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Joint Meetings of Tax and Environment Experts

ENVIRONMENTAL POLICY IN THE STEEL INDUSTRY: USING ECONOMIC INSTRUMENTS

This report discusses potential impacts on the steel sector of more widespread use of economic instruments to limit CO2 emissions.

It has been prepared by Dr. Ottar Mæstad of the Institute for Research in Economics and Business Administration, Bergen, Norway.

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FOREWORD

The 2001 OECD Ministerial Council Meeting identified Sustainable Development as an overarching objective for the organisation and its Member countries. To promote such a development OECD was asked help Member countries addressing how to overcome obstacles to a wider use of economic instruments in environmental policy, and the fear of loss of sectoral competitiveness has been identified as one of the main obstacles in this regard.

The Joint Meeting of Tax and Environment experts decided to analyse a series of case studies of the imposition of environmentally related taxes on specific industries, in order to gain greater understanding of the issues related to sectoral competitiveness. These case studies are not intended as such, to make policy recommendations in relation to the industries studied. Rather, the intention is to see whether general lessons could be drawn from the results of these case studies that can inform environmental tax policy.

This paper, prepared by Dr. Ottar Mæstad of the Institute for Research in Economics and Business Administration in Bergen, Norway, uses a partial equilibrium model of the steel sector to explore – as a case study – short to medium term impacts on the competitiveness of the steel sector of a potential broader use of economic instruments to limit CO_2 emissions. In addition to the steel sector itself, economic instruments are assumed to be applied on fossil fuels used as inputs in electricity generation. The paper explores several options to limit impacts on the sector if such economic instruments were to be introduced. It should be seen as a "what if" analysis, and the paper does not address the desirability, nor the necessity, as such of the policies being discussed.

The tax rate / quota price used in the simulations – 25 USD per tonne CO_2 – is relatively high, in particular given the short to medium term character of the analysis. For example, most recent estimates of an international "carbon price" in the implementation of the Kyoto protocol tend to be significantly lower than the tax rate / quota price explored here. A lower "carbon price" would obviously entail smaller impacts on production and CO_2 emissions.

Several other factors could cause the analysis to overstate the costs of the application of economic instruments:

- Economic instruments are by assumption *not* applied to products that are potential substitutes for steel, like aluminium, plastic, cement, etc. If substitute products also had been included in the analysis, it is likely that impacts on total steel demand of a given price increase would be lower than assumed here.

- Not all potential abatement options in the steel sector are included.

- The model used does not include any endogenous technological change. In the short to medium term – with production capacities largely given – this does not seem like a major restriction. However, in the longer term, considerable technological developments could take place in the sector if carbon taxes or tradable permits were to be applied.

The fact that the simulated price increase is relatively large compared to the value of certain steel products will in general increase the uncertainty of the results.

Impacts on the labour market have not been simulated in this study.

The report is issued under the responsibility of the Secretary General of the OECD.

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EXECUTIVE SUMMARY

This study sheds light on the consequences for the steel industry of more widespread use of economic instruments in environmental policy, with particular focus on climate/energy policy. The objective of the study is to get a better understanding of possible impacts of economic instruments and to assess the foundation for prevailing concerns of unwarranted relocations in the case of unilateral actions.

The steel industry is responsible for 7-10% of anthropogenic emissions of CO_2 …

The steel industry accounts for about 7% of anthropogenic emissions of CO_2. When mining and transportation of iron ore are included, the share may be as high as 10%. The CO_2 emissions associated with iron and steel production differ across countries and regions, depending on how much energy is used and the CO_2 intensity of that energy. About 75% of the global CO_2 emissions from steel production are related to the use of coke and coal in iron making. Other notable emission sources are the use of electric power for scrap melting and the use of natural gas in the production of directly reduced iron.

… but there are large differences in emissions depending on the steel production process used.

The two dominating steel production routes are:

- The integrated steel plant, where iron ore and coke are used to produce iron, and where iron is transformed to steel in a Basic Oxygen Furnace (the BOF process).
- The mini-mills, where steel is produced from recycled scrap in an Electric Arc Furnace (the EAF process).

Environmental taxes and tradable permits will affect the costs of these processes quite differently due to the different input combinations and the resulting differences in emission profiles.

The impacts of a carbon tax on the steel industry and its emissions of 25 USD per tonne CO_2 have been simulated for a number of different cases.

The consequences of implementing a carbon tax (which in this formulation is equivalent to a system of tradable emissions permits) has been simulated for the steel industry. The tax rate (or the price of permits) was set to 25 USD per tonne CO_2. A number of potential ways of designing the tax system were considered:

1. An OECD-wide tax.
2. A unilateral tax in selected OECD regions.
3. A unilateral tax in selected OECD countries.
4. An OECD-wide tax with exemptions for process-related emissions (i.e. an energy tax).
5. An OECD-wide tax with recycling of tax revenues back to the industry. Four different recycling schemes were considered.
6. An OECD-wide tax with border tax adjustments (i.e. import taxes and/or export subsidies) towards non-OECD countries. Six different border tax schemes were considered.

The reported results are largely based on simulation experiments with the steel industry model (SIM), developed at the Institute for Research in Economics and Business Administration, Norway. As there are uncertainties attached both to parameter values and the functional forms used in the model, the exact figures that come out of such numerical analyses should be treated with caution. Emphasis should instead be put on the qualitative insights. The main results are described below.

An OECD-with tax could reduce OECD steel production by about 9% …

An OECD-wide carbon tax would reduce OECD steel production significantly, by an estimated –9%. The reduction is much greater for the heavily polluting integrated steel mills (–12%) than for the scrap-based mini-mills (–2%). Non-OECD production would increase by almost 5%, implying a fall in world steel production of –2%.

… with some substitution towards more scrap-based production.

The carbon tax would induce some substitution from the use of pig iron towards more intensive use of scrap in BOF steel making. Scrap prices would then rise, thus weakening the competitiveness of scrap-based EAF steel producers.

A significant share of the gross tax burden would be borne by the steel consumers through price increases.

Because steel demand is relatively price inelastic and because steel is a non-homogenous good, a significant share of the gross tax burden would be carried by the steel consumers. The shift of the tax burden over to consumers would be facilitated by the increase in marginal production costs in non-OECD countries as steel producers in this region are pushed closer to their capacity limits.

Suppliers of inputs to the steel industry also carry part of the tax burden of BOF steel producers, but far less than the consumers. For EAF producers, a carbon tax would increase the input costs due to higher scrap prices.

OECD area CO_2 emissions from the sector would decrease by 19%, and global CO_2 emissions by about 4.6%.

An OECD-wide tax would reduce OECD emissions of CO_2 from the steel industry by 19%. Despite relatively high emission intensities in non-OECD countries, global emissions from the sector would decline by 4.6%, i.e. more than twice the reduction in global steel production. This is due to substitution towards a cleaner input mix and cleaner processes in the OECD area.

Unilateral policies may dramatically reduce BOF steel making.

Unilateral policies by single regions or countries may lead to quite dramatic cut-backs in the production of BOF steel, because unilateralism leaves smaller opportunities to shift the tax burden over to suppliers or customers. For EAF steel producers, the net effect of unilateral policies would not differ much from an OECD-wide approach, because unilateral policies will lead to a smaller increase in scrap prices.

An exemption for process-related emissions would not provide much relief for BOF steel producers.

Most of the emissions in the steel industry are related to the consumption of energy. To exempt process-related emissions from the carbon tax would therefore not imply a big relief in the tax burden of BOF steel producers. EAF steel producers would not be directly affected by the exemption for process emissions, but would nevertheless experience a cost increase as BOF steel production would expand and drive up the price of scrap.

Recycling revenues back to the sector could significantly lower impacts on the sector …

If the tax revenues were recycled back to the steel industry as an output subsidy, the decline in OECD steel production would be quite small (<1%). If the tax refund were uniform across processes, there would, however, be a significant restructuring in the OECD towards the relatively clean process (EAF steel making). Revenue recycling would reduce global emission reductions in the sector from 4.6% to around 3%.

… as could the use of border tax adjustments.

The effect of any border tax adjustments depends crucially on the scope and the design of the adopted scheme. If both import taxes and export subsidies were implemented and were differentiated across steel types, and if the border tax rates were linked to emission levels in non-OECD countries, the decline in OECD steel production might be as small as 1%. At the same time, the reduction in global emissions (5.1%) would be larger than without border tax adjustments. This is because border taxes keep a higher share of world steel production within the OECD area, thus making more steel producers subject to the OECD-wide carbon tax.

Negative impacts on the sector in total may be larger in the long run …

In the long run, an OECD-wide carbon tax would stimulate investments in new capacity in non-OECD regions. This would reduce the price/cost margin of OECD steel producers even further. However, due to large sunk costs, there is little reason to believe that the carbon tax in itself would lead to massive closure of firms in the OECD. But given the present imbalances in the steel industry, environmental taxes may speed up an inevitable restructuring process in the industry.

… with a stronger restructuring towards EAF steel making likely.

Carbon taxes would seriously hamper new investments in BOF capacity in the OECD area, whereas new investments in EAF steel making would still be profitable. In the long run, a stronger restructuring of the OECD steel industry towards EAF steel making is envisaged.

ENVIRONMENTAL POLICY IN THE STEEL INDUSTRY: USING ECONOMIC INSTRUMENTS

1. Introduction

1.1 Background

1. The Ministerial Council meeting 16-17 May 2001 highlighted sustainable development as an overarching goal of OECD governments and the OECD. The Council also asked for further analysis of how obstacles to policy reforms, in particular the better use of market-based instruments, can be overcome.

2. Fear of loss of international competitiveness in key industries is often identified as a major hindrance to more extensive use of market based environmental instruments, such as taxes and tradable emission permits. Taxes that are not imposed universally will normally put domestic industries at a competitive disadvantage, causing a loss in market shares and possibly also a loss in job opportunities. However, environmental taxes also bring benefits through improved environmental quality. The challenge for policy makers is to weigh these costs and benefits against each other and to strike the proper balance between environmental goals and other social and economic goals. In order to make informed decisions, research is needed to identify and, if possible, quantify some of the costs and benefits of environmental policies. This is what this report is all about.

3. This study attempts to shed light on the consequences for the steel industry of more widespread use of economic instruments in environmental policy, with particular focus on climate/energy policy. The objective of the study is to get a better understanding of possible impacts of environmental taxes and to assess the foundation for prevailing concerns of unwarranted relocations in the case of unilateral actions.

4. The production of steel causes emissions of a number of pollutants. In this study, though, the focus will be exclusively on the emissions of the greenhouse gas carbon dioxide (CO_2). According to Ecofys (2000), the steel industry accounts for about 7% of anthropogenic emissions of CO_2.[1] When mining and transportation of iron ore are included, the share may be as high as 10%. The CO_2 emissions associated with iron and steel production differ across countries and regions, depending on how much energy is used and the CO_2 intensity of that energy. About 75% of the global emissions from steel production are related to the use of coke and coal in iron making. Other notable emission sources are the use of electric power, particularly in the electric arc furnace, and the use of natural gas in the production of directly reduced iron.

5. More widespread use of economic instruments in the climate policy of OECD countries will increase the costs of steel production. A carbon tax, or an obligation to buy emission permits corresponding to the amount of carbon emitted, will increase the price of polluting inputs (e.g., coal, oil, natural gas and electricity). Energy costs typically account for 15-20% of the costs of steel production (OECD/IEA, 2000). Hence, a carbon tax may significantly increase the production costs, leading to lower

[1] This estimate fits nicely with our own estimate of the CO_2 emissions from the steel industry (see Section 2.4).

profits, either through lower margins or through a reduction in sales, or both. Reduced profits may in turn lead to closure of firms and/or relocation of activity to countries with less stringent climate polices.

6. The taxation of the inputs in steel production will not necessarily transform into a one by one reduction of profit margins. Part of the tax may be borne by input suppliers (e.g., producers of iron ore and metallurgical coal) through reduced prices on their products. Final consumers, who may accept a higher price of steel products, may carry another part. Moreover, the steel producers themselves may be able to substitute towards less polluting inputs, for instance by increasing the rate of scrap consumption. And finally, there will normally also be possibilities for substitution among different steel producing technologies, at least at the national level. An important part of this study is to assess the possibilities in the steel industry to pass cost increases on to input suppliers and customers, as well as to reduce the cost burden through changes in the input mix or changes in the choice of technology.

1.2 The analytical framework

7. The final cost burden that will fall on steel producers is determined through the interplay between all the factors mentioned above. In order to be able to evaluate the final outcome in a consistent manner, a numerical equilibrium model of the world steel industry has been employed. The steel industry model (SIM) divides the world into ten regions. Within each region, steel may be produced through three different technological routes. Steel is considered a non-homogenous good, both across technologies and across producing regions. Finished and semi-finished steel products are traded in a competitive world market, and the model makes sure that steel prices are adjusted in order to equate world production and world consumption.

8. The SIM model allows for differentiation of steel production costs both across regions, across technologies within a region, and across plants with a given technology in a given region. The production costs depend on technological parameters and the prices of inputs to production. The model includes the markets for several of the most important inputs in steel production. The model endogenously determines a world price of iron ore, metallurgical coal and scrap. Moreover, a shipping freight rate is determined, which impacts on the region specific *cif* prices of imported inputs and the *cif* prices of imported steel.

9. The results presented in this report are largely based on simulation experiments with the SIM model. Although the SIM model allows for a fairly rich description of the world steel industry, it has also a number of limitations. As always, the quality of the output depends on the quality of the input. The price and quantity data in the benchmark version of the SIM model can be considered of reasonably high quality. Considerably more uncertainty is attached to parameters that describe reactions to changing environments, such as the price sensitivity of steel demand, the degree of substitutability between inputs, and so on. Therefore, the simulation results should be treated with caution. The numerical simulations may tell the direction of change and give an idea of the magnitudes involved. The figures reported should not, however, be taken as exact predictions.

1.3 Outline

10. Section 2 presents some stylised facts about the steel industry. The dominating steel production processes are described, and important aspects of the steel market and the related input markets are discussed. Particular attention is devoted to the emission profiles of various production processes and different steel producing regions.

11. The Steel Industry Model (SIM), developed at the Institute for Research in Economics and Business Administration, has been used to simulate the effects of environmental taxes in the steel industry. Section 3 describes the key features of the model and discusses some of its crucial parameters.

12. The results of the simulation experiments are reported in Section 4. The basic experiment is the implementation of a uniform, OECD-wide tax on the emissions of carbon dioxide (Section 4.2). We also report a series of experiments where the tax is implemented in single OECD regions and single OECD countries (Sections 4.3 and 4.4). Section 4.5 discusses the effects of exempting process related emissions from the tax base, thus imposing the tax on energy related emissions only.

13. There are various ways of limiting the detrimental impacts on domestic production of unilateral environmental taxes. Revenue recycling and border tax adjustments are two examples. Section 4.6 reports the effects of four different schemes of revenue recycling. Six alternative schemes of border tax adjustments are discussed in Section 4.7.

14. The report closes with a discussion of the potential long-term impacts of an OECD-wide carbon tax in the steel industry (Section 4.8).

2. Stylised facts about the steel industry

2.1 Production processes[2]

15. Iron and steel are manufactured from iron ore and scrap in a number of different production processes. A steel making process involves five basic steps (OECD/IEA, 2000):

1. treatment of raw materials
2. iron making
3. steel making
4. casting
5. rolling and finishing

16. Iron making (step 2), which is the most energy intensive step, usually takes place in the blast furnace process, with iron ore and coke as the main inputs. Some iron is also produced through a direct reduction process, in which case iron ore and natural gas are the main inputs.

17. The dominating steel production processes (step 3) 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 now been phased completely out in most countries. Some new processes (e.g., the Corex process) have also been introduced in some countries. Due to their small share of the market, these processes will not be discussed explicitly in this study.

18. The share of various steel making processes varies considerably across regions. Globally, the basic oxygen furnace accounts for nearly 60%, while the electric arc furnace accounts for 34% of total steel production (Table 2.1.1).

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2 This section draws on Ecofys (2000) and on personal communication with Professor Leiv Kolbeinsen at NTNU/SINTEF.

Table 2.1.1. Steel production by process, 2000

Steel processes	Share of world production (%)
Basic Oxygen Furnace (BOF)	58
Electric Arc Furnace (EAF)	34
Open Hearth Furnace (OHF)	5
Other processes	3

Source: IISI (2001).

2.1.2 Basic Oxygen Furnace

19. In the BOF process, pig iron and scrap are converted to steel in an oxygen blown converter. The share of pig iron in the metal input varies between 65 and 90%, with scrap or scrap substitutes (e.g., directly reduced iron) accounting for the rest. To substitute scrap for pig iron in the BOF process is one way in which steel producers may adapt to changing climate policies. The actual degree of substitution is crucially dependent on the availability of high quality scrap at reasonable prices. Moreover, the energy balance of the BOF process puts limits on the share of scrap.

20. Steel making in the BOF process typically takes place in a large integrated steel plant that includes all the five process steps outlined above. The main raw materials in this integrated steel making route are iron ore and coal, and the process stages include ore treatment, coke making, and iron making. CO_2 emissions occur at all the process stages, with iron making being the most emission intensive one. Consider first the treatment of ores. In order to facilitate the reduction process, it is common to agglomerate the ore fines into larger particles (sinter or pellets). Especially the sintering process involves significant emissions of CO_2, because coke breeze is used as fuel in order to facilitate the process.

21. Coke is used in the iron making process as a chemical reducer, as a source of energy, and in order to provide a strong and permeable support to allow for a free flow of gases through the furnace. Coke is produced in coke oven plants, where coal is heated in the absence of air. The coke making process produces large amounts of coke oven gas, which is used as fuel or sold. The combustion of coke oven gas produces CO_2. The coke producers may be affected by climate policies either through a tax on their own use of coke oven gas or through a lower market value of the gas. Hence, the economic gain from replacing coke oven gas with cleaner fuels in the wake of CO_2 taxes is probably small.

22. Iron making takes place in the blast furnace process, where iron ore (i.e., a mix of ore fines, sinter and pellets) is reduced to pig iron with coke as the main reducing agent, and where the resulting iron is melted. Injection of pulverised coal (PCI), oil and natural gas directly into the blast furnace may reduce the coke consumption, but the substitution possibilities are limited because none of these fuels may serve the role as a strong and permeable support for free flow of gases. Hence, there is a minimum coke rate below which substitution is no longer possible.

23. The blast furnace process involves huge emissions of carbon monoxide (CO). If released into the atmosphere, carbon monoxide eventually forms carbon dioxide. The CO gas produced in the blast furnace is, however, recovered and used as an energy source. Much of the CO_2 emissions from the blast furnace therefore stems from the combustion of CO gas. In fact, the amount of CO produced in the blast furnace more than satisfies the energy requirements of the process. This implies that it is not at all trivial to discern whether CO_2 emissions in the blast furnace process are process related or energy related (see Section 4.5).

24. Finally, the integrated steel process involves a certain amount of electricity consumption, in particular for the production of oxygen for the steel making process. The power consumption is, however, far smaller than in the electric arc processes.

2.1.3 Electric Arc Furnace

25. In the EAF process, steel is melted via electric arcs between cathode and anode(s). The major raw materials are scrap or scrap substitutes [e.g. directly reduced iron (DRI)], normally accounting for more than 90% of the metal input. Small amounts of pig iron may be used as well. Electricity is the main energy source of the process, and the production of electrical power accounts for a major share of the CO_2 emissions from this steel making route. The production of electricity causes different levels of CO_2 emissions in various regions due to variations in the production method (coal, gas, hydro, nuclear etc.). These differences are taken into account in the calculation of CO_2 emissions.

26. In this study, a distinction is made between EAF processes based on scrap and EAF processes based on DRI, because the production of DRI involves significant CO_2 emissions, implying that different EAF processes may entail quite different CO_2 emission profiles.

27. DRI based processes account for 15-20 % of total EAF steelmaking. When DRI is used as input, the share of scrap in the metal input is normally between 20 and 50%. There are more than one hundred known technologies for producing 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 causes substantially higher CO_2 emissions than in the scrap-based route. This difference is reinforced by the fact that DRI based plants typically are more electricity intensive than scrap based mills.

2.2 The steel market

28. Steel is not a homogenous good. It comes in a wide range of different qualities. Due to impurities in the scrap, scrap-based routes are not always able to meet the same high quality standards as an ore-based process. Moreover, the capacity of electric arc furnace plants is normally not large enough for them to compete in certain product segments, such as the production of flat products. Hence, it is appropriate to treat BOF steel and EAF steel as differentiated products. Note, however, that technological development over time tends to make EAF steel increasingly competitive in a broader product spectre.

29. Price data on steel exports from different regions show substantial price variations also within each of these product categories. This may indicate either that the quality of the steel product differs across regions or that there is regional specialisation in different product segments. A natural implication is to treat steel from different regions as imperfect substitutes.

30. Steel demand is recognised to be relatively irresponsive to changes in steel prices. This implies that cost changes in steel production to some extent may be passed on to steel consumers. However, price increases are constrained by the competition from substitute materials, such as concrete, aluminium, wood, etc. It is important for our purposes that climate policies most likely also will increase the production costs for some of the major competing materials. Both the production of cement and aluminium, for instance, involves significant CO_2 emissions. Hence, a partial analysis of the steel market, like the present one, runs the risk of overstating the loss of competitiveness for the steel industry.

31. On the supply side, the steel market is characterised by notorious over-capacity. According to recent estimates, the world steel producing capacity exceeds actual production by some 25% (OECD 2001, 2002). Over-capacity is present in most regions, implying that significant shifts in the distribution of steel production across regions are conceivable even within a short to medium time horizon.

32. Steelworks using the EAF process can adjust their level of production at smaller costs than the large, integrated steel mills. Hence, they tend to respond more easily to changes in market conditions in the

short to medium term. This fact has been incorporated in our analysis by letting EAF plants respond more strongly to price signals than the BOF steel producers.

2.3 The markets for inputs in steel production

33. Input markets can be broadly classified into two groups; (1) input markets where the steel industry accounts for a minor share of total demand and the activity level in the steel industry therefore has no significant bearing on the price of the inputs, and (2) input markets that are significantly affected by changes in steel production volumes and where prices of inputs therefore cannot be taken as independent of the development in the steel industry. Inputs belonging to the latter category are particularly important in the present context, because part of the cost increases in the steel industry may be covered through lower prices on these inputs.

34. There are at least four important input markets that belong to the second category; the markets for iron ore, metallurgical coal and scrap, and the dry bulk transport market. These are all global markets. Iron ore and metallurgical coal are typically traded on long distance routes between continents. Although steel scrap more often is locally supplied, trade volumes are also significant, for instance between Europe and Asian countries.

35. The steel industry generates substantial amounts of transport work. The main transport routes go by sea.

Table 2.3.1. Major seaborne trades related to the steel industry (1995)

	Billion tonne miles
Steel	830
Iron ore	2160
Metallurgical coal	920

Source: Mæstad (2000).

36. These figures suggest that the steel industry is responsible for about 20% of world seaborne trade and close to 40% of the dry bulk market. At present, the transport demand related to the steel industry is dominated by transport of inputs. But a structural change in the localisation of steel production has the potential of boosting the transport of steel products substantially, because most of today’s production is for home markets. Anyway, the steel industry is undoubtedly large enough in the dry bulk market to impact on freight rates.

2.4 Emissions of carbon dioxide in steel production

37. Our estimate of carbon emissions from the steel industry is based mainly on input data at the plant level for about 70 steel mills, representing about 10% of world steel production. Only when the data coverage is especially thin, more aggregate data sources have been used. 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.

38. 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. Moreover, emissions related to the combustion of by-products that are sold outside the steel plant (e.g., coke oven gas) are counted as well, because we expect climate policies to influence the market price of these products. Finally, we also include separate reports on the emissions related to the transport of iron ore, coal, and semi-finished and finished steel products.

2.4.1 Emissions by process

39. We have estimated the total emissions from the steel industry to 1462 million tonnes CO_2 in 1995 (excluding transport).[3] As Table 2.4.1 shows, emissions differ substantially between processes. The BOF process is definitely the most polluting one with an average emission factor of 2.5 tonnes of CO_2 per tonne crude steel. The standard EAF process, based on 100% scrap, is the least polluting one with an average emission factor of 0.6, while the DRI based EAF route 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.

Table 2.4.1. Emissions of CO_2 in the steel industry, 1995 (million tonnes)

	Iron and steel production			Rolling and finishing			Total	CO_2 (t) per tonne steel
	Coal	*Power*	*Natural gas*	*Fuel oil*	*Power*	*Fossil fuels*		
BOF steel	1115	18	12	16	44	87	1292	**2.5**
Standard EAF steel	9	59	0	0	17	35	120	**0.6**
DRI based EAF steel	2	16	21	0	3	7	50	**1.2**
Total	**1126**	**94**	**33**	**16**	**64**	**129**	**1462**	**1.9**

Source: Mæstad (2000a).

40. About 75% of the CO_2 emissions from the steel industry are related to the combustion of coal in primary integrated steel mills. Coal is used in the production of coke, which again is used both as an energy source in the preparation of ore (sintering) and as a reducing agent and an energy source 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 (<1%), but most of it is released to the atmosphere as CO_2.

41. 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.

3 Ecofys (2000) has estimated the CO_2 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.

42. 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 three GJ per tonne 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.

Emissions by region

43. As shown in Table 2.4.2, emissions per tonne steel vary substantially across regions.

Table 2.4.2. Emissions of CO_2 per tonne crude steel, 1995 (Tonne)

	BOF steel	Standard EAF steel	DRI based EAF steel
EU (excl. Sweden and Finland)	2.1	0.5	1.0
Rest of Western Europe	2.0	0.2	-
Eastern Europe and FSU	2.4	0.8	1.6
North America	2.0	0.6	1.0
South America	2.5	0.3	1.1
Japan	2.5	0.4	-
China	3.9	0.9	-
Rest of Asia	2.4	0.7	1.3
Australia and NZ	2.5	0.7	-
Rest of world	2.8	0.6	1.5

Source: Mæstad (2000a).

44. 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.

45. Some of the variation, particularly in the EAF processes, is explained by varying emission rates in power production. In regions where hydropower 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.

46. Note that since our sample of firms does not cover all steel producers, there may be sample biases that lead to over- or underestimation of emission coefficients. Although our sample seems quite representative at the global level, there may still be biases in the regional emission coefficients reported in Table 2.4.2. Hence, theses figures should be treated with due caution.[4]

[4] Some commentators have indicated that the Japanese emission coefficient in BOF steel production may appear high relative to the emission coefficients in other industrialised countries. Errors in the relative emission coefficients may be a result of sample biases. Note, however, that a study by Gielen and Moriguchi (2002) on emissions in the Japanese steel industry provide empirical support for the emission coefficient used in this report.

2.4.3 Emissions from transport

47. 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 tonne CO_2 per billion tonne miles. With the transport volumes reported in Table 2.3.1, emissions from seaborne trade of iron ore, coal and steel products then amount to 105 million tonne CO_2 a year, or 0.14 tonne CO_2 per tonne steel. The transport work related to the steel industry is thus far less polluting than the production of steel itself.

3. The steel industry model (SIM)

48. The consequences of climate policies for steel industry have been analysed in a numerical model that incorporates essential aspects of the steel industry and the related input markets and transport markets. A full description of the model and the data is given in Mathiesen (2000) and Mæstad (2000b).[5] The basic structure of the model and some key model parameters are presented here.

3.1 The model structure

49. A schematic view of the model is presented in Figure 3.1.1. The key aspects of the model are the following:

- The model has 10 regions:

  EU (excl. Sweden and Finland)
  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)

- Total steel demand in each region is represented by an aggregate steel demand function.[6] Two types of steel are consumed in each region; oxygen blown steel (BOF steel) and electric arc steel (EAF steel).

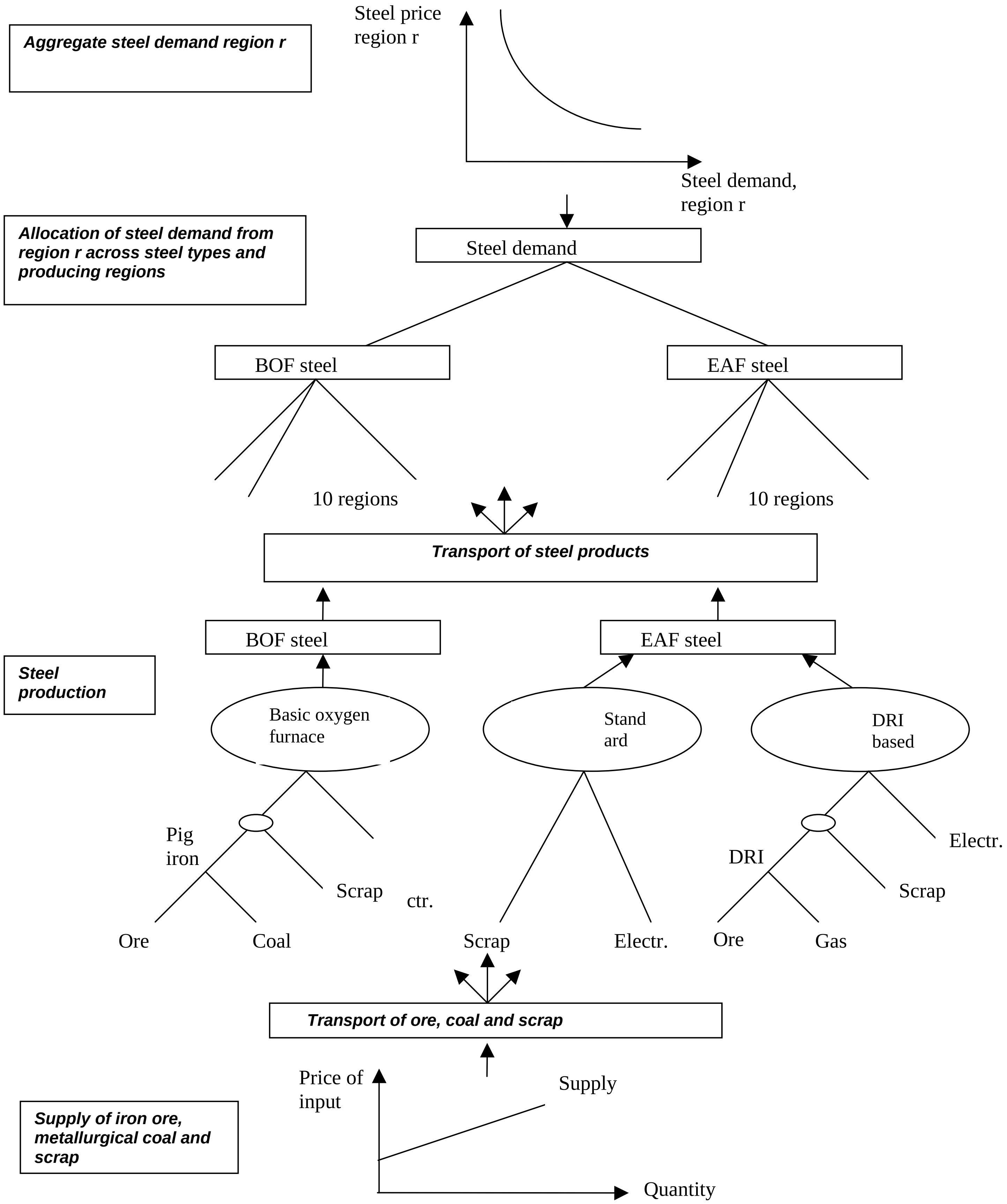
5 The model is calibrated to data from year 1995. The results may therefore be "biased" to the extent that significant changes have taken place since 1995 in the emission levels per tonne steel or in the cost structure of steel producers. The results that have to do with trade flows, such as the impact of border tax adjustments (Section 4.7), are generally the most sensitive ones to the chosen benchmark year, as trade flows typically are more volatile over time than the basic cost structure of the industry.

6 The steel demand function in the model entails constant demand elasticity. The elasticity of demand is a measure of the price responsiveness of demand; it measures the percentage change in demand when the price is raised by one percent.

These are treated as imperfect substitutes, because both the steel quality and the product mix differ between integrated steel mills and mini-mills.[7]

[7] A constant elasticity of substitution is assumed between the two steel types. The elasticity of substitution is a measure of the change in the relative demand of the two steel types as the relative price changes. A constant elasticity of substitution is to say that a one percent change in the relative price has always the same percentage effect on relative demand.

Figure 3.1.1. The Steel Industry Model (SIM)



- Steel is traded between regions, and steel from different regions is treated as imperfect substitutes (the Armington (1969) assumption[8]). 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 region-specific mix of directly reduced iron and scrap)

  The outputs from the two EAF processes are treated as perfect substitutes.

- The production of oxygen blown steel is modelled in several stages. At the first stage, coal (coke) and iron are combined in order to produce pig iron. At the next stage pig iron and scrap are combined in order to produce steel. Electricity is used in proportion to the amount of steel produced.
- DRI based steel making has a similar conceptual structure as the blast furnace-BOF process, except that natural gas is used rather than coal in the iron making process.
- The standard electric arc furnace has a simpler structure in the model, with only scrap and electricity as the major inputs.
- The model allows for a certain degree of substitutability between pig iron and scrap in the basic oxygen furnace. In all other processes and process stages, inputs are used in fixed proportions (Leontief technology).[9] The actual input mix per tonne steel may, however, differ between regions. Some differences may be explained by relative input prices that differ between regions. Other differences may result from managerial competence, experience and different vintages of capital. Such differences are taken as given.
- The prices and quantities per tonne steel of those inputs that are not explicitly modelled (e.g., labour), are taken as independent of the climate policy regime.
- Note that the model also accounts for some additional fossil fuels beyond those mentioned in Figure 3.1.1, such as some coal powder in the EAF process and some heavy fuel oil and natural gas in the blast furnace. These inputs are used in fixed proportions.
- There are global markets for iron ore, coal and scrap. The world prices of these goods are determined by world supply and demand. The local input prices vary due to differences in input qualities and transport costs.
- There are local markets for natural gas and electricity in each region. The prices of these factors are assumed to be exogenous to the steel industry. These input prices typically differ across regions, and they may change as a result of climate regulations.
- Production costs vary across regions due to differences in input mix and input prices. Production costs also vary within each region due to variations in productivity across plants. The profile of production

8 The assumption of imperfect substitution between steel from different regions is needed for technical reasons in order to reproduce the bilateral trade flows in the base year. In the model there is an equal and constant elasticity of substitution between steel from all the different regions. This implies that a one percent change in the relative price of steel from two different regions has always the same percentage effect on relative demand, independent of the level of trade and of the name of the region.

9 The model does not incorporate the substitution between scrap and DRI in DRI based steel making although a high degree of substitution is achievable in this process. This weakness is partly adjusted for by treating scrap based and DRI based steel as perfect substitutes.

costs for a given technology within a region is described by an industry cost curve. The total production in a region for a given technology is determined so that the unit cost of production in the marginal steel plant equals the steel price.

- The model describes a short-run equilibrium in the steel market. All changes in production volumes are assumed to 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 regional 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.

3.2 Key model parameters

50. The consequences of climate policy for steel production depend on several model parameters that are difficult to determine. Parameters of an equilibrium model can roughly be categorised into two classes; levels and price sensitivities. While the levels of variables are observable from yearly statistics, their price sensitivities are notoriously more difficult to get at. To estimate all these parameters empirically would be a separate project and beyond the scope of the present study. We have obtained empirical estimates only of the most crucial ones. Other price sensitivity parameters are based partly on previous literature and partly on advice from industry experts. The industry experts were given the opportunity to reconsider their initial beliefs based on the results of the model simulations.

51. In the SIM model, price sensitivity parameters appear at six levels: 1) the price sensitivity of steel demand, 2) the degree of substitutability between oxygen blown and electric arc steel, 3) the degree of substitutability between steel from different regions, 4) the degree of substitutability between inputs in the production processes, 5) the price sensitivity of steel supply, and 6) the price responsiveness of the supply of the major inputs (iron ore, coal, scrap and transport services). A few comments on each of these are needed in order to get a better understanding of the simulation results.

1. Steel demand is normally considered to be relatively irresponsive to changes in steel prices. Winters (1995) uses a demand elasticity of –0.3 for Europe. As we do not have estimates of the demand elasticity in other regions, a uniform steel demand elasticity of –0.3 has been imposed across all regions.[10] In practice, a CO_2 tax will most likely be implemented not only in the steel industry, but also in other industries that may be both competitors (e.g., aluminium, plastics and wood) and customers (e.g., the automotive industry). Our partial equilibrium model does not capture the effects on the steel industry of CO_2 taxes in these other industries.

2. Over time EAF steel producers have been able to substantially increase their market share at the expense of the integrated steelworks. Still, the range of products where actual competition between electric arc and oxygen blown steel products takes place is quite narrow. This implies a rather low degree of substitutability between the two steel types, at least in the short run. Based on an assessment by industry experts of the effect of a change in the relative price of the two steel types on the demand pattern, the elasticity of substitution between steel types has been calculated to 0.5.[11] In practice, there are some applications where electric arc and oxygen blown steel are readily substitutable, whilst in others substitution is more difficult or even impossible. By using an average elasticity of substitution, the model does not capture this diversity. It should however be noted that

10 This is to say that a 10% increase in steel prices will reduce steel demand by 3%.

11 This is to say that a 10% increase in the ratio of BOF steel prices to EAF steel prices will induce a 5% reduction in the ratio BOF steel demand to EAF steel demand.

sensitivity analysis shows that our results, somewhat surprisingly, are quite robust to changes in the elasticity of substitution between electric arc and oxygen blown is steel.[12]

3. The degree of substitutability between steel from different regions is, however, quite good. The elasticity of substitution between steel from different regions (i.e., the Armington elasticity) in the SIM model has been set to 8. This figure is somewhat higher than the Armington elasticity of 5.6 employed for the sector "ferrous metals" in the GTAP model (Hertel, 1997). We have chosen a higher elasticity in order to reflect the fact that the sector "ferrous metals", which includes iron ore, scrap, as well as steel, is a more heterogeneous product category than the steel products that are traded in our model.

4. In the SIM model, most inputs for steel production are used in fixed proportions (Leontief technology). However, the model recognises the possibility to alter the mix between scrap and pig iron in the BOF process. The technological possibilities to substitute between scrap and pig iron are reasonably good. However, the energy balance of the process does not allow the share of scrap to increase much beyond 30%.

   Based on a sample of 25 integrated steel mills, Mæstad (2002) estimated the elasticity of substitution between pig iron and scrap to 1.68. This estimate probably overstates the real substitution possibilities, because the estimation procedure does not take into account that technological differences between converters may imply smaller substitution possibilities for a given converter than across different converter types.

   The SIM model uses substitution elasticities between pig iron and scrap of 1.5 in all regions, except in North America, China, Rest of Asia and Rest of World, where the elasticity of substitution is set to 0.5. The scrap rate in North America is so high at the outset that the energy balance of the process will constrain a further increase in the scrap rate. In the three other regions, the scrap rate is so low at the outset that a further reduction is not very likely, because a certain amount of scrap is needed in order to control the temperature of the process.

5. Due to a more flexible cost structure, EAF steel producers tend to respond more easily to changes in steel prices than do BOF steel producers. This is reflected in the model by attaching a higher price sensitivity of steel supply to EAF producers. The price sensitivity of steel supply was determined based on assessments by industry experts. They were confronted with various price paths and were then asked to assess how the output from the industry would respond within one to two years' time. Due to large overcapacity in the steel industry, increasing steel prices may have a significant impact on output, even within such a short time horizon. The supply elasticity, i.e., the percentage increase in output following a 1% increase in steel producer prices, was set to 0.7 for basic oxygen furnaces and 1.2 for electric arc furnaces.

6. Finally, consider the price responsiveness of supply of the major inputs to steel production. These parameters are important determinants of the degree to which cost increases in the steel industry may be passed on to input suppliers. The supply of scrap is quite insensitive to price changes. The total amount of scrap is more or less given, and strong price incentives are needed in order to increase the collection rates. The low supply elasticity of scrap leads to substantial volatility of scrap prices over time as scrap demand fluctuates. Based on advice from industry experts, the SIM model uses a scrap supply elasticity of 0.5.

[12] The explanation is that a CO_2 tax will drive up the price of scrap to such an extent that the competitiveness of EAF steel producers will improve far less vis a vis BOF steel producers than we would expect based on a comparison of emission levels alone. Such equilibrium price effects are typically not accounted for in other similar studies (e.g., Lutz *et al.*, 2002).

The supply elasticity of coal, on the contrary, is quite high. Low cost coal reserves are huge, and higher coal prices therefore easily stimulate coal supply. Following Golombek *et al.* (1995), the SIM model uses a coal supply elasticity of 2.0.

Less is known about the supply elasticity of iron ore, but industry experts consider the price responsiveness of ore supply to be greater than for scrap supply and smaller than for coal supply. The SIM model uses an iron ore supply elasticity of 1.0.

The supply elasticity of dry bulk shipping of 0.27 was taken from the shipping model NORBULK (see Wijnolst and Wergeland, 1997).

52. The parameter values in our base scenario are summarised in Table 3.2.1.[13]

Table 3.2.1. Parameter values in the SIM model

Parameter	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)	8.0
Elasticity of substitution between pig iron and scrap in BOF steel production	1.5/0.5
Supply elasticity of steel production	BOF steel: 0.7 EAF steel: 1.2
Supply elasticity of major inputs	Scrap: 0.5 Coal: 2.0 Iron ore: 1.0 Transport: 0.27

4. Simulation experiments

4.1 On the climate policy scenario

53. We have studied the consequences of implementing carbon taxes or equivalent measures (e.g., tradable emission quotas) in OECD countries. Thus, climate policies will be implemented only in the following regions in the model; EU and the Rest of Western Europe, North America, Japan, and Australia. Both OECD-wide regulations and unilateral regulations by individual OECD regions or countries will be discussed. [14]

54. Whether the climate policy is implemented through a carbon tax or through tradable emission permits does not affect the results as long as the government auctions the emission permits. Grandfathering of emission permits, or other ways of distributing free permits, may make a difference, but only in the long run. In the short run, both taxes and free emission permits will increase the marginal costs of emissions and thus provide equally strong incentives to abate. In the long run, the allocation of free emission permits to domestic plants will in addition work as a location subsidy and thus reduce the relocation of firms to other regions. Since our simulations are concerned with medium term effects only, we do not distinguish between taxes and tradable permits in the following.

13 Sensitivity analysis with respect to key model parameters is performed in a related study by Mathiesen and Mæstad (2002).

14 For the sake of reference, a hypothetical scenario with a uniform tax implemented on a global scale has also been simulated. The results are reported in the Appendix.

55. Implementation of climate policies implies that the steel industry and the power producing sectors will have to pay a price 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 carbon tax on electricity varies across regions, reflecting the region specific fuels mix in power production. No carbon taxes are imposed on the transport sectors, because most transport work related to the steel industry goes by ship, and because emissions from international shipping are not included in the Kyoto Protocol.

56. We suppose that the carbon tax is uniform across countries that implement climate policies. Such a uniform price of emissions can for instance be achieved through international trading of emission permits.

57. The level of the carbon tax imposed on the model is an important determinant for the results. In this study, we use a carbon tax of 25 USD per tonne CO_2. Before the US withdrawal from the Kyoto Protocol, 25 USD per tonne CO_2 was considered a reasonable, though perhaps a somewhat high, estimate of the international price of emission permits following the implementation of the Protocol. After the USA decided to leave and after the "weakening" of several of the provisions of the Protocol in the last rounds of negotiations, several analyses point to emission permit prices of 5-10 USD per tonne CO_2. Hence, the results of this study should not be taken as predictions of the consequences for the steel industry of the actual international climate policy regime in the near future.

4.2 Uniform climate policy across OECD regions

58. Consider first the consequences of a uniform CO_2 tax across all OECD regions of the model; EU13, Rest of Western Europe, North America, Japan and Australia.[15] Table 4.2.1 shows the effect of a tax of 25 USD/tonne CO_2 on the marginal variable costs in crude steel production, assuming that all prices and quantities of inputs are kept constant.

Table 4.2.1. Gross tax in percent of marginal variable costs

	BOF steel	Standard EAF steel	DRI based EAF steel
EU (excl. Sweden and Finland)	22	5	9
Rest of Western Europe	24	2	-
North America	22	5	10
Japan	26	4	-
Australia and NZ	32	7	-

59. The first order effect of the CO_2 tax is a substantial increase in the costs of steel production, especially for BOF steel where variable costs rise by 20-30%. But as will be demonstrated shortly, BOF steel producers will have opportunities to reduce the cost burden by changing their input mix. Reductions in input prices are also likely to reduce the net tax burden for BOF steel producers (see Table 4.2.3).

60. By taking into account the equilibrium effects on all prices and quantities, the SIM model reports the following effects of the CO_2 tax on production volumes:

15 Our regional split implies that a few OECD countries in Central and Eastern Europe and Asia are included in Non-OECD regions.

Table 4.2.2. Change in steel production by process (%)

	BOF steel	Standard EAF steel	DRI based EAF steel	Total
OECD	-12.2	-1.7	-7.4	**-8.6**
Non-OECD	5.5	1.5	4.0	**4.5**
World	**-3.1**	**-0.5**	**0.4**	**-2.2**

61. A CO_2 tax that is implemented in all OECD regions causes a 12% reduction in OECD production of BOF steel. The reduction in EAF steel production is much smaller. DRI based steel comes in a middle position with a fall in production of 7%. Total steel production in the OECD region is reduced by 9%.

62. Given the large difference in emission rates between scrap based and ore based steel production, one might conceive that CO_2 taxes would lead to larger substitution towards EAF steel. However, such substitution is limited in the short run for two reasons. First, differences in steel qualities between EAF and BOF producers prevent dramatic shifts in the production pattern in the short run. In the longer run, though, substitution possibilities are greater, provided high-quality scrap is available in sufficient quantities. Secondly, because the CO_2 tax makes it attractive to increase the share of scrap in the BOF process, scrap prices will increase, in our simulation by about 5%. Higher scrap prices reduce the competitiveness of EAF steel relative to BOF steel, leading to less substitution towards EAF steel.

63. As shown in Table 4.2.2, lower steel production in the OECD countries is partly offset by increased volumes in Non-OECD regions, as the OECD-wide tax increases the competitiveness of Non-OECD producers. Given the substantial overcapacity in the steel industry, this reallocation of production between OECD and Non-OECD producers could probably be accommodated without much additional investment in Non-OECD regions.

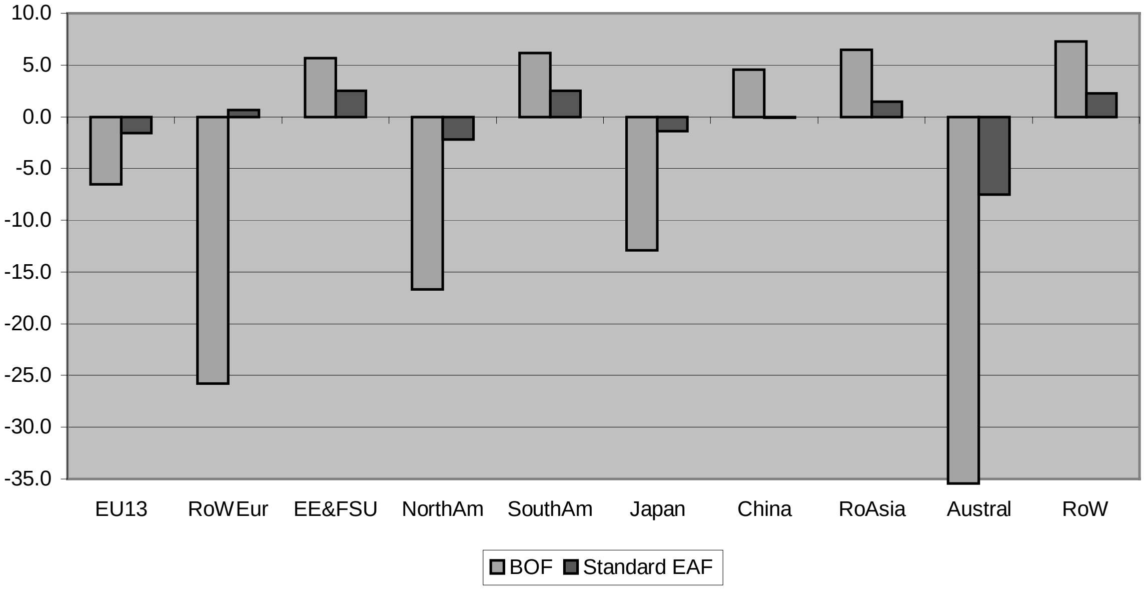
64. Figure 4.2.1 depicts changes in production of BOF steel and standard EAF steel across regions. (See the Appendix for details about DRI based production). Reductions in BOF steel production levels are particularly large in Australia and Rest of Western Europe (–25%–35%). The decline in EU is relatively small (-7%). Japan and North America experience reductions of around 15%.

65. Australia will also have a relatively big decline in EAF steel production, while in Rest of Western Europe the output of EAF steel producers actually increases! The other OECD regions will have a decline in EAF steel production of around 2%.

66. The explanations of the regional differences are quite complex, hinging on such parameters as differences in input mix, different locations and thus different transport costs, different trade patterns, different industry costs structures, etc.

67. In order to come somewhat closer to the explanations for the regional differences, Table 4.2.3 presents an analysis of the incidence of the CO_2 tax for each process and region. The first column is the gross tax, taken as the CO_2 tax per tonne steel at the base year input mix and input prices. The gross tax thus reflects the differences in the current emission levels per tonne steel. The second column is the reduction in the tax that is brought about by changing the input mix. The possibilities to substitute towards less polluting inputs are negligible in the standard EAF process compared to the BOF process, where some pig iron can be replaced by more scrap. Note, however, that due to the initially high share of scrap in BOF production in North America, the substitution possibilities are smaller there than in other regions. The figures in the second column reflect the net effect of 1) a reduction in the CO_2 tax payment as the input mix is changed and 2) the increased costs due to a new input mix that would not be costs-minimising in the absence of the environmental tax.

Figure 4.2.1. Change in steel production by region and process (%)



68. The third column summarises the effect of the price changes for ore, coal and scrap, including reductions in transport costs. While the scrap price is raised by 5%, the prices of ore and coal are reduced by 6% and 2%, respectively. The freight rate in dry bulk shipping drops by >20% due to a sharp reduction in aggregate transport demand. The main explanation for the differences across BOF producers is variations in the transport intensity of steel production. Regions with a high content of domestic inputs (North America and Australia) benefit less from reduced freight rates than a heavily import-dependent country like Japan.

Table 4.2.3. Tax incidence analysis (USD/tonne)

	Gross tax	Change input mix	Change input prices	Non OECD marginal cost increase	"Net" tax	Passed on to buyers
BOF steel						
EU 13	**52.5**	-4.0	-2.1	-18.5	**28.0**	-13.0
Rest of WEurope	**50.7**	-2.4	-2.2	-18.5	**27.6**	-17.5
North America	**50.3**	-2.2	0.0	-18.5	**29.6**	-20.0
Japan	**62.6**	-4.2	-4.4	-18.5	**35.7**	-17.1
Australia and NZ	**63.8**	-4.1	-0.4	-18.5	**40.9**	-28.4
Standard EAF steel						
EU 13	**12.4**	0.0	5.5	-7.5	**10.4**	-7.1
Rest of WEurope	**5.8**	0.0	5.8	-7.5	**4.1**	-5.6
North America	**14.0**	0.0	5.8	-7.5	**12.3**	-7.9
Japan	**10.1**	0.0	5.4	-7.5	**8.0**	-4.7
Australia and NZ	**16.9**	0.0	6.3	-7.5	**15.7**	-6.7
DRI based EAF steel						
EU 13	**24.4**	0.0	1.2	-9.2	**16.3**	-5.4
North America	**25.5**	0.0	2.2	-9.2	**18.5**	-6.2

69. Note that higher scrap prices bring about substantial extra cost increases for the scrap based EAF producers.

70. The fourth column is included in order to highlight the fact that the increase in production levels in Non-OECD countries is likely to push Non-OECD producers up their marginal costs curves as capacities are more fully utilised and less efficient production units are brought on board. The figures in this column are the weighted average of the increase in the marginal production costs in Non-OECD countries. If steel producers behave competitively (i.e., they do not exercise market power), there will, roughly speaking, be a one to one correspondence between marginal production costs and steel prices. Given that the increase in marginal costs in Non-OECD regions are reflected in world steel prices, the figures in the fourth column may be interpreted as a measure of the change in the level playing field as a result of the CO_2 tax in the OECD regions. Loosely speaking, there will be no reduction in the market share of OECD producers as long as producer prices are not raised by more than these figures indicate.

71. The "net" tax burden on OECD producers is calculated as the sum of columns one through four. Part of this "net" tax burden will in turn be passed over to steel consumers. Such price increases are, however, likely to reduce market shares. The degree of product differentiation determines how much prices can be increased without losing market shares.

72. Returning now to Figure 4.2.1, we notice that differences in the "net" tax appear as a reasonably good explanation of the regional differences in output changes. The exceptions are BOF production in North America and Rest of Western Europe where the cost structure probably is a better explanation of the relatively large fall in outputs. In both these regions, the costs structure is relatively homogenous across production units, implying that there are relatively few high productivity units that are able to "absorb" the tax increase through reduced margins rather than by cutting the output level.

73. Finally, consider the effect of an OECD-wide tax on the CO_2 emission levels. As Table 4.2.4 indicates, the reduction in aggregate emissions (–4.6%) is about twice the reduction in aggregate output. The driving force behind this result is the substitution towards cleaner inputs in the BOF process. In the OECD, the emissions from the steel industry are reduced by as much as 19%. This achievement is counteracted by an increase in Non-OECD emissions of 6%. In absolute terms, this is to say that an emission reduction in the OECD by 120 Mt CO_2 leads to a global reduction in emissions of 67 Mt CO_2. Thus, each unit of emission reduction in the OECD is counteracted by increased emissions of 0.45 in the Non-OECD countries.

74. It is noteworthy that a reduction in world emissions is achieved despite the fact that CO_2 emissions per tonne steel in Non-OECD countries in many cases are higher than in OECD countries due to lower energy efficiency. A pure reallocation of output would therefore increase the level of emissions. In addition, the induced changes in the world market price of inputs encourage even dirtier production processes (i.e., less scrap and more pig iron) in the Non-OECD.

Table 4.2.4. Change in CO_2 emissions

	Percentage change				Absolute change
	BOF	Standard EAF	DRI based EAF	Total	(mill. tonne)
OECD	-21.6	-1.8	-7.3	**-19.3**	**-120.4**
Non-OECD	6.9	1.4	4.0	**6.4**	**54.7**
World	**-5.2**	**-0.3**	**1.0**	**-4.6**	**-66.7**

75. On top of these emission reductions comes the fall in CO_2 emissions due to reduced transport activity related to the steel industry. Admittedly, the relocation of steel production away from the main consuming regions will boost the trade in steel products by 10%, but this is counteracted by a 11-12% reduction in the transport of coal and iron ore. Total transport demand from the steel industry thus falls by 7%, which corresponds to a reduction in CO_2 emissions of 7 million tonnes.

4.3 Unilateral policies by OECD regions

76. The implementation of environmental taxes will not necessarily be co-ordinated across OECD countries and regions. We have therefore investigated the consequences of imposing a tax of 25 USD per tonne CO_2 in one region at a time.

77. Table 4.3.1 reports the effect of unilateral tax policies in single OECD regions. Only the effects on the implementing regions are reported, as effects in other regions generally are small in relative terms and quite evenly dispersed across regions. For the sake of comparison, the consequences of a uniform tax across OECD regions are reported in brackets.

78. We would expect unilateral policies to have a more pronounced impact on production volumes than OECD-wide taxes. The simulations confirm this conjecture as far as aggregate steel production is concerned. In particular BOF steel production will be badly hit by unilateral policies. In the smaller regions (Australia and Rest of Western Europe), output declines by as much as 60-70%. The fall in North America and Japan is between 25 and 30%, while a unilateral tax in EU13 is expected to reduce output by 15-20%.

79. The picture is somewhat different when it comes to EAF steel producers, though. The difference between unilateral taxes and an OECD-wide tax appears not to have a big effect on the standard EAF producers. In EU13, production falls by 2.5% with unilateral taxes, as compared to 1.6% with an OECD-wide tax. The corresponding figures for Japan are –2.0% and –1.4%. In fact, the EAF producers may in some cases prefer unilateral before OECD-wide taxes, as seems to be the case in North America. The reason is that OECD-wide taxes, by inducing substitution towards scrap in many regions, will raise the price of scrap far more than will unilateral policies. As a matter of fact, unilateral taxes may in some cases reduce the scrap price.

80. As far as emissions are concerned, unilateral policies may achieve large emission reductions in the implementing region. However, most of the reduction is likely to be counteracted by higher emissions in other regions. The rate of leakage with unilateral policies is found to be about 60% on average. Hence, for each unit of unilateral emission reductions, emissions increase by 0.6 units in the rest of the world. Although this is a high leakage rate, the difference compared to the leakage rate of 45% in the case of OECD-wide regulation is not particularly large. Part of the explanation is that while leakage in the case of unilateral regulations primarily is a matter of relocation of production, an OECD-wide regulation will in addition have more pronounced effects on input prices. Lower world market prices of ore and coal and higher prices of scrap lead to a more polluting input mix in non-regulated regions, contributing to a high leakage rate also with OECD-wide regulations.

Table 4.3.1. Effect of unilateral policies on implementing region, % change

(Effect of OECD-wide tax in brackets)

	EU 13	Rest of WEurope	North America	Japan	Australia and NZ
Production					
Region BOF	-16.5 (-6.5)	-70.5 (-25.8)	-27.8 (-16.7)	-25.2 (-12.9)	-57.3 (-35.5)
Region Standard EAF	-2.5 (-1.6)	-2.5 (0.7)	-1.1 (-2.2)	-2.0 (-1.4)	-9.0 (-7.5)
Region DRI based EAF	-15.6 (-7.9)	-	-8.5 (-7.2)	-	-
Region total	-11.7 (-4.9)	-40.6 (-14.1)	-17.2 (-11.0)	-17.7 (-9.2)	-50.7 (-31.6)
World total	*-0.8*	*-0.2*	*-1.1*	*-0.7*	*-0.3*
Emissions					
Region	-24.8	-67.4	-27.7	-31.8	-60.4
World	*-1.4*	*-0.1*	*-1.4*	*-1.5*	*-0.4*

4.4 Unilateral policies by selected OECD countries

81. We are also interested in the consequences of environmental taxes that are implemented unilaterally by single OECD countries. Unfortunately, the SIM model is not well designed to perform such analyses, because the results for regions cannot be decomposed into country specific figures. The only OECD country that can be studied separately with the model is Japan (see above).

82. In general, we expect the following differences between country level studies and regional level studies:

1) Less effect on input prices
2) Less effect on output prices
3) Country specific deviations from the results at the regional level due to variations in the productivity level (or competitiveness) among countries within a region.

83. Unilateral policies by single countries will in general have less effect on input prices than regional policies, simply because the shift in demand will be smaller. For those production processes where adjustments in input prices following a CO_2 tax will reduce production costs, unilateral policies will therefore typically increase costs more than will regional policies. The opposite will be the case for production processes where adjustments in input prices typically increase the costs of production. This implies that unilateral policies at the country level will imply higher costs for BOF steel producers and lower costs for scrap based steel production, compared to environmental policies implemented at the regional level.

84. As was demonstrated in the tax incidence analysis above, the raise in the “world market price” of steel in the wake of environmental taxes has a potentially important impact on the ability to maintain market shares for steel companies in the regulated regions. The world market price of steel increases because relocation of production to countries that do not implement environmental policies will push the producers in these countries upwards on their marginal production cost curves. This effect is smaller with unilateral policies for two reasons. First, for a given percentage reduction in production in the regulated country, the production volume that will be relocated to non-regulated regions will be smaller. Secondly, the output that is relocated can now be distributed across more producers, since there are a greater number

of non-regulated countries. Hence, the world market price of steel will increase less with unilateral policies. The "net tax burden" will then be greater, inducing a sharper decline in production levels of the regulated country.

85. High productivity production units are more likely to survive a sharp tax increase than the less productive ones. Thus, if low cost and high cost producers are non-uniformly distributed across countries within a region, we would expect unilateral policies to have more dramatic consequences in the high cost countries.

86. Empirical studies of international trade and specialisation tell that there usually is a strong home market bias in the trade patterns. To the extent that there is a home market bias in the steel markets, there will be a tendency for countries that sell a large share of their output in the home market to be less affected by unilateral environmental policies than will countries that are more export oriented.

87. In order to get an impression of how unilateral policies at the country level might differ from regional level policies, we have estimated the increase in the net environmental tax when policies are implemented at the country level rather than at the regional level. The net tax is an expression of the tax burden faced by firms, after taking into account the change in the input mix, input prices and the world market price of steel. For simplicity, we have assumed that the change in the input mix is the same with country level regulations as in the case with unilateral regulations at the regional level. The changes in factor prices and steel prices are smaller with country regulations, and the rate of adjustment has been set inversely proportional to the respective country's share of steel production in the region. This implies, for instance, that when a unilateral regulation is implemented in the USA, which accounts for ¾ of total steel production in the region, factor prices in the USA will change with ¾ of the factor price changes in the case of a unilateral regulation in the North American region. The results for five OECD countries are reported and compared with regional and OECD-wide regulations in Table 4.4.1.

Table 4.4.1. "Net tax" for steel producers (USD/tonne)

	OECD regulation	Unilateral regional regulation	Country regulation
BOF steel production			
Germany	28.0	39.6	45.3
UK	28.0	39.6	47.3
France	28.0	39.6	47.2
USA	29.6	38.8	40.8
Canada	29.6	38.8	46.7
Standard EAF steel production			
Germany	10.4	11.7	12.2
UK	10.4	11.7	12.3
France	10.4	11.7	12.3
USA	12.3	12.1	12.6
Canada	12.3	12.1	13.7

88. For BOF steel producers in most of the countries considered, a unilateral tax is likely to raise the net tax significantly compared to a regional policy. The only exception is the USA, which completely dominates the North American region. For smaller countries, the increase in the net tax would have been even greater. Most of the increase in the net tax is due to the fact that the world market price of steel does not increase as much with unilateral as with more encompassing regulations.

89. The picture is quite different when it comes to EAF steel producers. We have already pointed out that unilateral regulations tend to put less upward pressure on the scrap price. For EAF producers, the fact that unilateral regulations do not allow for as large steel price increases as more broad-based regulations, is to a large extent neutralised by a smaller increase in scrap prices. Hence, net taxes for EAF producers are typically not much affected by the number of countries implementing the environmental tax.

90. To assess the effect on production levels of unilateral regulations at the country level is obviously difficult. We will not attempt to put down exact estimates here, but an idea about the magnitudes can be obtained by making comparisons with the increase in net taxes and the corresponding reduction in output levels when we move from OECD-wide regulations to regulations at the regional level (Table 4.3.1). For instance, in EU13 the increase in the net tax from 28 to 40 USD/tonne will amplify the fall in output from –6.5% to –16.5%. What then if the UK or France has its net taxes increased from 40 to 47 USD/tonne? By a simple extrapolation, we realise that the effect is likely to be very significant.

91. However, a simple comparison with the effect of unilateral taxes at the regional level is likely to underestimate the consequences of unilateralism at the country level. Consumers of steel will often find it easier to shift away from a domestic steel producer to a steel producer in a neighbouring country than to one in a completely different world region. Therefore, the competitive pressure from non-regulated countries is likely to be felt even stronger when environmental taxes are implemented at the country level.

92. In sum, these arguments suggest that the effect of unilateral taxes of 25 USD per tonne CO_2 in any single OECD country is likely to cause quite dramatic cutbacks in the level of BOF steel production. The effect on EAF steel production will probably not be particularly stronger than with OECD-wide regulations, though. In general, we would also expect unilateral policies to have less pronounced impacts in large countries than in small ones.

4.5 Exemptions for process related emissions

93. Emissions of CO_2 from the steel industry are partly related to the use of fossil fuels as a source of energy and partly to the use of fossil fuels as a chemical reducer. This section discusses the consequences of a tax on CO_2 emissions from the steel industry if only energy related emissions were taxed.

94. To make a distinction between energy related and process related emissions of CO_2 in steel production is far from a trivial task. In the blast furnace process, where the bulk of the emissions takes place, the chemical reduction process is closely intertwined with the use of energy. A number of processes are simultaneously going on in the furnace.[16] Some of these are pure energy producing processes, e.g. the combustion of coke in order to provide the heat needed for the process. However, part of the carbon dioxide (CO_2) that is produced in this combustion process may be converted into carbon monoxide (CO) higher up in the furnace where temperatures are somewhat lower. Carbon monoxide (CO) then enters into various chemical reduction processes, e.g., the reduction of hematite (Fe_2O_3) to wustite (FeO). These are energy releasing processes that also produce carbon dioxide (CO_2). Hence, some of the emissions of carbon dioxide from the energy producing process may in the end appear as process emissions. Should these emissions then be counted as process related or energy related emissions?

95. Our approach has been the following: We calculate the amount of carbon that is strictly needed in the chemical reduction process of iron making. Then we calculate the amount of CO_2 emissions that is

16 This section is based on Ecofys (2000).

connected with this carbon consumption.[17] All emissions of CO_2 that are not a direct result of the very chemical reduction process are counted as energy related emissions. This approach implies that we are using a “lower bound” estimate of the process emissions.[18]

96. The chemical reduction of iron oxide in the blast furnace involves emissions not only of CO_2 but also of CO (carbon monoxide). If released into the atmosphere, this CO gas will be transformed to CO_2. The CO gas released in the blast furnace process is, however, normally used as a source of energy in the steel plant. The CO_2 emissions that are produced in this process are counted as energy related emissions in our analysis. But since CO_2 will be formed anyway, it could alternatively be argued that these emissions should be counted as process emissions. This example clearly illustrates the difficulties involved in drawing the borderline between process related and energy related emissions.

97. In the blast furnace process the process related CO_2 emissions are calculated to 378 kg CO_2 per tonne pig iron.[19] In the standard EAF process, there is no reduction of iron oxide, and all emissions of CO_2 are therefore counted as energy related. When it comes to EAF processes based on directly reduced iron (DRI), we have to deduct the process emissions of CO_2. These are calculated to 396 kg CO_2 per tonne DRI.[20]

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17 Professor Leiv Kolbeinsen and Professor Johan Kristian Tuset at NTNU/SINTEF have assisted in these calculations.

18 Alternative approaches that would lead to higher estimates of process related emissions are conceivable. For instance, one might count as process emissions all the emissions from the use of fossil fuels that cannot technically be replaced by alternative energy sources. Process emissions might also include the emissions related to the carbon that is contained in the iron until it is released in the basic oxygen furnace.

19 One tonne liquid iron contains roughly 960 kg iron (Fe). The atomic weight of Fe is 55.8 g/mole. 17.2 kmole Fe is then needed per tonne iron. Iron usually enters the blast furnace process as sinter or pellets, with the chemical composition Fe_2O_3. Thus, 1.5 oxygen atom must be removed per Fe atom. The amount of oxygen to be removed is thus 25.8 kmole. The reduction process proceeds through stages. First, Fe_2O_3 is reduced to FeO with carbon monoxide as a reducer

$$Fe_2O_3 + CO \quad = \quad 2FeO + CO_2$$

Then, FeO is reduced to Fe with carbon as the reducing agent

$$2FeO + 2C \quad = \quad 2Fe + 2CO$$

In sum, two molecules of carbon are needed in order to reduce one molecule of Fe_2O_3 to 2Fe. In the process, one molecule of carbon monoxide (CO) and one molecule of carbon dioxide (CO_2) are produced. Thus, 2/3 of the oxygen is bound in CO_2 and 1/3 in CO, i.e., 17.2 kmole O in CO_2 and 8.6 kmole O in CO. Hence, in order to remove 25.8 kmole O, there will be emissions of 8.6 kmole CO_2 and 8.6 kmole CO. The atomic weights of CO and CO_2 are 28 and 44 g/mole respectively. Hence, there will be emissions of 378 kg CO_2 and 241 kg CO per tonne liquid iron.

20 The reducing agents in the DRI process are hydrogen (H_2) and carbon monoxide (CO), and the following reactions take place:

$$2\ Fe_2O_3 + 6H_2 = 4Fe + 6H_2O$$

$$2\ Fe_2O_3 + 6CO = 4Fe + 6CO_2$$

The reducing gases (CO and H_2 or syn gas) are produced from methane (CH_4) in the following process, using recycled CO_2 from the reduction process top gas in a reforming reaction:

$$3CH_4 + 3CO_2 = 6CO + 6H_2$$

The “total net reaction” describing the reduction work in the process is then:

$$4\ Fe_2O_3 + 3CH_4 = 8Fe + 3CO_2 + 6H_2O$$

98. In our simulations, the exemption for process related emissions is implemented by giving a tax rebate per unit of pig iron and DRI used in steel production. The tax rebate thus differs across regions. (Alternatively, the tax refund could have been made proportional to the use of fossil fuels, but this makes little sense as long as most of the variation in the use of fuels across plants is due to different levels of energy efficiency.) The exemptions for process related emissions, expressed in terms of the tax rebate per tonne crude steel, are shown in Table 4.5.1.

Table 4.5.1. Subsidy equivalent of exemptions for process related emissions (USD/tonne crude steel)

	EU 13	Rest of WEurope	North America	Japan	Australia and NZ
BOF steel	8.0	8.5	8.1	9.4	8.5
DRI based steel	4.3	-	4.2	-	-

99. Simulations with the SIM model show that exemptions for process related emissions in the OECD countries would have the following consequences on output levels.

Table 4.5.2. Change in production with exemptions for process emissions (%)

	BOF steel		Standard EAF steel		DRI based EAF steel	
	No exemption	Exemption	No exemption	Exemption	No exemption	Exemption
OECD	-12.5	-10.3	-1.7	-1.9	-7.3	-5.1
Non OECD	5.6	4.7	1.5	1.4	4.0	3.5
World	**-3.2**	**-2.6**	**-0.5**	**-0.6**	**0.4**	**0.8**

100. Not surprisingly, exemptions for process related emissions in the OECD countries would imply a smaller reduction in output of BOF steel. The change is not very large, though, reflecting that most of the CO_2 emissions from the steel industry are related to the consumption of energy.

101. Standard EAF steel production is not affected directly by the exemptions for process related emissions. Nevertheless, the levels of output decline both in OECD and Non-OECD countries due to a rise in the scrap price as BOF steel production expands.

102. For DRI based steel producers, there are several counteracting effects. The exemption for process related emissions is clearly an advantage. On the other hand, the rise in scrap prices increases the costs of production. In our simulations, the first effect clearly dominates. The exemption for process emissions thus offers an improvement of the competitiveness of DRI based producers relative to standard EAF producers, leading to a higher market share for DRI based steel production.

103. Figures 4.5.1, 4.5.2 and 4.5.3 show how the exemption for process emissions affects production levels in various regions.

In directly reduced iron, the Fe-content is close to 100%. With an atomic weight of 55.8 g/mole, the number of Fe atoms in a tonne DRI is 18 kmole. The amount of oxygen that must be reduced is thus 27 kmole O. Half of this amount (13.5 kmole) will leave the process in the form of CO_2, producing 6.75 kmole CO_2. The atomic weight of CO_2 is 44, and the CO_2 emissions related to the reduction work in this process are then 297 kg.

The main assumption for this calculation is that only CO_2 is used as oxidant for the syn gas production, giving a H_2/CO-ratio of 1. Using pure oxygen for this purpose will give a H_2/CO-ratio of 2, while use of H_2O gives H_2/CO-ratio of 3. A ratio close to 1 is most common since this is the most economical solution.

104. The effect of the exemption for process related emissions appears to be quite uniform across regions. This is due to the relatively small differences across OECD regions in terms of the amount of pig iron and DRI per tonne steel. These differences are likely to be even smaller after the implementation of CO_2 taxes than they are today. We notice that the effect of the exemptions on DRI based production in Non-OECD countries is quite modest. This reflects that exemptions for process related emissions will produce more than a relocation of DRI based production back into the OECD; DRI based steel production actually expands by capturing market shares from its competitors.

Figure 4.5.1. Change in BOF steel production with and without process exemptions (%)

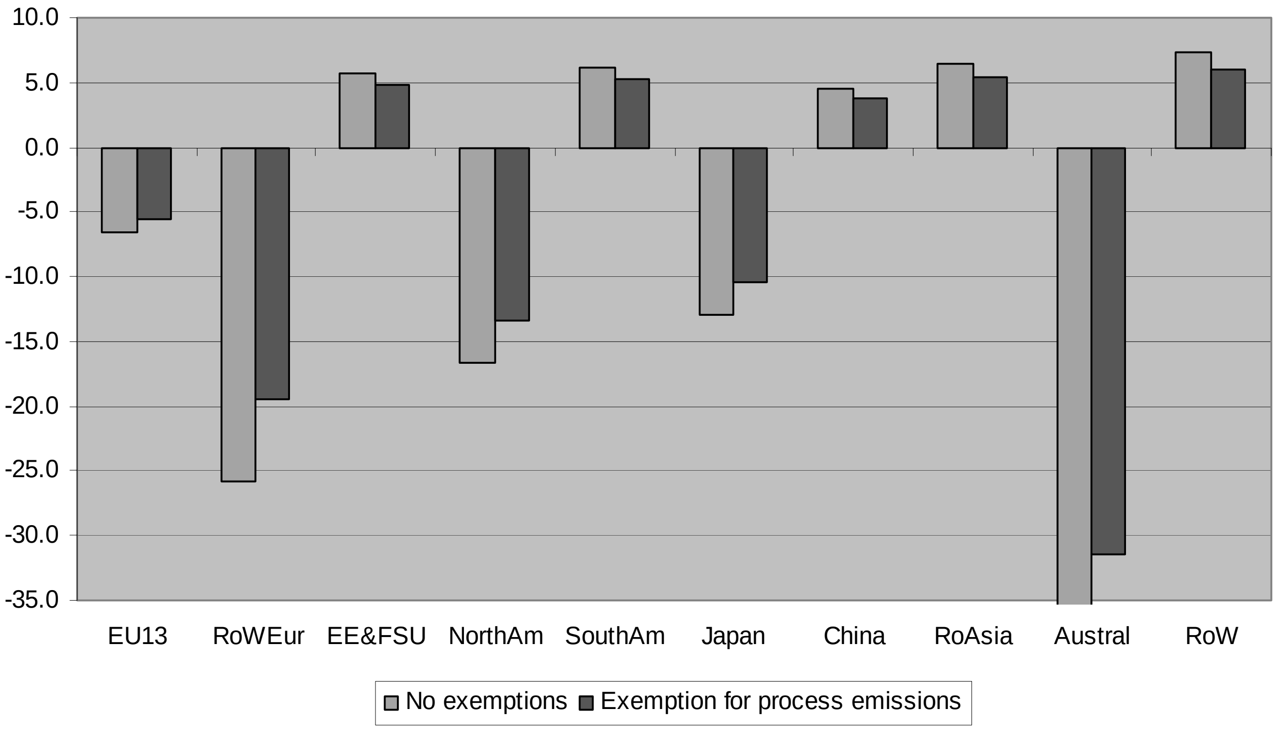


Figure 4.5.2. Change in standard EAF steel production with and without process exemptions (%)

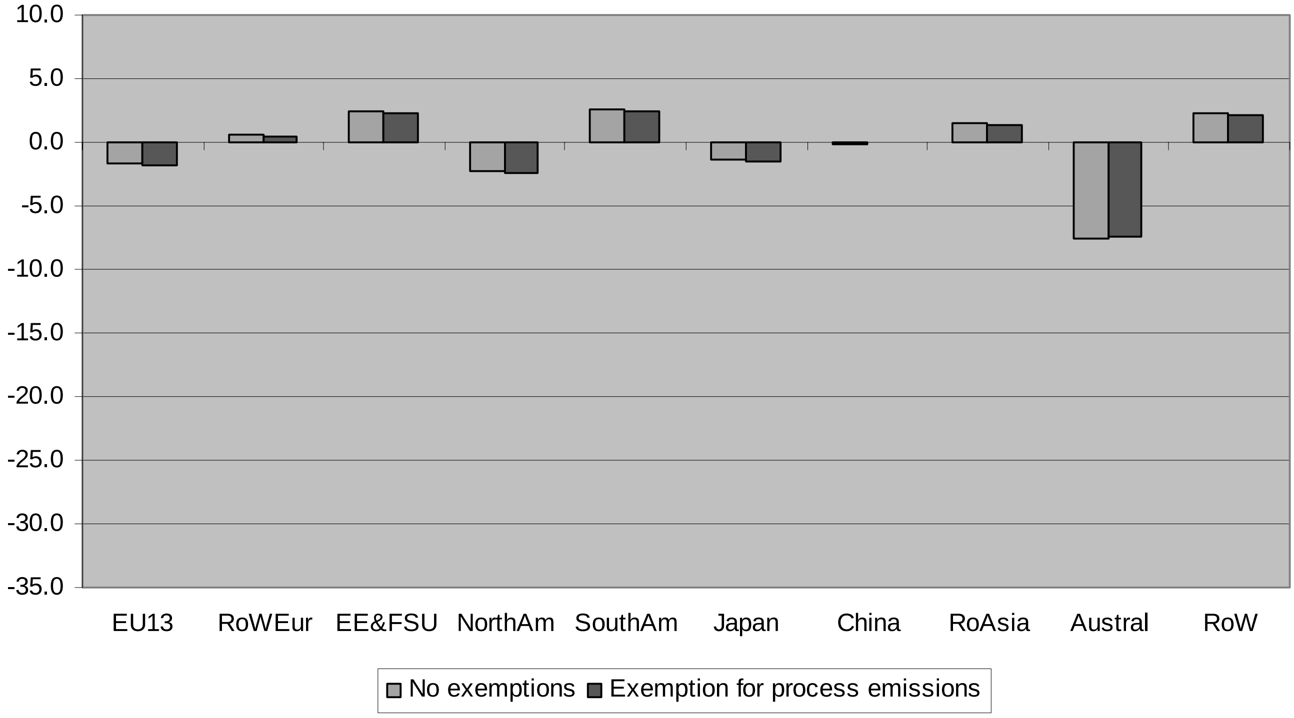
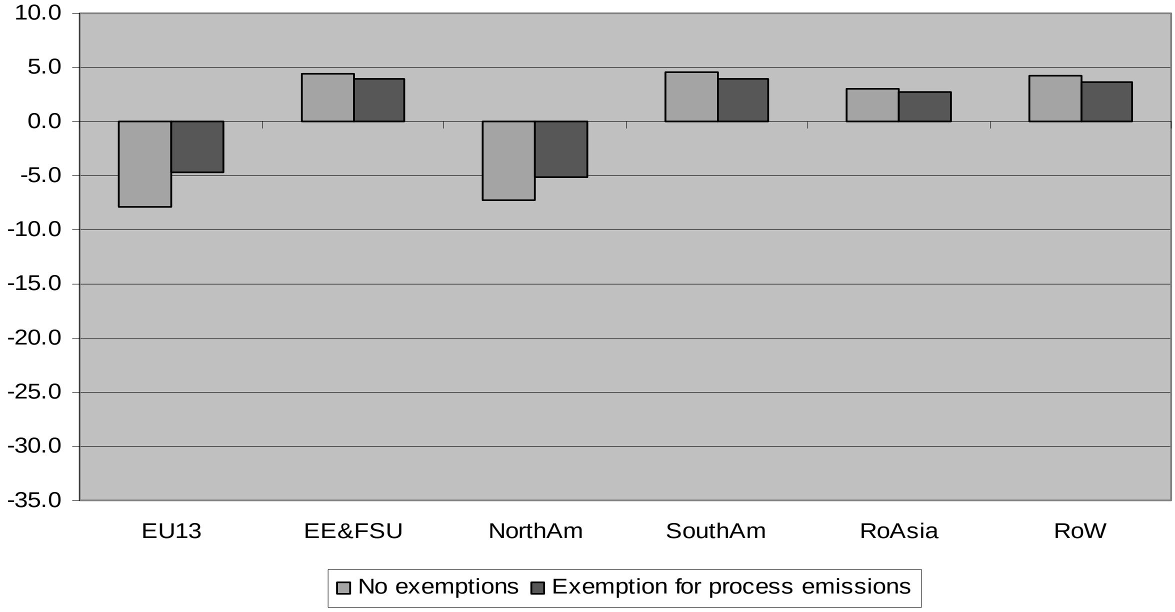


Figure 4.5.3. Change in DRI based EAF steel production with and without process exemptions (%)



4.6 Revenue recycling

105. A tax of 25 USD per tonne CO_2 in the steel industry will generate substantial revenues. Table 4.6.1 shows the calculated revenues in the case of an OECD-wide tax.

Table 4.6.1. Estimated tax revenues (mill USD)

	EU 13	Rest of WEurope	North America	Japan	Australia and NZ
BOF	4277	245	3010	3632	381
Standard EAF	616	26	551	329	20
DRI based EAF	34		283		
Total	**4927**	**271**	**3843**	**3961**	**402**

106. The analysis so far has assumed that taxes collected from the steel industry have been used on general public spending. In this section, we investigate the implications of transferring (part of) the tax revenues back to the industry.

107. The consequences of revenue recycling depend crucially on the design of the transfer scheme. The problem of defining a transfer scheme can be divided into two sub-problems:

a) How to define the aggregate transfer.

b) How to determine the share received by an individual firm.

Defining the aggregate transfer

108. There are two principally different ways of defining the aggregate amount of subsidy to be paid to the steel producers.

1. Exogenous amount (e.g., equal to (a fraction of) the historic emissions in the steel industry times the actual tax rate).

2. Endogenous amount (e.g. equal to (a fraction of) the total CO_2 taxes actually paid by the industry, which is actual emissions times the actual tax rate).

109. The important difference between these approaches is that when the transfer amount is determined endogenously, the steel industry itself will be able to affect the aggregate subsidy. Since any emission reducing efforts will also reduce the subsidy payment, incentives to abate are weakened. However, as long as each individual steel producer is small relative to the total steel production in the region, this weakening of abatement incentives will be negligible. In our analysis, where the regions are quite large, it is therefore natural to assume that even if the subsidy amount is endogenously defined, there will be negligible effects on the individual firm's incentives to abate. However, if such policies are implemented at the national level, there is clearly more reason to worry about reduced abatement incentives in the case of an endogenous subsidy.

110. Given the assumption that abatement incentives are not affected by the choice between the two approaches, the only difference is that the aggregate subsidy may differ. The first approach would require financing from other sources as long as the refund rate is set to 100%. But the refund rate may of course be set below 100%. It is also possible to define, ex ante, a declining level of aggregate subsidy to the industry over a given time frame (e.g., 5-10 years). In our simulations, we have explored the effect of 1) a 100% refund rate based on historic emissions, 2) a 100% refund rate based on actual emissions, and 3) a 50% refund rate based on actual emissions.

Defining the share received by an individual firm

111. The share of the subsidy received by an individual firm can be related both to the use of inputs (e.g., capital and labour) or to the level of output. Since the SIM model does not include the use of these inputs explicitly, we will constrain our analysis to the transfer schemes based on output levels. Again, there are two principally different approaches that can be chosen:

1. Share based on historic production.
2. Share based on actual production.

112. If historic emissions are used as the allocation rule, the subsidy will have the same effect as a pure capital transfer to the firms. The only effect would be to increase equity values; the subsidy would have no effect whatsoever on output and the use of inputs. Even to close a plant and move to another region will not affect the subsidies received. Our preceding results are therefore valid also for the case with revenue recycling based on historic production levels.

113. An allocation rule based on historic emissions – in its pure form – is not a very likely policy alternative. There will most likely be additional constraints on the refund scheme, for instance that production level in the home region should be kept above a certain level in order to become eligible for subsidies. Such a scheme can be interpreted as a combination of allocations based on historic and actual emissions. In the following, we will constrain our attention to schemes where the allocation of tax revenues to individual firms is based on actual production. Such a revenue recycling scheme is equivalent to a pure output subsidy.

114. An important issue in the practical implementation of revenue recycling schemes in the steel industry will be whether subsidies per unit of output within a region should be differentiated across technologies or not. If the subsidy rate is the same across all firms, the scheme will implicitly favour the less polluting technologies, by leaving the relatively clean producers with a negative net tax burden. We have simulated the effect of both a non-differentiated and a differentiated system. In the non-differentiated

system, all firms in a region receive the same output subsidy per unit. In the differentiated system, there are different subsidy rates for the three technologies and there is no cross subsidising, implying that the amount received by firms with technology *t* does not exceed the aggregate tax payments paid by these firms. For the case of 100% revenue recycling of the actual tax payment, the distinction between a differentiated and non-differentiated system can be expressed formally as follows;

No differentiation of subsidy: $$s_r = \sum_i \sum_t T_{itr} / \sum_i \sum_t x_{itr}$$

Differentiation of subsidy: $$s_{tr} = \sum_i T_{itr} / \sum_i x_{itr},$$

where *s* is the subsidy rate per unit of output and x_{itr} and T_{itr} are the production and the tax payments of firm *i* with technology *t* in region *r*.

115. Figures 4.6.1 and 4.6.2 show the effect of revenue recycling on BOF steel production and standard EAF steel making, respectively. The figures compare the change in production without revenue recycling with three different schemes of revenue recycling; first, an output subsidy determined by historical emissions, and secondly an output subsidy determined by actual emissions. In both these schemes, there is no differentiation of the rate of subsidy across technologies. The final scheme considers the case where the output subsidy is differentiated across technologies and based on actual emissions. A case with recycling of 50% of the collected taxes has also been simulated, and results are reported in the Appendix. Not surprisingly, the figures lie approximately in the middle between the case of no recycling and the case of full recycling.

116. Revenue recycling turns out to have a potentially large effect on output levels. Much of the output reduction caused by the environmental tax can be eliminated through output subsidies. With refund scheme (3), i.e., a 100% refund of actually paid taxes, differentiated across technologies, BOF steel production in the OECD declines by only 0.5%, as compared to 12% without recycling.

Figure 4.6.1. Change in BOF production with and without revenue recycling (%)

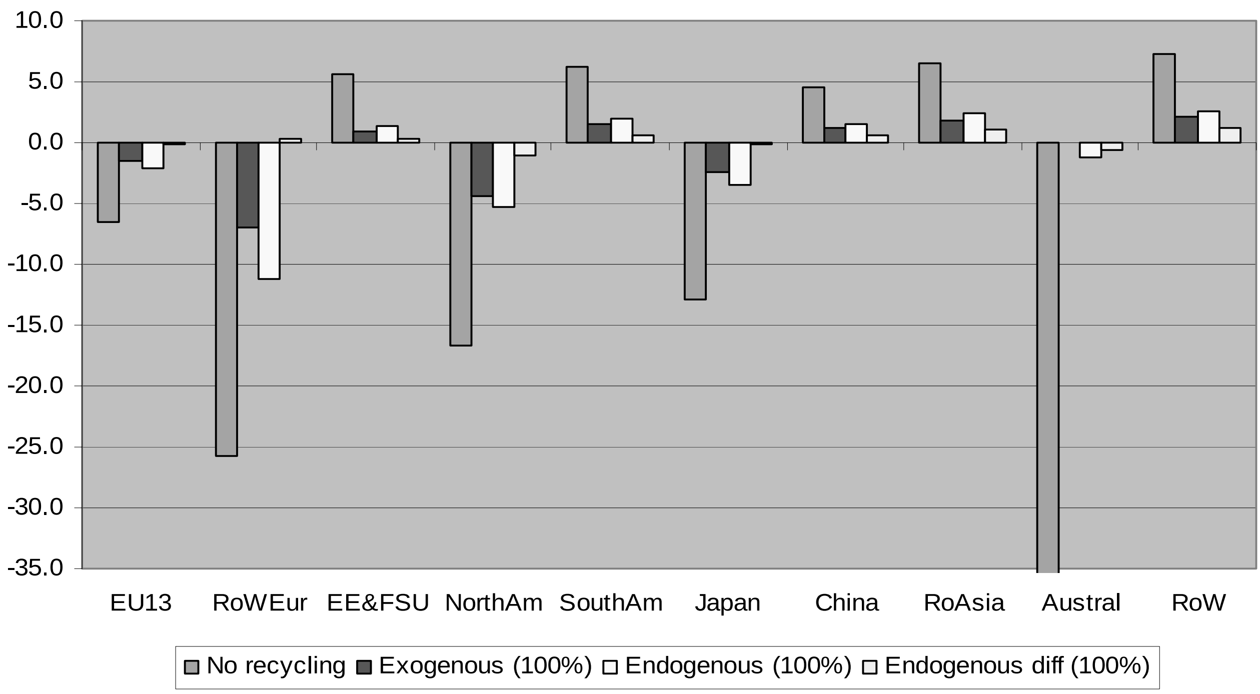
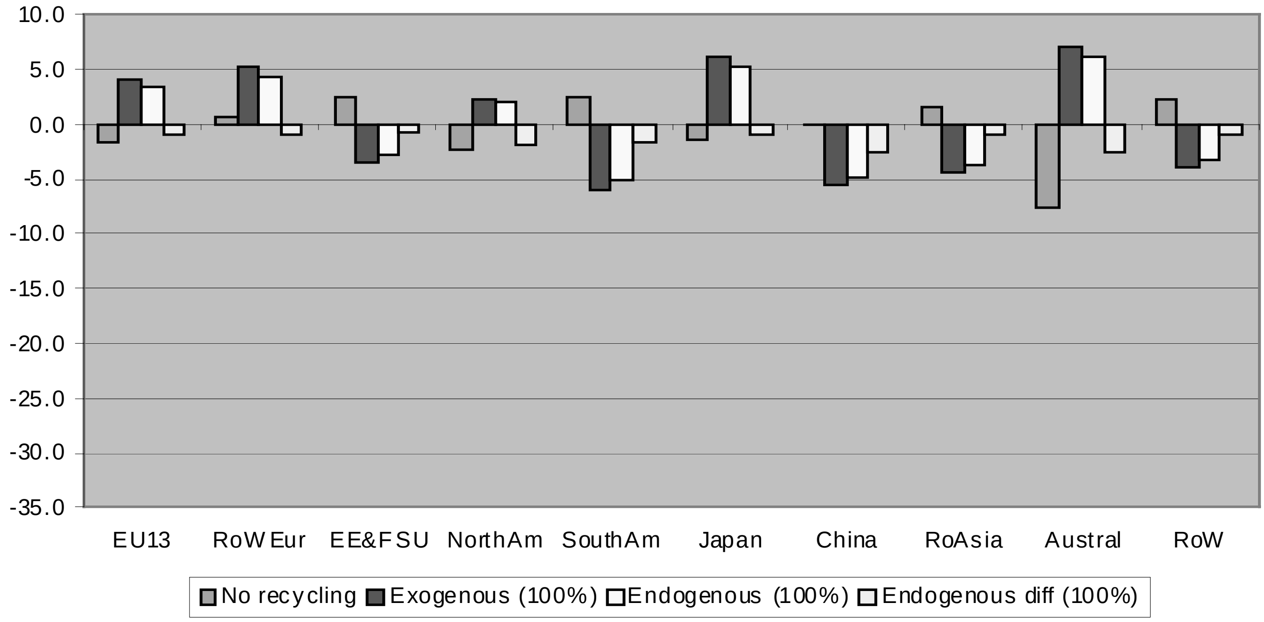


Figure 4.6.2. Change in standard EAF steel production with and without revenue recycling (%)



117. The fall in production in standard EAF steel production is much less affected by revenue recycling, though. Under refund scheme (3), OECD production is reduced by 1.3%, compared to 1.7% in the case with no revenue recycling. The small effect of revenue recycling on EAF steel production may appear surprising at first glance. Recall that emissions in EAF steel production are modelled as strictly proportional to the output level. A tax on emissions is therefore equivalent to an output tax. To collect emissions taxes and distribute them back as an output subsidy should therefore have no effect whatsoever on this sector, everything else being the same. Again, the explanation is to be found in the scrap market. The scrap price will typically increase more with revenue recycling than without. In our simulations, the scrap price increases by 8-9% with revenue recycling, and by only 5% without, primarily due to higher output levels in BOF steel production. Hence, revenue recycling puts an additional cost burden on EAF steel producers.

118. Despite the extra cost burden for EAF steel producers in the case of revenue recycling, revenue recycling without differentiation implies a net stimulus to this part of the industry. In the absence of differentiation, there will be a negative net tax burden on the EAF producers due to their relatively low emission level. This net subsidy is large enough to outweigh the effect of higher scrap prices. As a result, standard EAF steel production in the OECD is predicted to increase by 3.5-4.1%, depending on whether or not the refund is based on actual or historic emissions. As for BOF steel production, the lack of differentiation of the output subsidy has the opposite effect; the net tax burden will be higher and production will be lower than with a differentiated subsidy.

119. Revenue recycling comes at a cost of reduced environmental benefits. As shown in Table 4.6.2, global emissions are reduced by only 3% with 100% revenue recycling, compared to 4.6% without recycling. A more positive interpretation of the results would be to say that quite substantial emission reductions are attainable even with minor changes in output levels. With 100% revenue recycling, total OECD steel production declines by 1.1% or less, while the fall in production was 8.8% without recycling.

Admittedly, the emission reductions in OECD are about halved. But due to a reduction in the leakage rate from 45% to 28% [with refund scheme (3)], global emissions reductions do not fall correspondingly.

Table 4.6.2. Change in CO_2 emissions (%)

	OECD	Non OECD	World
No recycling	-19.3	6.4	**-4.6**
Exogenous (100%)	-10.3	2.4	**-3.0**
Endogenous, no differentiation (100%)	-11.1	2.8	**-3.1**
Endogenous, with differentiation (100%)	-9.3	1.9	**-2.9**
Endogenous, with differentiation (50%)	-13.9	4.1	**-3.6**

120. It is interesting to note that refund schemes without differentiation of the output subsidy across technologies imply somewhat larger emission reductions than do differentiated policies. The reason, of course, is that undifferentiated policies involve a stronger substitution from BOF steel towards EAF steel due to cross-subsidies. The surprising result is perhaps that the difference is not greater than it actually is. The explanation is that a relatively strong restructuring of the steel sector in the OECD countries is counteracted by higher emissions in Non-OECD countries, leading to small differences in global emissions change.

4.7 Border tax adjustments

121. An alternative way of preventing a weakening of the competitiveness of domestic steel producers in the wake of environmental taxes would be to implement border taxes, i.e., import taxes and/or export subsidies, on the trade flows to and from regions that do not implement such taxes.

122. Theoretical studies have shown that when global environmental problems are attempted solved by only a subset of the countries involved, it might be economically efficient to implement border taxes (e.g., Hoel (1996), Mæstad (1998)). The economic justification for border tax adjustments is that unilateral solutions to global environmental problems cause environmental leakage due to a weakening of the competitiveness of domestic firms. The most efficient way of coming to grips with the leakage problem (apart from implementing environmental regulations in all countries) is to address the issue of loss of competitiveness directly through border taxes and subsidies. The theoretical studies have demonstrated that this approach is a more efficient way of reducing leakage, both from a domestic point of view and from a global point of view, than by lowering the environmental tax rate or by subsidising output.

123. The impacts of six different forms of border tax adjustments have been simulated. In all cases, the border taxes are implemented only on trade flows between OECD regions and Non-OECD regions. There are no border taxes on the trade among OECD countries, because all these countries implement the environmental tax. The five different border tax schemes are:[21]

124. An import tax in the OECD regions corresponding to the average emissions per tonne steel in the importing region.

I. An import tax in the OECD regions corresponding to the average emissions per tonne steel in the exporting region.

[21] Some of these regulations imply different border taxes for the same product in different regions. In such cases, a certificate of origin would be needed in order to prevent steel from being imported into a low tariff region and then be re-exported to other regions with higher border taxes.

II. An import tax in the OECD regions that differentiates between BOF steel and EAF steel and corresponds to the emission level per tonne steel for the respective production technologies in the exporting region.

III. An export subsidy in the OECD regions corresponding to the emission level per tonne steel in the exporting region and with differentiation between BOF and EAF steel.

IV. The combination of an import tax of type (III) and an export subsidy (IV).

V. The combination of an import tax of type (III) and an export subsidy that corresponds to the emission level per tonne steel in the importing region and with differentiation between BOF and EAF steel.

125. From an efficiency point of view, border tax adjustments should include both import taxes and export subsidies. Moreover, the tax and subsidy rates should relate to emission levels in the non-regulated countries, because the rate of leakage is related to the emission levels in these countries. Only the latter of these policy alternatives fulfils both these requirements. However, such a policy could easily be undermined by re-exports among non-regulated countries; OECD producers would be tempted to export to countries with high pollution levels before shipping the products further to their final destinations.

126. Table 4.7.1 displays the effect of environmental taxes on aggregate steel production with various border tax adjustment schemes. We notice that border taxes are successful in dampening the negative impact on OECD steel production. In particular, import taxes based on emission levels in the exporting regions (II and III) turn out to be effective. This is partly a consequence of relatively high emissions per tonne steel in Non-OECD regions.

Table 4.7.1. Change in production levels with border tax adjustments (%)

	OECD	Non OECD	World
No border tax	-8.8	4.6	**-2.3**
(I) Import tax, based on average emissions in importing country	-6.0	2.3	**-2.0**
(II) Import tax, based on average emissions in exporting country	-4.7	1.4	**-1.8**
(III) Import tax, based on emissions by product in exporting country	-4.6	1.4	**-1.7**
(IV) Export subsidy based emissions by product in exporting country	-6.2	2.7	**-1.9**
(V) = (III) + (IV)	-2.2	-1.2	**-1.7**
(VI) = (III) + export subsidy, based emissions by product in importing country	-1.0	-2.6	**-1.8**

127. By combining import taxes based on emissions in the exporting country with export subsidies, the reduction in OECD steel production can be brought down from –8.8% to –1.0%. The reduction in world steel production will then be –1.8%, as compared with –2.3% without border tax adjustments. The small effect of border taxes on world steel production reflects that the achievement of border taxes essentially is to prevent the relocation of steel production to Non-OECD countries. In fact, environmental taxes in the OECD combined with border tax adjustment schedules (V) and (VI) will reduce steel production both in the OECD and in Non-OCED regions.

128. Figures 4.7.1 and 4.7.2 show the effect of border taxes on BOF and EAF steel production in the various OECD regions.

129. As expected, border taxes that are based on average rather than technology specific emission levels typically favour the least polluting producers. Thus, moving from undifferentiated taxes to technology specific differentiation is favourable for BOF producers and unfavourable for EAF producers.

130. We also observe that in regions with relatively low emission levels (Europe and North America) it is advantageous for domestic producers to relate the import tax to the emission level in the exporting region rather than the importing one.

Figure 4.7.1. Change in BOF steel production with border tax adjustments (%).

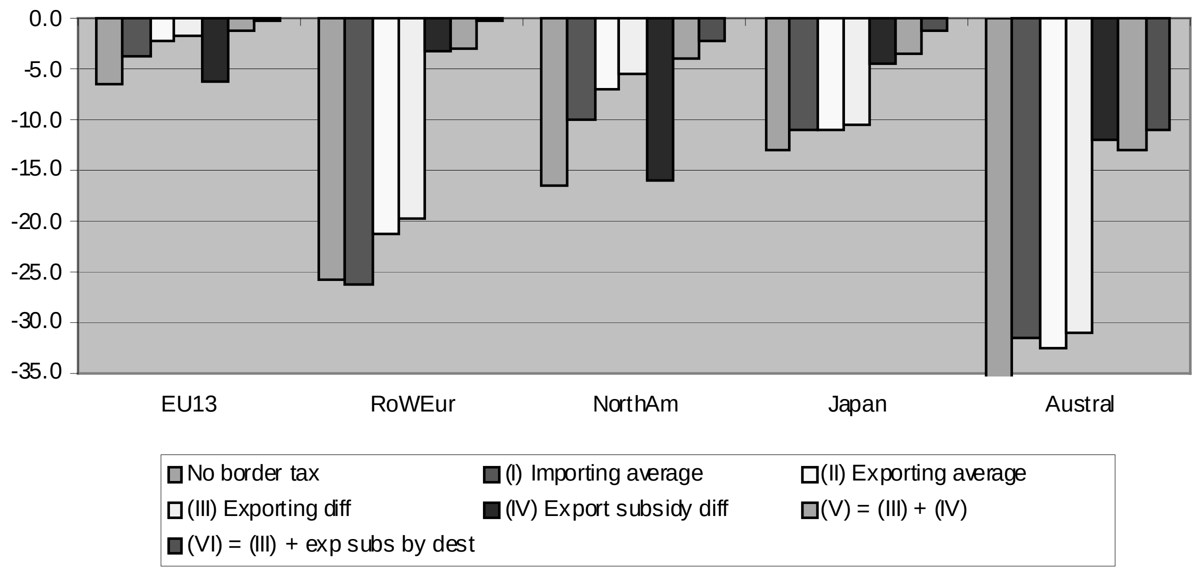
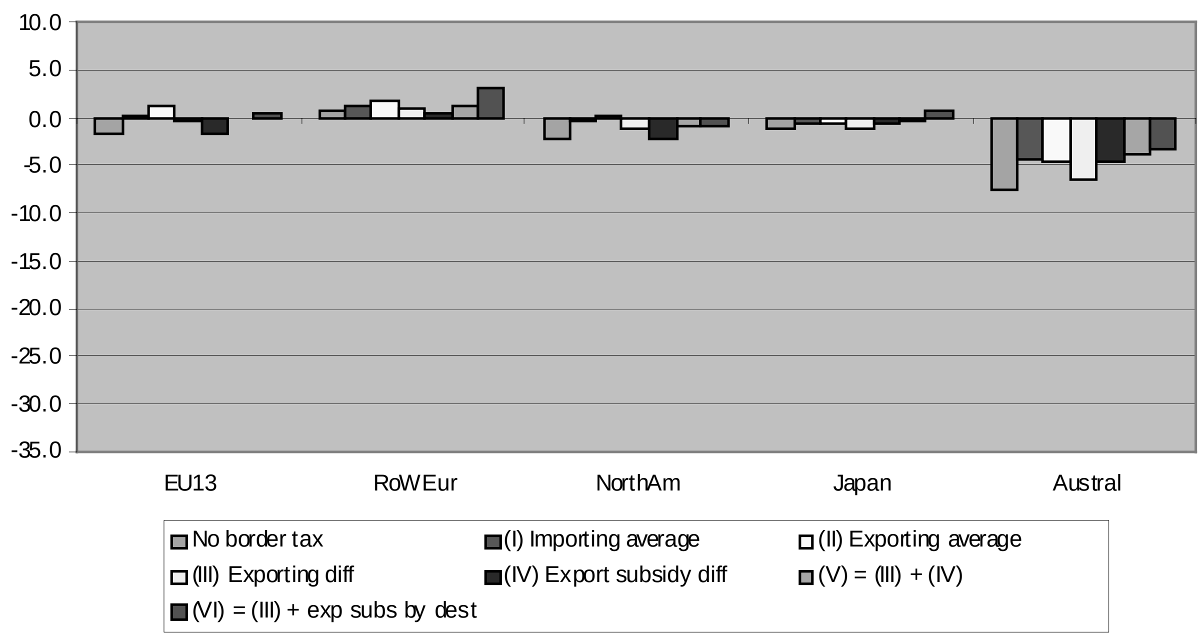


Figure 4.7.2. Change in standard EAF steel production with border tax adjustments (%)



131. Export subsidies turn out to have quite different impacts across regions. While output in most regions is clearly stimulated by export subsidies, this effect is almost absent in EU13 and North America. The main explanation is probably that only a small fraction of total production is exported in these regions, especially in North America, where the exports share in our base year was only 3%. In the choice between import taxes and export subsidies as a means to stimulate domestic steel production, these regions are therefore likely to prefer import taxes.

132. Quite interesting results are obtained as to the effect of border taxes on emission levels. As a matter of fact, the use of border tax schedules (V) and (VI) (i.e., the combination of import taxes and export subsidies) will lead to larger emission reductions than will environmental taxes alone. Border tax adjustments increase the share of world steel production that takes place in the OECD. Since steel producers in the OECD pay environmental taxes, a larger share of world steel producers will then have incentives to abate. Although border tax adjustments will increase domestic emissions in the OECD, they may therefore reduce global emissions.

Table 4.7.2. Change in CO_2 emissions with border tax adjustments (%)

	OECD	Non OECD	World
No border tax	-19.3	6.4	**-4.6**
(I) Import tax, based on average emissions in importing country	-16.3	4.3	**-4.4**
(II) Import tax, based on average emissions in exporting country	-14.9	3.4	**-4.4**
(III) Import tax, based on emissions by product in exporting country	-14.4	3.1	**-4.3**
(IV) Export subsidy, based on emissions by product in exporting country	-16.0	4.4	**-4.3**
(V) = (III) + (IV)	-11.3	0.1	**-4.7**
(VI) = (III) + export subsidy based on emissions by product in importing country	-10.0	-1.4	**-5.1**

133. When compared to revenue recycling as a means of avoiding relocation of production between OECD and Non-OECD countries, border tax adjustments appear to be better suited to ensure a level playing field at the same time as environmental benefits are attained. This is in line with the results from the theoretical literature discussed above.

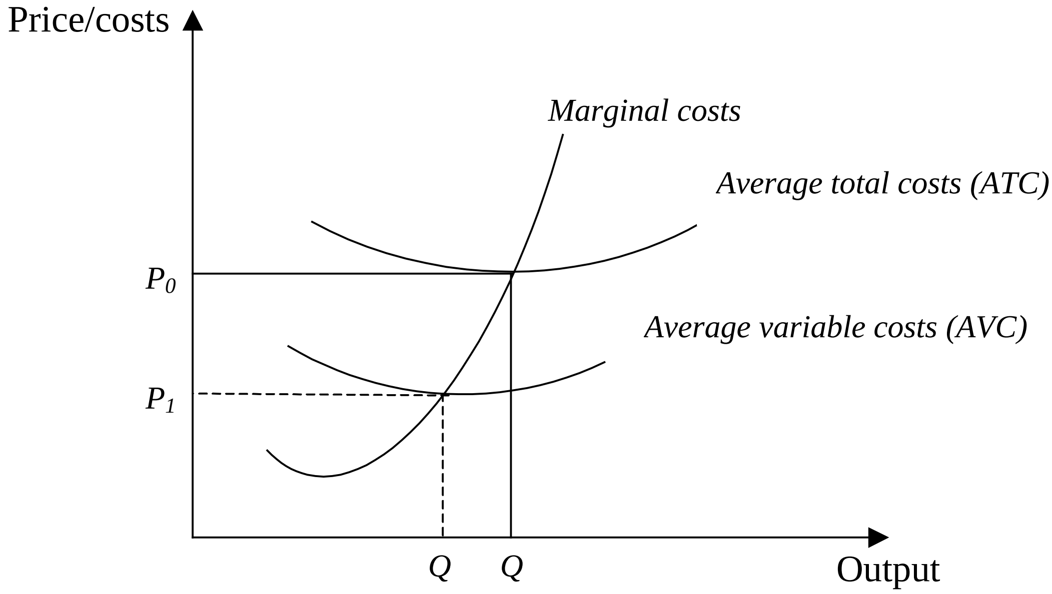
4.8 Long-term effects of climate policies

134. The analysis above was conducted with a focus on adjustments that may take place within a time horizon of only a few years. No account was taken of the fact that the substantial shifts in the costs structure of the steel industry that is brought about by a CO_2 tax of 25 USD/tonne may induce closure of plants in the regulated economies and investments in new capacities in regions without such taxes. Neither did the analysis take into account tax-induced technological change towards less emission intensive processes. In order to perform a long-term analysis, the SIM model would have to be reformulated, incorporating the investment and disinvestment behaviour of steel producers, including the investment in R&D and the investments in cleaner technologies. That is beyond the scope of this study.

135. In an industry with free entry and exit, a long-run equilibrium will be characterised by the price of outputs being equal to the average production costs of the marginal firm. If the price is higher than this, it will be profitable to increase investments and expand capacities. If the price is lower than average costs, it will not be profitable to maintain the production capital, and the production capacity will gradually be phased out. If the price does not even cover the average variable costs of production, production will be closed down immediately. Figure 4.8.1 illustrates.

136. A profit maximising firm with no market power will choose its level of output so that the marginal costs of production are equal to the price. Since the average total costs per unit are also equal to the price in the long-run equilibrium (see above), the long-run equilibrium output must be Q_0. The margin between the average total costs and average variable costs covers the fixed costs of production. When environmental taxes are imposed, the costs curves will shift upwards. And as we have seen from the simulations; so will the steel price. However, the margin between the steel price and the average variable costs will decline. The total effect can be illustrated in the figure by reducing the price below P_0.[22] A small decline in the price will make it profitable to reduce output along the marginal cost curve; the price P_1 will induce the output level Q_1. However, if the price falls below P_1, the average variable costs exceed the price, and production will no longer be profitable. The plant will then be closed down.

Figure 4.8.1. Long-term equilibrium



137. From this simple diagram, we realise that in an industry where there are high fixed costs of production, the long-run equilibrium entails a substantial margin between the average total costs and the average variable costs. Thus, a substantial reduction in the margin between price and marginal costs is needed in order for firms to close production plants.

138. Our data indicate that the level of fixed costs is around 40-50 USD/tonne in BOF steel production and 25-30 USD/tonne in EAF steel making. These figures provide a very rough estimate of how much the price/cost margin of steel must drop in order to make it profitable to close a steel plant. However, there are also considerable fixed costs of closing a steel plant that must be taken into account.

139. A CO_2 tax of 25 USD/tonne CO_2 in the OECD countries is estimated to increase production costs as reported in Table 4.8.1. These figures take into account the cost effects of changes in the input mix and input prices.

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22 This simplification will not capture the effect of a change in the input mix, but this is a minor point in this discussion.

Table 4.8.1. Cost effect of CO_2 taxes in the OECD (USD/tonne)

	BOF steel	Standard EAF steel	DRI based EAF steel
EU (excl. Sweden and Finland)	46.4	17.9	25.6
Rest of Western Europe	46.1	11.6	-
Eastern Europe and FSU	-0.5	5.6	1.4
North America	48.1	19.9	27.7
South America	-2.6	6.2	0.1
Japan	54.1	15.5	-
China	-4.4	6.2	-
Rest of Asia	-5.4	4.9	0.6
Australia and NZ	59.4	23.2	-
Rest of world	-3.5	4.0	-0.8

140. These figures suggest that if steel prices are unaffected by the tax, a CO_2 tax of 25 USD/tonne CO_2 may bring BOF steel producers close to the limit where it is profitable to close their production plants. The impact on EAF steel producers is not as dramatic as that, although DRI based production may seem to be threatened.

141. The assumption of constant output prices is not a realistic one. In our model simulations, the producer price of steel in the affected regions will increase considerably, both due to a general increase in world steel prices as production expands in non-regulated regions and because the steel producers that are taxed will be able to exploit the differentiation of steel products to increase their prices beyond the general rise in world market prices. Table 4.8.2 summarises how the implementation of CO_2 taxes in the OECD regions will affect the margin between steel prices and variable costs of production in our short run analysis.[23]

Table 4.8.2. Change in price/variable cost margin (USD/tonne)

	BOF steel	Standard EAF steel	DRI based EAF steel
EU (excl. Sweden and Finland)	-15	-3	-11
Rest of Western Europe	-10	2	-
Eastern Europe and FSU	21	6	10
North America	-10	-4	-12
South America	27	5	11
Japan	-19	-3	-
China	20	0	-
Rest of Asia	25	3	7
Australia and NZ	-12	-9	-
Rest of world	27	5	10

23 These figures do not take into account that changes in production levels will affect the average variable costs. Average variable costs will be reduced in countries that reduce their production levels, because firms move downwards on their marginal cost curves. The converse is true in countries where production expands. The changes in average costs are, however, quite small, usually in the range between 1-2 USD or less per tonne steel for BOF producers. Even smaller changes are expected for EAF steel producers, because their production volumes do not change much.

142. These figures suggest that there is little reason to believe that the price/cost margin will be reduced so much that closure of steel plants will become a profitable alternative in the OECD countries in the short run. But one should be aware that these results hinge on the presumptions that higher steel prices are needed on the world market in order to stimulate Non-OECD steel production sufficiently in the short run, and that steel products are sufficiently differentiated to make it possible for the regulated regions to increase their steel prices somewhat above the world average without too much loss in output.

143. What will then happen in the long run? As can be seen from Table 4.8.1, the price/cost margin of Non-OECD producers will increase considerably as environmental taxes are imposed in the OECD. This will stimulate the investment in new capacities. When capacities become higher, production may expand with a smaller increase in marginal costs. In the long run, therefore, a smaller increase in world market prices of steel is needed in order to sustain higher production levels in Non-OECD countries. This implies that the reduction in the price/cost margin in the OECD countries will be more pronounced in the long run.

144. Our estimate of the short-run increase in the world market price of steel may serve as a crude measure of the maximal reduction in world market prices when moving from the short-run to the long-run equilibrium. These price changes are shown in Table 4.2.3 and correspond to the increase in marginal costs in Non-OECD countries. By adjusting the figures in Table 4.8.2 correspondingly, we arrive at the following maximum reduction in price/cost margins in the long run.

Table 4.8.3. “Maximum” long-run reductions in price/cost margin (USD/tonne)

	BOF steel	Standard EAF steel	DRI based EAF steel
EU (excl. Sweden and Finland)	-33	-11	-20
Rest of Western Europe	-29	-6	-
North America	-28	-12	-21
Japan	-37	-11	-
Australia and NZ	-31	-17	-

145. If the steel industry is in a long-run equilibrium at the time when environmental taxes are implemented, the margin between price and variable costs will be significantly reduced, especially for BOF steel producers. However, there is little reason to believe that there will be extensive closure of firms. There are considerable sunk investments in the steel industry, and higher taxes than 25 USD/tonne CO_2 will therefore be needed in order to make it profitable to close an established steel plant.

146. In the OECD countries, investments in new green-field plants for BOF steel making may seem to be somewhat unlikely at the tax rates considered here. In EAF steel making, on the other hand, the margin earned by the most efficient producers will probably be large enough to cover the fixed costs of production, thus making a further expansion of this segment profitable also within the OECD region. In the long run, we therefore envisage a stronger restructuring of OECD steel making capacity towards EAF steel. BOF steel producing capacities will decline, while EAF steel production will increase. The rate of reduction in BOF capacity depends critically on the profitability of investing in the maintenance of the existing production capacity. Unfortunately, we do not have data that can assist us further on this issue.

147. In a study of the German steel industry, Lutz *et al.* (2002) conclude that a CO_2 tax of the magnitude discussed in this paper will induce significant technological development towards cleaner production processes. In addition to innovations within existing technological paradigms, there are also possibilities of further developing new technological paradigms with lower emission rates, such as the “smelting reduction technology”. Hence, the burden of CO_2 taxes is likely to be reduced in the long run, making closure of firms less likely than it otherwise would be.

148. To take a long-run equilibrium as the starting point of our analysis of the consequences of environmental taxes in the steel industry may appear somewhat odd. The steel industry has for years been plagued by excessive over-capacity and low price/cost margins relative to what is needed to cover the fixed costs of production. A number of US firms have recently gone bankrupt. Thus, the present structure of the industry cannot be characterised as a long-term equilibrium. Most likely, therefore, the future will hold closure of capacity and significant industry restructuring, independently of the implementation of environmental taxes.

149. Environmental taxes may affect the industry differently when structural imbalances are present at the outset. For instance, the implementation of CO_2 taxes may trigger off a wave of firm closures that otherwise would have been postponed to a later date. Environmental taxes might thus speed up the restructuring process. But it is important to bear in mind that firm closures that then appear as a consequence of the environmental tax in reality are inevitable consequences of more fundamental imbalances in the structure of the industry.

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APPENDIX

Tables A.1 and A.2 provide an overview of our results about changes in production and emission levels in the various policy experiments.

Some explanations:

World tax

A hypothetical scenario where an environmental tax of 25 USD per tonne CO_2 is imposed in all regions of the world

Unilateral tax

Environmental tax implemented in one single region at a time

Revenue recycling

A = Exogenous amount based on historic emissions, 100% recycling, no differentiation between technologies
B = Endogenous amount, 100% recycling, no differentiation between technologies
C = Endogenous amount, 100% recycling, differentiation between technologies
D = Endogenous amount, 50% recycling, differentiation between technologies

Border tax adjustments

I = Import tax equal to average emission factor in importing country
II = Import tax equal to average emission factor in exporting country
III = Import tax defined by emissions by steel type in exporting region
IV = Export subsidy equal to domestic emission tax
V = The combination of III and IV
VI = The combination of III and an export subsidy based on emissions by steel type in importing region

Table A.1. Change in steel output levels (%)

	Base year production (mill tonne, 1995)	World tax	OECD-wide tax	Uni-lateral tax	Energy tax	Revenue recycling				Border tax adjustments					
						A	B	C	D	I	II	III	IV	V	VI
BOF steel															
EU (excl. Sweden and Finland)	95.846	0.0	-6.5	-16.5	-5.6	-1.6	-2.2	-0.2	-3.6	-3.8	-2.3	-1.7	-6.1	-1.1	-0.2
Rest Western Europe	5.621	0.3	-25.8	-70.6	-19.5	-6.9	-11.3	0.4	-6.8	-26.1	-21.3	-19.9	-3.1	-2.9	-0.2
Eastern Europe and FSU	101.473	-4.1	5.7	n.a.	4.8	0.9	1.4	0.3	2.9	3.1	1.8	1.3	3.5	-1.9	-3.0
North America	70.162	-2.4	-16.7	-26.3	-13.3	-4.5	-5.3	-1.1	-8.2	-10.2	-7.0	-5.4	-15.9	-3.9	-2.2
South America	23.777	-6.9	6.2	n.a.	5.2	1.5	2.0	0.6	3.4	3.6	2.4	1.5	4.2	-2.1	-3.3
Japan	68.842	-0.8	-12.9	-25.2	-10.5	-2.4	-3.4	-0.2	-5.8	-11.1	-11.0	-10.4	-4.5	-3.4	-1.4
China	77.250	-32.9	4.6	n.a.	3.9	1.2	1.5	0.6	2.5	2.9	2.0	1.7	2.7	-1.2	-3.9
Rest of Asia	48.813	-2.5	6.5	n.a.	5.5	1.9	2.3	1.1	3.7	4.3	3.6	3.0	4.0	-0.4	-1.1
Australia	8.030	-11.1	-35.5	-54.9	-31.4	0.0	-1.2	-0.7	-16.9	-31.6	-32.6	-31.2	-12.1	-12.9	-11.2
Rest of world	9.331	-5.9	7.3	n.a.	6.0	2.1	2.6	1.2	4.1	5.5	4.9	4.3	3.3	0.1	-1.8
World BOF steel	**509.145**	**-7.1**	**-3.2**	**n.a.**	**-2.6**	**-0.6**	**-0.9**	**0.1**	**-1.4**	**-2.7**	**-2.4**	**-2.3**	**-2.4**	**-2.2**	**-2.2**
OECD BOF steel	*248.501*	*-1.3*	*-12.5*	*n.a.*	*-10.3*	*-2.7*	*-3.6*	*-0.5*	*-6.0*	*-9.0*	*-7.4*	*-6.6*	*-8.5*	*-3.0*	*-1.5*
Non OECD BOF steel	*260.644*	*-12.6*	*5.6*	*n.a.*	*4.7*	*1.3*	*1.7*	*0.6*	*3.0*	*3.4*	*2.4*	*1.8*	*3.4*	*-1.4*	*-2.9*
Standard EAF steel															
EU (excl. Sweden and Finland)	50.386	-0.2	-1.6	-2.5	-1.8	4.0	3.5	-0.8	-1.3	0.3	1.1	-0.2	-1.6	0.0	0.5
Rest Western Europe	4.419	2.5	0.7	-2.5	0.4	5.2	4.4	-0.9	-0.2	1.2	1.9	1.1	0.5	1.3	3.1
Eastern Europe and FSU	23.204	-1.9	2.5	n.a.	2.3	-3.5	-2.9	-0.7	0.8	-0.7	-2.2	0.2	1.2	-0.8	-1.6
North America	40.159	-2.4	-2.2	-1.1	-2.5	2.3	1.9	-1.9	-2.2	-0.4	0.3	-1.1	-2.2	-1.0	-0.9
South America	3.809	1.1	2.5	n.a.	2.4	-5.9	-5.0	-1.7	0.4	-2.4	-4.4	-0.8	1.2	-1.9	-2.7
Japan	32.798	0.6	-1.4	-2.0	-1.5	6.2	5.3	-1.0	-1.3	-0.8	-0.8	-1.2	-0.6	-0.3	0.8
China	18.110	-7.2	-0.1	n.a.	0.1	-5.4	-4.9	-2.6	-1.4	-2.1	-2.9	-2.0	-1.0	-2.9	-3.9
Rest of Asia	30.520	-1.4	1.4	n.a.	1.4	-4.4	-3.8	-1.0	0.2	-0.6	-1.1	-0.1	0.5	-1.2	-2.1
Australia	1.272	-5.9	-7.5	-9.1	-7.5	7.0	6.2	-2.5	-5.0	-4.4	-4.7	-6.5	-4.6	-3.8	-3.3
Rest of world	2.935	0.6	2.3	n.a.	2.1	-4.0	-3.3	-0.9	0.7	0.7	0.2	0.8	0.4	-0.9	-3.6
World standard EAF steel	**207.612**	**-1.4**	**-0.5**	**n.a.**	**-0.6**	**0.9**	**0.7**	**-1.3**	**-1.0**	**-0.5**	**-0.5**	**-0.6**	**-0.8**	**-0.8**	**-0.8**
OECD standard EAF steel	*129.035*	*-0.7*	*-1.7*	*n.a.*	*-1.9*	*4.1*	*3.5*	*-1.3*	*-1.6*	*-0.2*	*0.4*	*-0.8*	*-1.5*	*-0.4*	*0.2*
Non OECD standard EAF steel	*78.577*	*-2.7*	*1.5*	*n.a.*	*1.4*	*-4.4*	*-3.8*	*-1.3*	*0.0*	*-1.0*	*-2.0*	*-0.5*	*0.4*	*-1.5*	*-2.4*
DRI based EAF steel															
EU (excl. Sweden and Finland)	1.440	-1.4	-7.9	-15.6	-4.8	2.0	1.2	1.4	-2.1	-3.9	-2.4	-4.6	-8.2	-4.2	-3.3
Eastern Europe and FSU	1.467	-7.1	4.5	n.a.	3.9	0.0	0.5	2.1	3.2	1.7	0.5	2.6	3.4	1.8	1.2
North America	11.431	-3.4	-7.2	-8.6	-5.1	-0.3	-0.8	0.4	-3.1	-4.5	-3.5	-5.3	-7.0	-5.1	-4.8
South America	8.016	-0.9	4.6	n.a.	4.0	-0.8	-0.3	1.9	3.2	0.6	-0.9	2.1	3.7	1.3	0.8
Rest of Asia	8.817	-4.9	3.1	n.a.	2.8	-0.7	-0.3	1.4	2.2	1.6	1.3	2.0	2.2	1.2	0.6
Rest of world	9.536	-5.9	4.3	n.a.	3.7	-0.2	0.3	1.9	3.1	3.1	2.8	3.3	2.6	1.9	-0.2
World DRI based EAF steel	**40.707**	**-3.9**	**0.4**	**n.a.**	**0.8**	**-0.4**	**-0.2**	**1.3**	**1.0**	**-0.1**	**-0.3**	**0.1**	**-0.3**	**-0.6**	**-1.2**
OECD DRI based EAF steel	*12.870*	*-3.1*	*-7.3*	*n.a.*	*-5.1*	*0.0*	*-0.6*	*0.5*	*-3.0*	*-4.5*	*-3.3*	*-5.2*	*-7.1*	*-5.0*	*-4.7*
Non OECD DRI based EAF steel	*27.837*	*-4.2*	*4.0*	*n.a.*	*3.5*	*-0.5*	*-0.1*	*1.7*	*2.8*	*1.8*	*1.1*	*2.5*	*2.8*	*1.5*	*0.4*
All technologies															
World steel	**757.464**	**-5.4**	**-2.3**	**n.a.**	**-1.9**	**-0.2**	**-0.4**	**-0.2**	**-1.2**	**-2.0**	**-1.8**	**-1.7**	**-1.9**	**-1.7**	**-1.8**
OECD steel	*390.406*	*-1.1*	*-8.8*	*n.a.*	*-7.3*	*-0.3*	*-1.1*	*-0.7*	*-4.5*	*-6.0*	*-4.7*	*-4.6*	*-6.2*	*-2.2*	*-1.0*
Non OECD steel	*367.058*	*-9.9*	*4.6*	*n.a.*	*3.9*	*-0.1*	*0.4*	*0.2*	*2.4*	*2.3*	*1.4*	*1.4*	*2.7*	*-1.2*	*-2.6*

Table A.2. Change in CO_2 emission levels (%)

	Base year emissions (Mt)	World tax	OECD-wide tax	Uni-lateral tax	Energy tax	Revenue recycling				Border tax adjustments					
						A	B	C	D	I	II	III	IV	V	VI
EU (excl. Sweden and Finland)	228	-7.6	-15.9	-24.8	-13.5	-10.9	-11.4	-10.6	-13.5	-13.4	-12.0	-11.7	-15.7	-11.2	-10.4
Rest Western Europe	12	-4.6	-28.9	-67.4	-22.5	-12.2	-16.0	-6.7	-12.8	-29.0	-24.9	-23.7	-9.8	-9.3	-6.8
Eastern Europe and FSU	264	-14.3	8.6	n.a.	7.1	4.6	5.1	3.7	6.1	6.2	4.9	4.6	6.6	1.6	0.7
North America	175	-6.9	-19.0	-27.7	-15.6	-8.6	-9.4	-6.7	-12.3	-13.7	-11.1	-10.2	-18.4	-9.1	-7.7
South America	70	-13.9	7.7	n.a.	6.5	3.2	3.7	2.6	5.2	5.1	3.9	3.5	5.9	0.3	-0.8
Japan	186	-8.2	-20.7	-31.8	-17.3	-11.1	-12.1	-10.1	-14.7	-19.0	-18.8	-18.4	-13.9	-12.5	-10.8
China	315	-33.1	4.5	n.a.	3.8	1.1	1.4	0.6	2.5	2.8	2.0	1.7	2.7	-1.1	-3.7
Rest of Asia	149	-4.9	5.9	n.a.	5.0	1.2	1.7	1.1	3.4	3.7	3.1	2.8	3.6	0.0	-0.8
Australia	21	-17.7	-41.0	-60.4	-36.5	-9.3	-10.5	-10.5	-24.8	-37.4	-38.3	-37.2	-20.7	-21.2	-19.7
Rest of world	42	-7.9	6.2	n.a.	5.2	1.3	1.8	1.6	3.8	4.7	4.2	4.0	3.1	0.9	-1.1
World	**1462**	**-14.5**	**-4.6**	**n.a.**	**-3.8**	**-3.0**	**-3.1**	**-2.9**	**-3.6**	**-4.4**	**-4.4**	**-4.3**	**-4.3**	**-4.7**	**-5.1**
OECD	*622*	*-7.9*	*-19.3*	*n.a.*	*-16.2*	*-10.3*	*-11.1*	*-9.3*	*-13.9*	*-16.3*	*-14.9*	*-14.4*	*-16.0*	*-11.3*	*-10.0*
Non OECD	*840*	*-19.3*	*6.4*	*n.a.*	*5.3*	*2.4*	*2.8*	*1.9*	*4.1*	*4.3*	*3.4*	*3.1*	*4.4*	*0.1*	*-1.4*