table 3.7. Change in production (%). Price elasticity –0.15.

	BOF	*Standard EAF*	*DRI based EAF*	***Total***
Annex I	-7.1	0.4	-5.4	**-4.9**
Non Annex I	6.1	3.3	5.0	**5.4**
Total	**-3.0**	**1.7**	**1.3**	**-1.6**

We observe that the price elasticity of demand matters for total steel production. Total steel production is now reduced by only 1.6%, compared to 2.8% in the base scenario. It is important to note, however, that the reduction in BOF steel production in Annex I countries is almost as large as in the base scenario (-7.1% compared to –8.8%). This implies that changes in the price elasticity of demand will not have a large impact on the transport demand for iron ore and coal.

We now return to the original price elasticity of demand of –0.3 and perform sensitivity analysis on the substitution elasticities. Figure 3.4 shows how total steel production is affected by the elasticity of substitution between BOF and EAF steel at different levels of substitutability between steel from different regions (ESR). We have let the measure of ESR take on some very high values in order to resemble a situation with extremely strong competition between regions. In the case of ESR=250, practically no changes in relative steel prices between regions are allowed in equilibrium. We have also tried to increase the elasticity of substitution between steel types in order to reflect that over some time, it might be possible for EAF producers to cover a larger share of the product spectre of the BOF producers. We conclude that total steel production is not very sensitive to the substitution elasticities. A reduction in steel production of 3-4% must be expected when the price elasticity of demand is –0.3.

Figure 3.4. Change in total steel production (%)

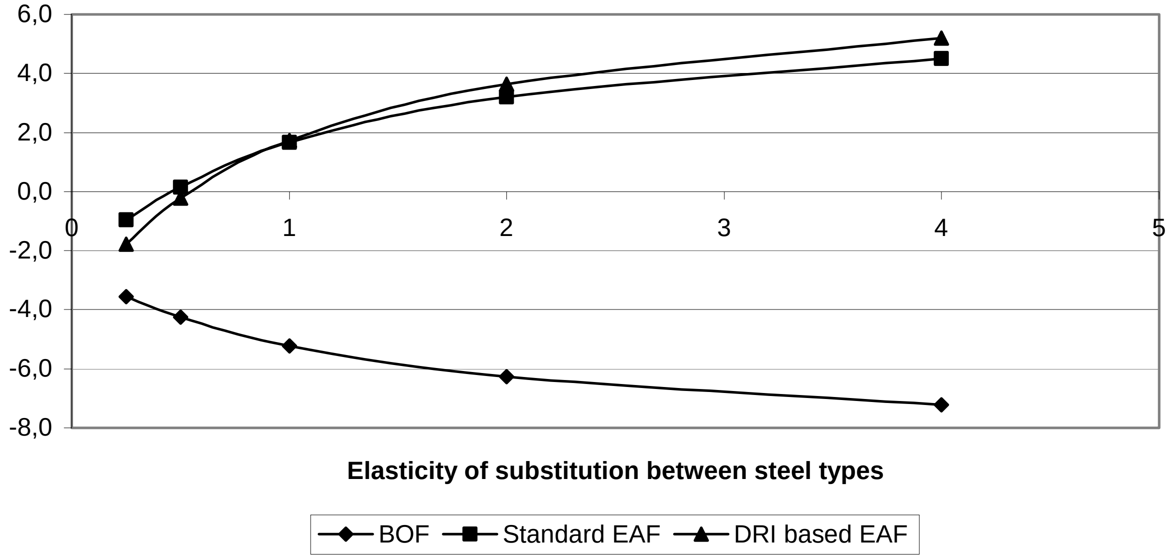


As is shown in Figure 3.5, the elasticity of substitution between steel types is crucial for the distribution of steel production between different processes. Hence, if the EAF producers are able to enlarge their product spectre, the decline in world BOF production might become about twice as large as in the base scenario (i.e., a total reduction of 40 million tons, with a reduction of some 50-60 million tons in the Annex I countries).

We might have expected an even larger increase in EAF production as we increase the substitutability between steel products. But the shift towards EAF production is constrained by the availability of scrap. As EAF production expands, the scrap price will increase and make EAF producers less competitive. The scrap price is also driven up by a certain substitution of scrap for pig iron in the BOF process in Annex I countries.

Changes in factor prices might also explain why DRI based EAF steel performs relatively well compared to standard EAF steel at high degrees of substitutability between steel types. Higher scrap prices have a stronger negative impact on standard EAF production, which is based solely on scrap, than on processes where scrap is combined with DRI. Moreover, as BOF steel production is more significantly reduced, the price of iron ore drops. This also makes the DRI line more competitive relative to the standard EAF production line.

Figure 3.5. Change in steel production by process (%)



3.8 Impact on transport demand

3.8.1 The base scenario

Tables 3.8 and 3.9 summarise the effect of climate policy on transport demand from the steel industry. While steel production falls by 2.8%, total transport demand falls by 5.3%. And while the reduction in production of BOF steel is 4.3%, the transport of iron ore and coal falls by 5-6%. There are two reasons why transport demand for iron ore and coal declines more than BOF steel production. First, producers of BOF steel in the Annex I countries reduce their use of pig iron per ton steel by 3-7% (which is compensated by increased scrap consumption). Admittedly, lower prices of coal and ore in non-Annex I countries lead to the opposite development there, but this effect is rather weak.

Secondly, the average transport distances decrease slightly. The effect is negligible in the coal transport, but in the transport of iron ore, average distances decrease by about 0.5%. Finally, one should note that consumption of iron ore and coal per ton steel typically is higher in non-Annex I countries than in Annex I countries. Hence, relocation of production towards non-Annex I countries should increase transport demand per ton steel. Since the opposite happens, we can conclude that this effect is more than outweighed by substitution away from pig iron in Annex I countries.

Table 3.8. Change in transport demand (%).

Steel	-4.5
Ore	-5.5
Coal	-5.6
Total	**-5.3**

Table 3.9 shows that the main reduction in steel transport comes from a reduction in the transport between Eastern Europe & the Former Soviet Union and countries in Asia. This decrease is partly offset by higher steel exports from South America, China and other Asian countries to North America and Europe.

When it comes to iron ore, it is the transport to Japan that is most badly hurt, followed by the transport to Europe. This decrease is partly offset by more transport to Rest of Asia. It is worth noticing that the high degree of self-sufficiency of iron ore in Eastern Europe and China implies that big changes in production volumes in these regions do not have a great impact on transport demand.

A very similar pattern is observed in the coal trade. Again, it is the transport on Japan and Europe that declines most, while production changes in China and Eastern Europe have a negligible impact on transport demand due to a high degree of self-sufficiency.

Table 3.9. Change in transport demand by destination and origin. Billion tons miles.

	Steel		**Iron ore**		**Coal**	
	Dest	*Origin*	*Dest*	*Origin*	*Dest*	*Origin*
EU13	5.7	-3.7	-54.1	-0.1	-19.7	-0.0
RoWEur	-0.3	-2.4	-1.7	-0.5	-2.0	-
EEoFSU	3.7	-59.3	-12.4	0.5	-8.0	-3.5
NorthAm	14.7	-2.5	-6.6	-6.1	-0.4	-22.4
SouthAm	-2.4	12.8	-	-50.4	5.8	-0.8
Japan	2.7	-1.0	-83.9	-	-40.5	-0.4
China	-19.6	11.2	9.2	-	-	-
RoAsia	-38.2	11.2	26.7	-12.0	11.6	-0.4
Austral	2.4	-4.8	-	-36.9	-0.0	-21.5
RoW	-5.7	1.5	3.8	-13.5	1.3	-2.9
Total	**-36.9**	**-36.9**	**-119.0**	**-119.0**	**-51.9**	**-51.9**

3.8.2 Sensitivity analysis

Changes in the price elasticity of steel demand do not have a strong impact on transport demand. By lowering the elasticity from –0.3 to –0.15, the reduction in total transport demand falls from 5.3% to 4.3%.

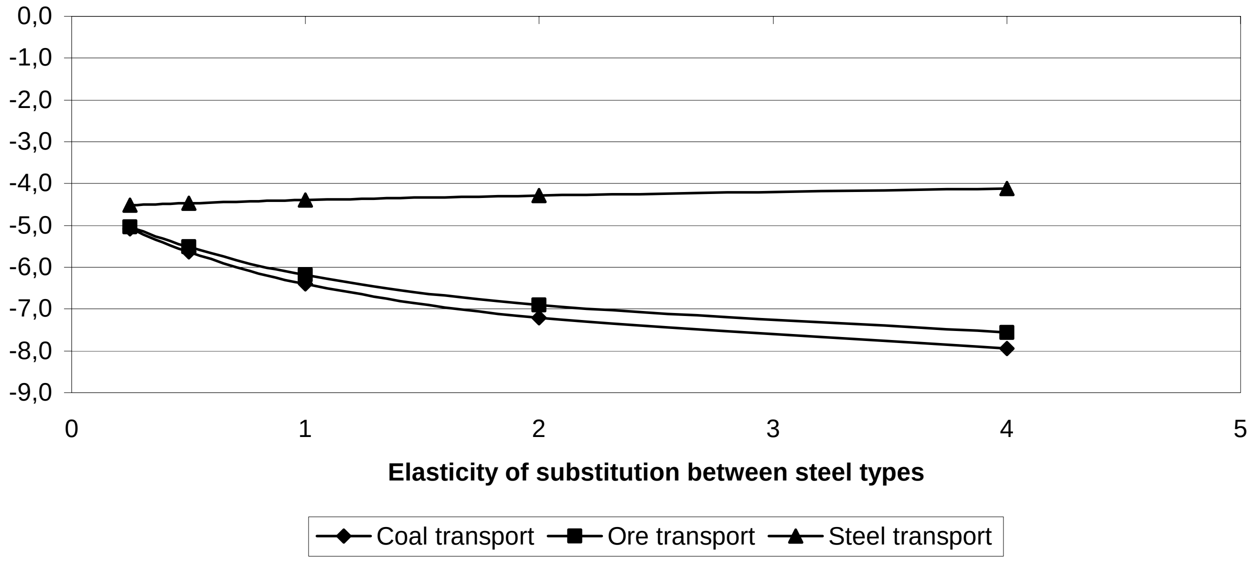
Table 3.10. Change in transport demand (%). Price elasticity of demand –0.15.

Steel	-4.3
Ore	-4.3
Coal	-4.3
Total	**-4.3**

The steel transport is practically not affected at all. The transport of iron ore and coal increases somewhat due to higher production of BOF steel. But since much of the change in transport demand in the base scenario is due to a change in input mix in BOF steel production rather than to the production volume as such, transport volumes are not particularly sensitive to the price elasticity of steel demand.

Let us now return to the base case price elasticity of demand and investigate the sensitivity of transport demand with respect to the elasticities of substitution. Consider first how transport demand is affected by the elasticity of substitution between steel types. We know that as the degree of substitutability between BOF and EAF steel increases, BOF steel production will lose market shares. This is likely to hurt the transport of iron ore and coal. This is confirmed by Figure 3.6.

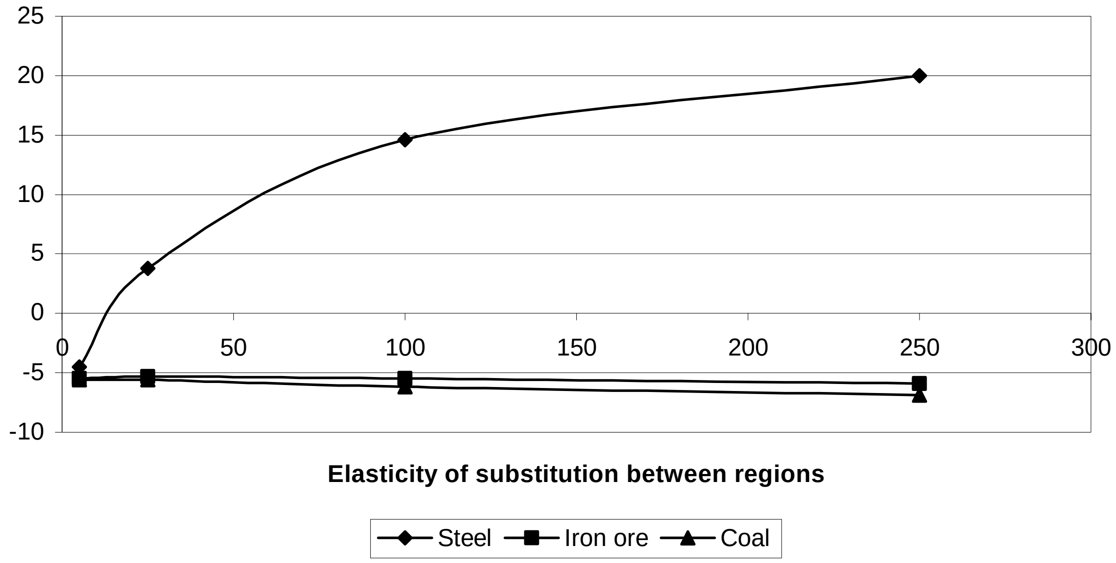
Figure 3.6. Change in transport demand by commodity (%)



While steel transport is practically unaffected by the degree of substitution between steel types, the transport of iron ore and coal will decline by up to 7-8% when the elasticity of substitution is increased to 4, compared to a reduction of 5.5% in our base scenario. One interpretation of this result is that the long run effects on ore and coal transport are probably greater than the short run effects.

Consider next the consequences of varying the elasticity of substitution between steel from different regions (ESR). Figure 3.7 shows that this parameter may have a significant impact on steel transport, while the effect on iron ore and coal transport is negligible.

Figure 3.7. Change in transport demand by commodity (%)



When the elasticity is low, steel trade volumes decline, because Eastern Europe exports less steel to Asia. But climate policy also has potential positive impacts on steel trade. These positive effects dominate over the negative one when the elasticity of substitution between regions becomes higher. The positive effects of climate policy on steel trade are due to (1) relocation of production away from the main consumer regions, and (2) a general tendency towards less production for the home markets. The latter is the most important one.

As the elasticity of substitution between regions increases, the competition between regions will become tougher. The cost increase in the Annex I countries will then induce a larger shift of production towards non-Annex I countries. In particular, China and the Rest of Asia will increase their share of the world market. Much of this steel will be sold to consumers in North America and Europe and thereby increase steel transport volumes.

But more importantly, climate policies lead to a general reduction in the production for the home market and thus cause an increase in steel trade and steel transport. The explanation is as follows: Due to transport costs and import duties, the consumer price of steel will typically be lower in the home region than in the export markets. When climate policies raise production costs, the price of domestic steel will therefore typically increase relatively more than the price of steel delivered abroad. For the same reason, the price of imported steel will tend to increase relatively less than the price of domestic steel. Both these effects lead to smaller production for the home market; export increase and imports increase. Hence, climate policies tend to boost the steel trade. This effect will be stronger the fiercer is the competition between steel from different regions, because even small changes in relative prices then will have a significant impact on the demand pattern. This is the main reason why steel trade increases with the elasticity of substitution between steel from different regions.

Since the volume of steel trade is much smaller than the volume of transport of inputs to the steel industry, the increase in steel trade does never outweigh the fall in transport of iron ore and coal. Even in the most optimistic scenario, where steel trade increases by 20%, total transport falls by 0.5-1.0%.

3.9 Impact on CO2 emissions

Our model results suggest that emissions of carbon dioxide from the steel industry will decline almost twice as much as steel production (-4.8% compared to –2.8% in the base scenario). This happens despite the fact that steel production increases in regions that are relatively energy inefficient. The main explanation is that BOF steel producers in the Annex I countries use less pig iron per ton steel and therefore reduce their coal consumption. Hence, emissions from BOF steel production in Annex I countries are reduced by 12.6% while production is reduced by only 8.8%. Moreover, climate policies will increase the market share of EAF steel by about 1% in the short run.

Emission reductions of about 100 million tons CO2 in Annex I countries are partially outweighed by higher emissions in countries that do not implement climate policies. If we assume, as we do in the model, that the energy efficiency of the incremental production in non-Annex I countries is at the same level as the regional average, emissions in non-Annex I countries increase by 30 Mt CO2. However, this number would have been lower if best available technology is used to expand production. For instance, if increased production in China does not cause higher emission per ton steel than in Europe, the increase in emissions in non-Annex I countries would not have been higher than 20 Mt CO2. Three things can be learnt from this: (1) The leakage problem in the steel industry is significant. (2) Technological factors matter a great deal for the extent of the leakage problem. (3) Despite leakage problems, substantial reductions in total emissions can be achieved even though climate policies only encompass the Annex I countries.

Climate policies in the steel industry will also reduce emissions of greenhouse gases from the transport sector. In the base scenario, the reduction is about 5-6 Mt CO2. Hence, total emissions from the steel industry are reduced by about 75 Mt CO2. This is almost twice the total CO2 emissions of Norway.

Table 3.11. Change in emissions of carbon dioxide (%).

	BOF	*Standard EAF*	*DRI based EAF*	***Total***
Annex I	-12.6	-0.9	-8.2	**-11.4**
Non Annex I	5.6	2.4	3.9	**5.3**
Total	**-5.5**	**0.2**	**0.2**	**-4.8**

4 CLIMATE POLICY AND OPTIMAL SHIPPING OPERATIONS AND MANAGEMENT

Olsen (2000) has studied the consequences for optimal shipping operations and management of including the shipping sector in a system of tradable emission quotas. Such policies are not likely to be implemented on a global scale before we get a climate agreement that encompasses virtually all major countries in the world. However, tradable emission quotas may be implemented on a more regional basis at an earlier date. We have seen that countries have implemented CO2 taxes on national transport on a unilateral basis (e.g., Norway). Similar policies might be initiated in larger regions (e.g., Western Europe) before a global system of emission trading is implemented in the shipping sector.

The immediate implication of making the shipping sector obliged to buy emission quotas (or pay emission taxes) is that the costs of bunkers will increase. This may lead to changes in the optimal operation of existing vessels as well as to changes in the design of new ones. In this section, we report how a quota price of 200 NOK/ton CO2 will affect bunkers costs and thereby

(1) the optimal speed for existing vessels
(2) the optimal design speed of new vessels, and
(3) the profitability of investing in more fuel efficient technology.

The analysis has been based on case studies. All cases are from international shipping within Europe.

4.1 The effect on bunkers prices

The effect of emission quotas on bunkers prices depends on the CO2 emissions per unit of bunkers and on the price of the emission quotas. In addition, the quota system may lead to a fall in producer prices of bunkers. This will dampen the increase in the user price of bunkers.

The CO_2 emissions vary slightly between different types of fuels. The emissions per ton of marine diesel oil (MDO) are about 3.13 ton CO_2 per ton fuel, while the emission factor is 3.21 for heavy fuel oil (HFO). In our calculations, we have used a uniform emission factor of 3.15 ton CO_2 per ton fuel.

The future price of emission quotas is highly uncertain. It will depend on factors such as the emission targets, the policies that are implemented in order to reach the emission targets, the rules for international emission trading and the role of developing countries in the climate agreement. In this study, we use a quota price of 200 NOK per ton fuel, which is a relatively high quota price compared to most predictions.

A quota price of 200 NOK per ton CO_2 implies an additional cost of about 630 NOK per ton fuel. Current fuel prices in Rotterdam are 1017 NOK per ton heavy fuel oil and 2026 NOK per ton marine diesel oil. Bunkers prices are thus expected to rise by 31% for MDO and by 62% for HFO.

The increase in fuel prices might be smaller if climate policies reduce the price of crude oil. However, other studies have concluded that oil prices to producers are likely to remain fairly constant (e.g., Mæstad and Holtsmark, 2000). Climate policies will probably lead to a quite small reduction in oil demand since most of the emission reductions will come through a fall in coal consumption. Reduced oil production in OPEC is also likely to keep the oil price at fairly high levels.

We therefore conclude that integration of the shipping sector into the international system of tradable emission permits is likely to increase bunkers prices substantially.

4.2 Changing the operating speed

Higher fuel costs increase the profitability of fuel saving measures. One measure that is easy to implement is to reduce the operating speed. Since fuel consumption increases exponentially with speed, fuel consumption per tonne-mile will decrease with lower speed. But these cost savings must be weighed against the income loss from fewer trips as the speed is reduced. This section discusses whether an increase in fuel costs of 31% for MDO and 62% for HFO is large enough to make speed reductions profitable.

Three different ships are considered. The ships are used in short sea shipping in Europe. Some key data are provided in Table 4.1.

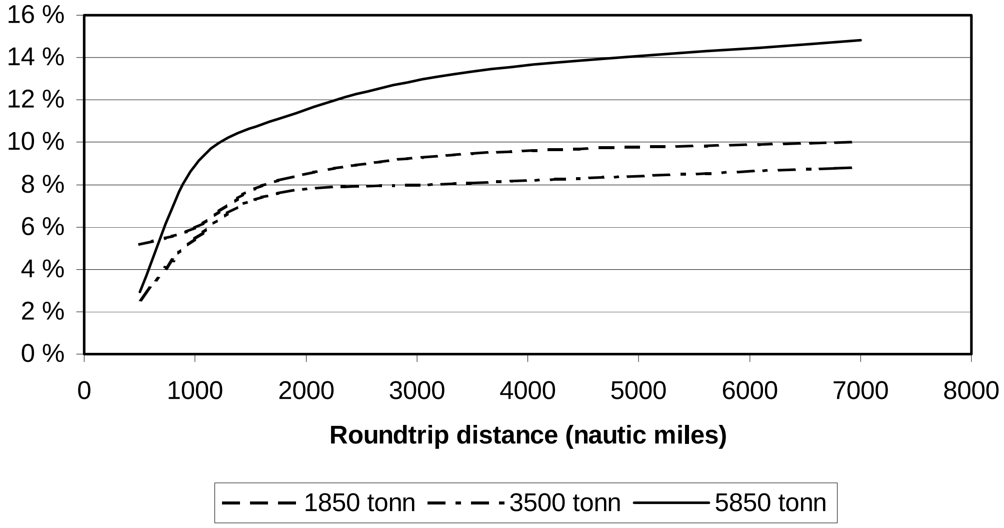
Table 4.1. Key characteristics of the ships in the study.

Ship	*Capacity (ton)*	*Operating speed (knots)*	*Fuel consumption (per day)*
1	1850	9.0	3.5 ton MDO
2	3500	11.5	4.7 ton MDO
3	5850	12.5	11.0 ton HFO

As shown in Figure 4.1, the effect of climate policies on operating costs depends both on ship type and on average distance per roundtrip. The cost increase is larger for long distances than for short ones; since the time in harbour is constant, ships that travel on long routes spend relatively more time at sea.

Ships using heavy fuel oil experience a relatively sharp cost increase, because the price of emission quotas will constitute a larger share of the bunkers costs than for ships using marine diesel oil. We also observe, by comparing the two smallest ships, that the cost increase is not necessarily larger for large ships and for faster ships.

Figure 4.1. Change in operating costs (%)



We want to investigate whether this increase in operating costs will cause a reduction in the optimal operating speed. Let *R* denote profits per year, and let *V* be the speed. Reduced speed is profitable if a reduction in *V* leads to an increase in *R* (i.e., $dR/dV < 0$).

Profits per year can be defined as

$$R = (I - C)A,$$

where *I* is net income per trip (before fuel costs), *C* is fuel costs per trip and *A* is the number of trips per year. Fuel costs per trip are equal to fuel costs per day (*F*) times the number of days at sea per trip (*DS*). Fuel costs per day are assumed to be a function of speed in the following way

$$F = F_0 \left(\frac{V}{V_0} \right)^3 ,$$

where subscript 0 denotes variable values at the outset. The potential for fuel savings is determined by the value of the exponent. The larger the exponent, the more fuel can be saved by reducing the operating speed. Empirical studies suggest that the parameter value 3 is quite representative for a wide range of ships.

The number of days at sea per trip is given by the following identity

$$DS \cdot V = DS_0 \cdot V_0 ,$$

which states that the distance per trip is independent of speed.

A reduction in the speed will reduce the number of trips. The number of trips per year is given as

$$A = D / (DS + DH) ,$$

where D is the number of operating days per year and DH is the number of days in harbour per trip.

Revenue per year can now be written as

$$R = \left(I - \frac{DS_0 V_0}{V} F_0 \left(\frac{V}{V_0} \right)^3 \right) \frac{D}{\frac{DS_0 V_0}{V} + DH} .$$

We assume that income per trip is unaffected by speed. By differentiation we then obtain that it is optimal to reduce the operating speed ($dR / dV < 0$) when

$$(I - C) \frac{DS}{DS + DH} < 2C .$$

This inequality says that it is optimal to reduce speed when the freight rates are sufficiently low relative to the costs of fuel.

We use this formula to calculate the threshold level of the freight rate below which speed reductions become profitable. Climate policies will increase fuel costs and thereby increase the threshold level. By comparing the new threshold with actual rates, we can tell whether it is optimal to reduce the operating speed.

Our calculations are based on a trip between Bergen and Rotterdam for the same three ships as above. The results are reported in Table 4.2.

Table 4.2. Freight rate levels below which speed reduction is profitable (NOK/ton).[3]

	Vessel		
	1850 ton	*3500 ton*	*5850 ton*
Without climate policy	52	32	30
With emission quotas of NOK 200 per ton CO2	68	42	43
Actual rates	100	80	60

Climate policy causes the threshold freight rate to increase by 30-40%. However, this is not sufficient to make the threshold higher than the actual rates, which is required in order to make speed reductions optimal. We conclude that climate policies are unlikely to reduce the optimal speed in short sea shipping, because freight rates are so high that the costs of reducing the number of trips would outweigh the savings in fuel costs.

[3] Calculations are based on fuel prices of NOK 1550 per ton MDO and NOK 1000 per ton HFO. Harbour taxes of 24 NOK/ton for the smallest vessel and 16 NOK/ton for the two other vessels are included.

We have also calculated by how much the optimal speed would have been reduced if the freight rates were at the threshold level at the outset for the largest vessel. We find that the climate regulations would have reduced the optimal operating speed from 12.5 to 10 knots.

4.3 Changing the design speed of new vessels

Even though climate policies are unlikely to reduce the operating speed of existing vessels in short sea shipping, the design speed of new vessels might still be affected. For a new ship, a reduction in design speed will save capital costs, whereas capital costs for existing vessels are unaffected by speed. This makes speed reductions more likely for new vessels.

We have studied the consequences of climate policy for the optimal design speed of a vessel of 3500 DWT. Since very few new vessels have been built recently, data on the costs of new ships are scarce. Our estimate of the capital costs should therefore be interpreted with caution.

We have assumed that capital costs are linear in installed motor effect (*BHP*). The installed effect increases with the design speed according to the formula

$$BHP = aDWT^{2/3}V^3 + b,$$

where *a* and *b* are constants. The values of *a* and *b* are estimated on data from existing vessels. The assumptions imply that the capital costs increase exponentially with the design speed.

We have calculated the design speed that maximises profits before and after climate policies are implemented. We take into account that a reduction in design speed affects both the fuel costs per trip, the number of trips in a given period, and the capital costs. The data are based on traffic between Bergen and Rotterdam.

Figure 4.2. Climate policy and optimal design speed

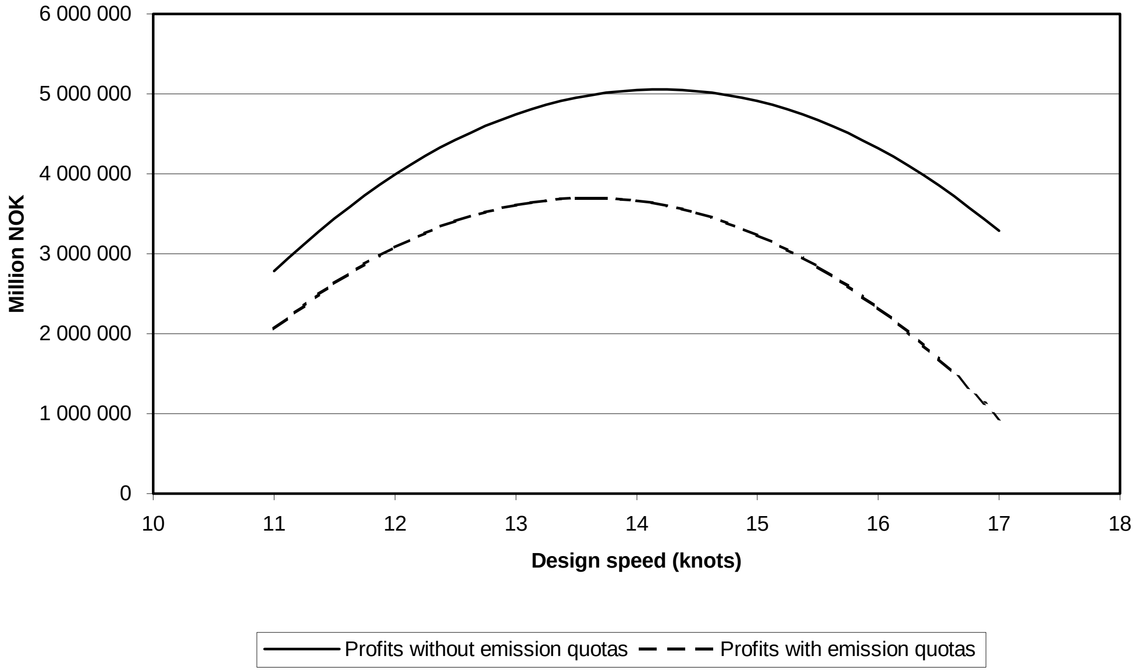


Figure 4.2 shows that climate policies will have a slightly negative impact on the optimal design speed of a vessel of this type. Without emission quotas, the maximal profit is obtained at 14.2 knots. When the shipowners have to pay for emission quotas, the profit curve shifts downwards and slightly to the left. Profits will then be maximised at 13.7 knots. Hence, the optimal design speed is reduced by about 0.5 knots.

We conclude that climate policies might have a negative impact on design speed, but the effect is likely to be quite small.

4.4 Investing in more fuel efficient engines[4]

Fuel can also be saved by making engines more fuel efficient. In this section we study how climate policies will affect the profitability of rebuilding engines of existing ships in order to save fuel.

Unfortunately, we do not have data on the costs of improving fuel efficiency of existing ships. However, we have data on the costs of rebuilding engines in order to reduce emissions of NOx. It turns out that these investments also reduce fuel consumption by 4-5%. The cost data related to NOx-reductions can therefore be used as an upper limit on the costs of reducing CO2 emissions by 4-5%. However, since there is a trade-off between emissions of NOx and CO2 at the margin, it will be possible to reduce fuel consumption further without additional costs. In practice, fuel consumption might be reduced by 6-7% if NOx emissions are allowed to increase.

We calculate the profitability of investing in a more fuel-efficient engine on two different ships, one twenty year old vessel fuelled by marine diesel oil and one ten year old ship that is somewhat larger and runs on heavy fuel oil. The basic data are provided in Table 4.3, and the results are reported in Figure 4.3.

[4] The analysis and the results of this section differ somewhat from Olsen (2000) because new data have become available and some of the assumptions used in Olsen (2000) have been revised.

Table 4.3. Data for investment in more fuel efficient engines.

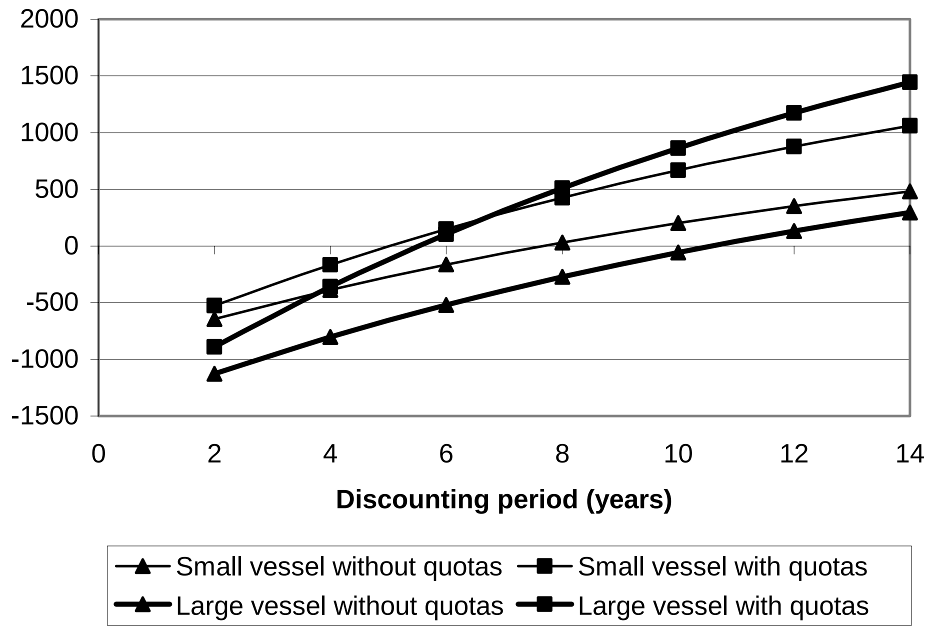
Ship size	1950 dwt	5400 dwt
Building year	1980	1990
Investment cost[5]	940 000 NOK	1 500 000 NOK
Bunkers savings	7%	6.5%
Annual bunkers use	1 500 ton (MDO)	3 160 ton (HFO)
Bunkers price	1 550 NOK/ton	1 000 NOK/ton
Price of emission permits (200 NOK per ton CO2)	627 NOK/ton fuel	638 NOK/ton fuel

We notice that the percentage fuel saving potential is about the same in the two vessels, despite the big age difference.

Without emission quotas, the investment will be repaid after a period of 8 years for the old vessel and 10.5 years for the newer one. With an expected lifetime of the vessels of 30 years, both investments will have a positive net present value at the fuel prices in our example. However, by taking into account the uncertainties involved, and in particular the fact that fuel prices in the example are quite high by historical standards, it is very unlikely that these investments will be undertaken.

[5] We do not include costs of off-hire since the engine in practice will be rebuilt during ordinary maintenance.

Figure 4.3. Net present value of engine rebuilding (1 000 NOK)



Emission quotas increase the profitability of the investments and reduce the repayment period to about 5 years for both vessels. This is probably enough to induce investment on the ten-year-old ship. Investment might also take place on the older vessel, although this clearly is a more risky business.

We notice that emission quotas seem to have a stronger positive impact on the profitability of engine rebuilding on the new vessel than on the old one. The explanation is that the new vessel is fuelled by heavy fuel oil whereas the old one uses marine diesel oil, and climate policies will lead to a stronger relative increase in the price of HFO than of MDO.

We conclude that there is a potential for fuel saving through rebuilding of engines in existing ships of about 5-7%. Without emission quotas in the shipping sector, these investments are only marginally profitable, even at the presently high fuel prices. But if the shipowners have to buy emission quotas at 200 NOK per ton CO2, they will probably have a sufficient incentive to realise this fuel saving potential. In other words, it is likely to be cost efficient for society that the shipping sector contributes to reducing emissions of greenhouse gases through an upgrading of engines in existing vessels.

5 CLIMATE POLICY AND THE COMPETITION BETWEEN SEA AND LAND TRANSPORT

An underlying assumption throughout Section 4 was that climate policies in the shipping sector only affect costs and that freight rates remain unchanged. With constant freight rates, transport demand will not be affected by making shipowners obliged to buy emission quotas.

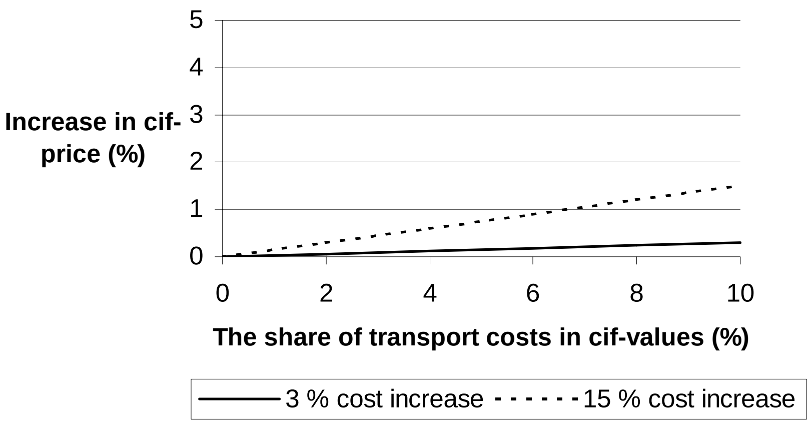
In this section, we go to the other extreme and assume that the costs of emission quotas will be completely shifted on to the freight rates. The question we want to address is how this increase in the rates might affect the demand for sea transport.

The demand for sea transport is determined by (1) total transport demand and (2) the market share of sea transport relative to other transport modes. In principle, climate policies might affect both total transport and the market shares of different modes. But, as will be argued below, total transport demand is probably too inelastic to be much affected by climate policies. We shall therefore pay most of our attention to the issue of market shares, and in particular how climate policies will affect the competition between sea and land transport. But before turning to that subject, we shall briefly discuss the consequences of climate policy for total transport demand.

5.1 Climate policy and total transport demand

An increase in freight rates will reduce transport demand if the *cif*-prices of the transported commodities increase sufficiently to reduce trade volumes. The largest reduction in trade volumes will happen if the increase in freight rates is shifted completely on to the *cif*-price. We shall assume that this does in fact happen. The effect of climate policies on transport demand will then depend on

Figure 5.1. Climate policy, transport and cif-prices



(1) the effect on climate policies on *cif*-prices and (2) the elasticity of trade volumes with respect to the *cif*-prices.

Consider first the effect of climate policy on *cif*-prices. In section 4.1, it was argued that emission quotas of 200 NOK per ton CO2 would increase the cost of short sea shipping by 3-15%, depending on transport distances and type of vessel. If this cost increase is completely shifted on to the final consumers, cif-prices might increase as illustrated in Figure 5.1. A crucial variable that will determine how much *cif*-prices rise, is the share of transport costs in *cif*-values. This share obviously varies tremendously among goods. The average in industrial countries is below 5 % (Wergeland and Wijnolst, 1997). In those examples that we have studied, taken from short sea shipping between Norway and continental Europe, transport costs have generally been less than 2 % of *cif*-values. Anyway, the share of transport costs in *cif*-values is so small in most trades that those climate policies that we are talking of here would have only a negligible effect on the *cif*-prices (<2%).

Against this background we conclude that the effect of climate policy on total transport demand (through the freight rates) is likely to be small, even if final demand is price elastic. In the following, we therefore concentrate on the effect of climate policy on the market shares of different transport modes.

5.2 Competition between sea and land transport

Even though total transport demand is unlikely to change much as a result of climate policies, the demand for sea transport might still be affected if climate policies affect the competitiveness of sea transport relative to other transport modes.

In this section, we analyse how a non-discriminating climate policy will affect the competitiveness of sea transport relative to land transport (truck). Two specific cases are studied, (1) container traffic between Oslo and Rotterdam, and (2) transport of frozen fish from Ålesund to Bologna. These cases represent trades where real competition between sea and land transport takes place.

The effect of a non-discriminating climate policy on relative competitiveness of transport modes depends on

- The price of CO2 emission quotas
- The relative emission level per unit of transport work
- How much of the cost increase that is shifted on to the freight rates
- Whether there are any discriminating climate policies in place at the outset

It will be assumed, in line with the rest of this study, that the price of CO2 emission quotas will be 200 NOK per ton CO2. Further, we shall assume that the costs of CO2 emissions will increase freight rates one by one. This is a reasonable assumption over a long time horizon, since the long run supply capacity in the transport markets is fairly price elastic.

The analytical approach is a simple one: (1) Calculate CO2 emissions per unit transport work for alternative transport modes. (2) Calculate the increase in freight rates under the assumptions outlined above. (3) Evaluate the significance of the changes in relative freight rates based on interviews with representatives from the relevant industries. The results reported in the following are based on Evensen (2000), which also contains a detailed description of the underlying assumptions and procedures.

5.2.1 Container transport between Oslo and Rotterdam

Three alternative transport routes are compared:

1. Oslo-Rotterdam by ship
2. Oslo-Rotterdam by truck, by ferry from Oslo to Kiel
3. Oslo-Rotterdam by truck, by ferry from Oslo to Fredrikshavn

The data on fuel consumption and capacity utilisation in sea transport are collected from Lys-Line AS. The ship has a capacity of 200 TEU[6] and an average utilisation rate of 70%.

Nor-Cargo AS and Color Line AS have been the main sources of information about combined land and ferry transport. 100% capacity utilisation has been assumed for the trucks. At the time of calculation, the CO2 tax on diesel in Norway was about 178 NOK per ton CO2. An increase in CO2 costs to 200 NOK therefore represents only a small increase in fuel costs for trucks that are fuelled in Norway. In our calculations, we have assumed, however, that trucks are fuelled in Germany, where diesel is relatively cheap and where no CO2 taxes are collected at present.

Transport with truck from Norway to the continent invariably involves some ferry transport. This represents a methodological challenge, because the CO2

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[6] TEU is short for ”twenty feet equivalent unit”, i.e. a standard container of 20x8x8 feet.

costs of the ferry have to be distributed among the different customer segments. What we would have liked to do, would be to allocate the CO2 costs among segments in the same way as the ferry company would have done through their pricing policy. However, this information is hard to obtain, so what we have actually done is to allocate the CO2 costs according to each segments share of the ticket income.

The results are summarised in table 5.1, and we notice that:

- A uniform CO2 cost across different transport modes will favour sea transport, because emissions per unit of transport are lower at sea than on land. The effect would be even stronger with less than 100% capacity utilisation of the trucks.

- The overall impact of climate policies on freight rates is very small, even though freight rates are increased one by one with the transport costs. In our examples freight rates increase by 0.8 % - 2.9 %.

Table 5.1. CO2 costs Oslo-Rotterdam per container equivalent at NOK 200 / ton CO2.

Transport mode	*CO2 cost on sea*	*CO2 costs on land*	***Total CO2 costs***	*Present freight rate (rough estimate)*	***Freight rate increase (%)***
Ship	46	0	**46**	6000[7]	**0.8**
Truck, by ferry to Kiel	114	54	**168**	6000	**2.8**
Truck, by ferry to Fredrikshavn	80	94	**174**	6000	**2.9**

Customers in the container market have been asked whether changes in freight rates of the magnitudes shown in Table 5.1 would have any impact on the

[7] Includes transport costs from the harbour to a final destination in Rotterdam.

market shares of different transport modes. The unanimous answer is that the consequences for market shares are negligible.

We therefore conclude that although sea transport is the most environmentally friendly transport mode, a non-discriminating climate policy is unlikely to increase the market share of sea transport at realistic price levels for CO2 emission quotas.

5.2.2 Transport of frozen fish from Ålesund to Bologna

Three alternative transport routes are compared:

1. Ship from Ålesund to IJmuiden, truck from IJmuiden to Bologna
2. Truck from Ålesund to Bologna via Oslo and Kiel, by ferry from Oslo to Kiel
3. Truck from Ålesund to Bologna via Oslo and Fredrikshavn, by ferry from Oslo to Fredrikshavn

Nor-Cargo AS has been the main source of information. Data on sea transport from Ålesund to IJmuiden are based on average data from three different ships (Nordjarl, Nordkyn, and Nordvær). An average capacity utilisation rate of 90% has been assumed.

Fish that is transported via IJmuiden is transported by truck from IJmuiden to Bologna. These trucks are assumed to be fuelled in the Netherlands, where currently there is a small CO2 tax on diesel. It has been assumed that a quota price of 200 NOK per ton CO2 will increase fuel prices in the Netherlands by 179 NOK per ton CO2. Trucks are assumed to be fully loaded.

Trucks that depart from Ålesund use fuel filled in Norway until they reach the Danish/German border. The present CO2 tax on diesel in Norway is about 178 NOK per ton CO2, implying that a non-discriminating CO2 tax of 200 NOK will lead to only a small increase in fuel costs. On the distance Germany-Bologna, the trucks use German fuel, which is currently not exposed to CO2 taxes. Note that the diesel consumption of the freezing aggregates of the trucks has been included as well.

CO2 costs related to the ferry transport between Oslo and Kiel/Fredrikshavn have been calculated in the same way as in Section 5.2.1, i.e., based on the trucks' share of the ticket income of the ferry companies.

The results are summarised in table 5.2:

- A uniform quota price of CO2 leads to the smallest cost increase for the transport alternative that is based mainly on sea transport (alternative 1), reflecting that the emissions are lower in sea transport than in land transport.

- The gain in competitiveness for sea transport (if any) is smaller here than in the previous case. One obvious explanation is that both ship and truck are used on all transport routes, and the various alternatives are therefore not that different at the outset. Furthermore, since a significant CO2 tax is paid for diesel in Norway at present, there is very little effect of a uniform climate policy on the costs of truck transport in Norway. In fact, the costs per ton for the distance Ålesund-Oslo increase by only 0.7 NOK. Finally, since the freight rate is significantly lower for sea transport than for land transport at present, a smaller absolute increase in the freight rate for sea transport does not necessarily imply that sea transport becomes more attractive *relative* to land transport.

Table 5.2. CO2 costs Ålesund-Bologna per ton fish at NOK 200 / ton CO2.

Transport route	*CO2 cost on sea*	*CO2 costs on land*	*Total CO2 costs*	*Present freight rate (rough estimate)*	*Freight rate increase (%)*
Ålesund-IJmuiden-Bologna	8.4	5.7	14.1	700	2.0
Ålesund-Oslo-Kiel-Bologna	11.2	9.6	20.8	900	2.3
Ålesund-Oslo-Fredrikshavn-Bologna	7.8	10.2	18.0	900	2.0

As might be expected, representatives of fish exporting companies did not give any indication that the freight rates changes shown in Table 5.2 would have an impact on their choice of transport mode.

Our conclusion is therefore the following: Although emissions of CO2 are lower in sea transport than in land transport, the market share of sea transport is unlikely to increase as a consequence of the implementation of non-discriminating climate policies. The reasons are: (1) At realistic price levels for CO2 quotas, the increase in freight rates will be very small (<3%). (2) In some countries (e.g., Norway and the Netherlands), CO2 taxes are levied on land transport already. Implementation of a non-discriminating climate policy therefore implies a disadvantage for sea transport. (3) In cases where freight rates in sea transport are lower than in land transport, a smaller *absolute* cost increase in sea transport does not necessarily imply that the *relative* freight rates will change to the advantage of sea transport.

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