SNF REPORT NO 17/05

The steel giant goes green?
Global implications of restructuring to cleaner steel production in China

by

Julie Riise Kolstad

SNF project no. 1305

"Global climate policy, changes in demand patterns and new technological developments"

The project is financed by the Research Council of Norway and the Norwegian Shipowners' Association

INSTITUTE FOR RESEARCH IN ECONOMICS AND BUSINESS ADMINISTRATION
BERGEN, JUNE 2005

ISBN 82-491-0360-2 Trykket versjon
ISBN 82-491-0361-0 Elektronisk versjon
ISSN 0803-4036

SIØS –CENTRE FOR INTERNATIONAL ECONOMICS AND SHIPPING

SIØS – Centre for international economics and shipping – is a joint centre for The Norwegian School of Economics and Business Administration (NHH) and Institute for Research in Economics and Business Administration (SNF). The centre is responsible for research and teaching within the fields of international trade and shipping.

International Trade

The centre works with all types of issues related to international trade and shipping, and has particular expertise in the areas of international real economics (trade, factor mobility, economic integration and industrial policy), international macro economics and international tax policy. Research at the centre has in general been dominated by projects aiming to provide increased insight into global, structural issues and the effect of regional economic integration. However, the researchers at the centre also participate actively in projects relating to public economics, industrial policy and competition policy.

International Transport

International transport is another central area of research at the centre. Within this field, studies of the competition between different modes of transport in Europe and the possibilities of increasing sea transport with a view to easing the pressure on the land based transport network on the Continent have been central.

Maritime Research

One of the main tasks of the centre is to act as a link between the maritime industry and the research environment at SNF and NHH. A series of projects that are financed by the Norwegian Shipowners Association and aimed directly at shipowning firms and other maritime companies have been conducted at the centre. These projects include studies of Norwegian shipowners' multinational activities, shipbuilding in Northern Europe and the competition in the ferry markets.

Human Resources

The centre's human resources include researchers at SNF and affiliated professors at NHH as well as leading international economists who are affiliated to the centre through long-term relations. During the last few years, the centre has produced five PhDs within international economics and shipping.

Networks

The centre is involved in several major EU projects and collaborates with central research and educational institutions all over Europe. There is particularly close contact with London School of Economics, University of Glasgow, The Graduate Institute of International Studies in Geneva and The Research Institute of Industrial Economics (IUI) in Stockholm. The staff members participate in international research networks, including Centre for Economic Policy Research (CEPR), London and International Association of Maritime Economists (IAME).

The Steel Giant Goes Green?

Global implications of restructuring to cleaner steel production in China.

Julie Riise Kolstad
The Norwegian School of Economics and Business Administration (NHH)
Bergen, Norway
Spring 2005

Advisor: Professor Dr.Oecon. Kjetil Bjorvatn

This thesis was written as a part of the "Høyere Avdeling" program leading to the Cand.Oecon degree at the Norwegian School of Economics and Business Administration. Neither the institution, the advisor, nor the sensors are - through the approval of this thesis - responsible for the theories and methods used, or results and conclusions drawn in this work.

Abstract

China has experienced an impressive growth in steel production over the last two decades. In 2003, China alone represented 22.8% of the global steel supply and 27.7% of the global steel demand. The growth in steel production brings with it severe environmental problems related especially to the emissions of greenhouse gases and sulfur dioxide. Some sort of change in the Chinese production structure seems inevitable. This report uses a steel industry model to analyse the global consequences of two different types of restructuring. It is concluded that a substitution of technologies will be the most effective measure in terms of emission reductions, but this measure has the potential of severe negative effects on the production level. Substitution between input factors in the BOF process on the other hand, does not seem to affect the production level much, but it is less effective at reducing emissions.

Contents

Chapter 1

Introduction

Why study the Chinese steel market? With a gross production of 220.1 million tons of crude steel in 2003, China produced more steel than has ever been produced in one year by any single nation state - a record likely to be broken again in 2004. This impressive performance means that China alone stands for about 22.8% of the world total production of crude steel. The Chinese consumption of crude steel amounted to 232.4 million tons the same year - in other words, this single nation represented about 27.7% of the world total steel consumption in 2003! Furthermore, China is situated in a region of the world where steel consumption is expected to continue to expand the next years.

The Chinese steel market is per today short of high quality steel as well as flat steel products, and the expectations are that this need will only reinforce itself over the next years. Chinese consumers will be dependent on the rest of the world to supply them with these products. On the other hand, the world market will have to meet the increased competition on long steel products as well as steel with a lower quality. The global market for input factors in the steel production process is also affected strongly by the growth in the Chinese steel sector as China is highly dependent on importing especially scrap and iron ore from the world market. Steel and steel-related goods are mostly transported by sea and represent the main demander of dry bulk shipping facilities. Changes in the Chinese production and consumption pattern will therefore unavoidably have consequences for the dry bulk business.

Why the Chinese steel market and environmental problems? Unfortunately, there is also a more negative side to the impressive development of the Chinese steel sector. The People's Republic of China is one of the worst polluters of the world in terms of the absolute amount of pollution. The Republic accounted in 2001 for more than 3074.66 million tonnes of CO2 emissions [IEA(2004)] and close to 20 million tonnes of SO2 emissions [ZhiDong(2003)], and the steel sector is responsible for a substantial amount of these emissions.

The Chinese steel industry has, during the years of communist rule, been held out as an especially important sector for the industrialisation and modernisation of China. It is still considered an important sector for the economy, but at the same time it causes severe damages on air, water and the global atmosphere. Environmental awareness normally increases with industrialisation, economic growth and modernisation of the society. The standard pattern is that industrialisation comes first, followed by and strengthened by economic growth. In China there has been a strong focus on the industrialisation of the country, and the growth rates have by many become the sure sign of this policy's success. The environmental problems related to the rapid industrialisation and modernisation have, however, become increasingly evident to all parties involved, and are considered an important issue even by the Chinese authorities. Pan Yue, for example, deputy head of the State Environmental Protection Administration (SEPA), calls in an interview with "The Economist" the waste and water pollution "the bottleneck constraining economic growth in China" [The Economist(2004)]. Most of all, however, it is an especially important and devastating problem to the Chinese, who will have to live with (or sacrifice great amounts of income to deal with) the more local environmental effects like heavily polluted water and degenerated air quality in addition to the global problems connected to CO2 emissions. The pollution coming from this single country clearly affects people and nature all over the world, and is therefore also a global problem. The external pressure to reduce emissions is increasing, and several international agencies are actually tying the use of their funds in China to environmental criteria.

The expanding Chinese steel industry will somehow have to meet a number of challenges related to its negative environmental impact. Pressure from the population, national authorities, international institutions like WTO and the Kyoto protocol, as well as the markets themselves will most likely force the industry to restructure and implement a greener technology. Different reactions from the steel industry to environmental problems will lead to different consequences for the affected parties. The goal of this study is to look closer at some possible actions that can be initiated by the government to make the steel producers reduce the negative environmental impact of steel production. An examination of the different profiles of consequences of these actions on the world steel market will also be presented.

The report is organised as follows: Chapter 2 gives a brief introduction to the main steel-making processes and their environmental impacts. Chapter 3 describes the historical development of the steel sector in China and shows the important role the industry has played during the last five to six decades. Chapter 4 presents the situation for steel production in China today and tries to position China in the world steel market. Chapter 5 contains a brief examination of the environmental aspects of the Chinese steel production. Possible actions that can be initiated by producers as well as by the authorities will be discussed. Finally in chapter 6, a steel industry model (SIM) developed by Ottar Mæstad and Lars Mathiesen [Mæstad and Mathiesen(2002)] is used to analyse some of the effects of Chinese "green restructuring" on the world steel market.

Chapter 2

Steel Production Technologies

2.1 The Steel Production Process

Steel production has a long history, and the production process has accordingly taken a variety of forms. It is, however, possible to identify a few common structures among the different production technologies. There are, for example, according to the OECD [OECD/IEA(2000b)] 5 steps present in all steel production processes: (1) treatment of raw materials, (2) iron making, (3) steel making, (4) casting, (5) rolling and finishing.

Having these five basic production steps in mind, it is possible to divide the production processes in use today in three main categories. Steel is produced on small scale in open hearth furnaces (OHF), in a larger scale by basic oxygen blowing (BOF), and more recently it is produced with the use of electric arc furnaces (EAF). The tendency is that there is a movement away from the OHF technology as it has proved to be very inefficient, not suitable for the modern steel demand and also extremely polluting. By the end of 2001, the OHF production only accounted for 4,3% of the world total production of crude steel [IISI(2003)]. Both EAF production and BOF production are increasing, in absolute as well as relative numbers.

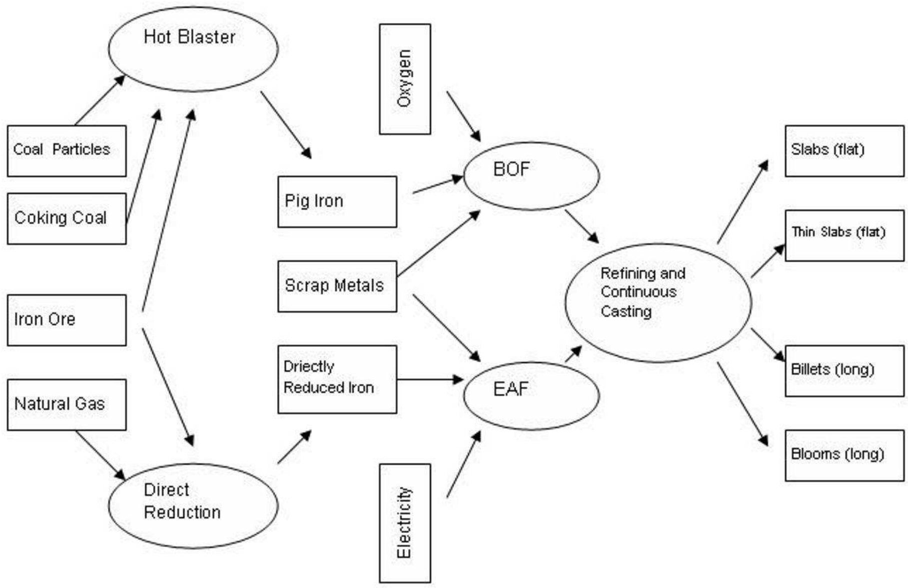

Figure 2.1: The Steel Production Process

Even within the three main technology groups, there are differences in production between regions, countries and companies, and it would be an honest piece of work to describe them all. The next sections will be restricted to presenting a broad outline of the structure of the two most important of these technologies, namely the basic oxygen furnace method and the electric arc furnace method. These following sections will to a large extent be based on introductions to the BOF [Stubbles(2005)], the EAF [Jones(2005)] and the Continuous Casting [Kozak and Dzierzawski(2005)] processes from the American Iron and Steel Institute. Figure 2.1 provides a graphic representation of the general flowlines in the steel making process.

2.2 Basic Oxygen Furnace

The first step of the BOF production is to prepare and refine coal and iron ore in order to make pig iron in a hot blaster. The pig iron is then led into the basic oxygen furnace together with a certain amount of scrap. Oxygen is then blown into the furnace and reacts with its contents until molten steel comes out. The steel is then ready for refining of different kinds. The total BOF process is quite comprehensive, and it demands a lot of space. Six-story buildings are needed to house the Basic Oxygen Furnace (BOF) vessels and to accommodate the long oxygen lances that are lowered and raised from the BOF vessel and the elevated alloy and flux bins. Large integrated mills are as a consequence the typical producers of BOF steel, and these integrated mills are the main suppliers of flat steel products (slabs).

Crude steel produced in basic oxygen furnaces accounted in 2001 for 59,1% of the total world production [IISI(2003)], and the world steel production with this technology has been increasing from 409 241 million tons (Mt) in 1992 to 502 129 Mt in 2001. This increase does, however, not characterize the whole industry, as it is mainly driven by the increased use of BOF technology in China, and to some extent Japan. China has, during the last couple of years, increased its total production of steel faster than other steel producing countries. The main share of this increase is the result of large-scale expansion of already existing integrated plants. In addition, China has, as one of the last important steel making countries in the world, finally exchanged most of its old OHF technology with BOF technology. This development in the direction of increased use of the BOF technology is partly a consequence of lack of capital for the heavy investments needed to build modern EAF plants, and partly an adjustment to the steel demand pattern in China. The ever expanding constructing sector, and maybe more important, the manufacturing sector, are important users of flat high quality steel products, and these are most commonly made in large integrated plants which make use of BOF technology. Other steel giants like USA and Germany however, have seen a decline in both absolute numbers produced with BOF, as well as in the percentage of total production. All in all, the observed increased use of BOF technology may give biased information, if any, about the world steel technology trend. But in the end, even though there exist varying regional trends in the use of the BOF technology, it is still the undisputable dominant steel-making technology both in China and in the world market.

2.3 Electric Arc Furnace

In the electric arc process, either scrap or directly reduced iron (iron reduced by natural gas), hereafter called DRI, or a mix of the two are charged into the electric arc furnace, and electricity is lead into it. Some plants also make use of pig iron, but this is always a relatively small part of the total metal input. The molten steel coming out of the furnace must then be refined at various levels.

EAF production is less space-demanding than BOF production, and most EAF steel is produced in so-called mini mills which combine the EAF with continuous casting technologies. The typical mini mill is mainly a supplier of long steel products like billets and blooms, but can to a certain degree also produce flat steel products. This picture is reinforced by the fact that the EAF producers have traditionally concentrated their forces on production of long products rather than the higher value added flat rolled products due to the impurity of the scrap base used in the EAF production.

In 2001 the electric arc method constituted about 33,6% [IISI(2003)] of the total world production, a number that has been more or less constant the last decade, although there was a increase in total EAF production from 212 437 Mt in 1992 to 285 276 Mt in 2001. New EAF plants require high initial investment costs. The operating costs, however, are much smaller in an EAF plant than in a BOF plant.

2.4 Continuous Casting

Continuous Casting is the dominating technology used to make semi finished steel products. In this process the molten steel from either an electric or a basic oxygen furnace is directly solidified into a "semifinished" billet, bloom, or slab for subsequent rolling in the finishing mills. Prior to the introduction of Continuous Casting in the 1950s, steel was poured into stationary molds to form "ingots". Since then, "continuous casting" has evolved to achieve improved yield, quality, productivity and cost and energy efficiency. Depending on the product end-use, various shapes are cast. In recent years, the melting/casting/rolling processes have been linked while casting a shape that substantially conforms to the finished product.

2.5 Environmental Consequences

The steel industry is a major source of greenhouse gas emissions. Steel production accounts for about 7% of the world carbon emissions. By adding the emissions related to the mining of iron ore and coal, the share may rise to as much as 10% *(Ecofys, 2000)*.

The BOF process The process of refining iron ore to make it suitable for the BOF consumes a vast amount of energy in the form of electricity and natural gas. Much research has been done to improve the energy efficiency, and it has brought results. However, there is still an extended use of energy involved in this process, especially in developing countries like China.

Environmental challenges at BOF production facilities include: (1) the capture and removal of contaminants in the hot and dirty primary off-gas from the converter; (2) secondary emissions associated with charging and tapping the furnaces; (3) control of emissions from ancillary operations such as hot metal transfer, desulfurisation, or ladle metallurgy operations; (4) the recycling and/or disposal of collected oxide dusts or sludges; and (5) the disposition of slag. The desulfurisation is especially important as high emissions of SO2 cause severe air pollution and acid rain. Many of the pollution preventing actions taken at this level, can be initiated and carried out at the firm level. However, in some cases national regulations and financial support are needed in order to make every producer use the wanted technologies.

The blast furnace process typically involves large emissions of carbon monoxide (CO). When this gas is led out in the atmosphere, it will eventually react with oxygen and form Carbon Dioxide (CO2). The CO gas produced in the blast furnace is, however, mostly recovered and used as an energy source. Much of the CO2 gas emissions from the blast furnace therefore stem from the combustion of CO gas. These emissions are, contrary to the SO2 emissions, difficult and maybe impossible to restrict in other ways than by reducing the use of fossil energy. This is because there at the present not exists suitable technological solutions to reducing the emissions or abating the consequences in the form of climate change. This fact indicates that the reduction of CO2 emissions will be too expensive and inefficient to be initiated at the firm level. It should be, and has been in many parts of the world, initiated by national and international governments and institutions.

The EAF process Electric arc technology is by some nicknamed the "greenfield technology" due to its potential to be much more lenient with the environment than traditional methods. The important polluting step of the BOF process, namely the hot blasting of iron ore, is not necessary with EAF technology and there is practically no (or very very small) amounts of coal used in the steel making process. However, the EAF process differs however, from the BOF in an important matter that has the potential for another type of serious pollution; large amounts of electricity, or other energy sources like chemical energy, have to be added from outside the vessel to start the process. Especially in developing countries this is a problem, as the production of electricity more often than not is based on coal burning. In China, the electricity is mainly supplied from huge and extremely polluting coal-based power plants.

The difference between DRI and scrap based EAF production is also important when it comes to emissions of CO2. The DRI is produced with natural gases as the main reducer of iron ore. A large volume is needed and this results in vast emissions of CO2. This tendency is reinforced by the need of electricity on a larger scale in the DRI-based production. The green production profile of EAF is, in other words, highly dependent on the type of EAF.

Chapter 3

The Steel Market in China; historical background

3.1 Geography

China's Steel industry is characterised by geographic dispersion. In fact, all 31 provinces have some sort of steel production, although the types and sizes vary widely. Earlier, the industry tended to locate close to its input sources, but more responsible for the spread of steel mills all over the country, is probably the decentralisation policy driven forth by the "communist" ideal of regional self-sufficiency.

Turning to the map in Figure 3.1, one can get an impression of the production pattern. This map seems to contradict the statement about geographical dispersion from above, and a clarification is needed. There are production facilities in use in all 31 provinces of China, but the output from the steel industry is, as with almost every type of industry in China, in reality highly concentrated in the coastal and central provinces, which are responsible for about 89% of the total production of steel. In particular Hebei, Liaoning and Shanghai are important steel producers, with 35% of the total steel output in 2001 [Wu(2000)].

The great, and to some extent artificial, spread of the Chinese steel industry

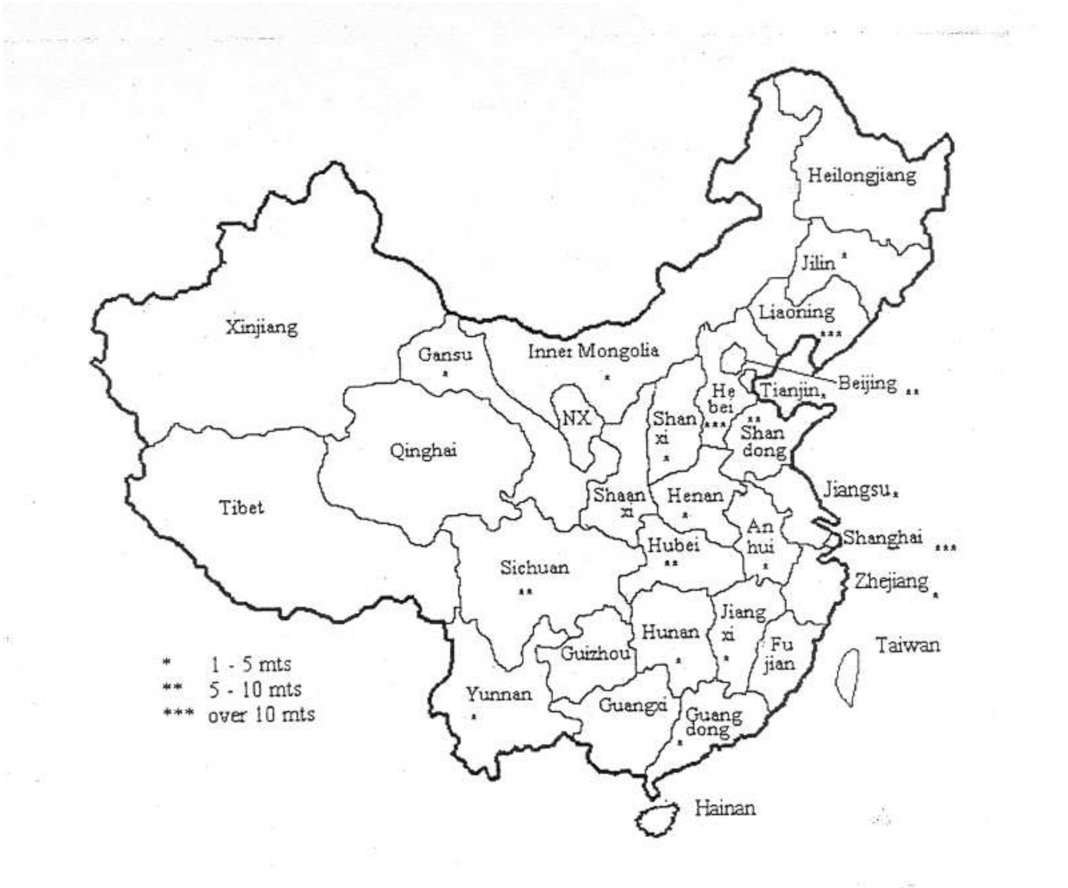

Figure 3.1: Output level. Source: Wu (2000) [Wu(2000)]

has been a source of worry for the economic planners the last couple of years. The problem is that maintaining this spread has a great alternative cost because it prevents the enterprises from profiting from the advantage of economies of scale. This phenomenon will be discussed later in the paper.

3.2 History

The history of the Chinese steel industry follows closely the history of the development of Chinese industry and society in general. [1]

[1] The following subsection is based on the China country report in the series of country reports by the Library of Congress [Worden et al.(1987)Worden, Savada, and Dolan]

Before the end of World War II, the steel industry in China consisted of only quite few and little developed mills scattered around the country. The Japanese dominated the scarce development of the industry, and were between the first and second World War the first to build a modern steel facility in China, in the Liaoning province. Unfortunately, civil war and continuous conflicts with the Russians soon put an end to this plant and with it, the potential development of a modern steel industry.

In 1949 the People‘s Republic of China was established. For the new leaders the most pressing thing to start with, was to rebuild the economy from the damages made by years of war and chaos, and restore a viable economic base. The long-term goal of the leaders, however, were to transform China into a modern powerful socialist nation, which in economic terms meant industrializing, improving living standards, narrowing income differences and producing modern military equipment. Steel production was recognised as a cornerstone in the industrialization process, and was given an accordingly important political and developmental role.

A natural consequence of alienating the country from the capitalist part of the world was the political leaders‘ focus on self-reliance. Having a strong and vital national steel industry became a necessity to be able to show the west and other political enemies that "the Chinese way" was a competent and successful development strategy. In order to control the development in the right direction and speed, the government kept the already existing state ownerships, and established new state ownership and central management in some areas. This was especially the case in key industries, among them the steel industry.

The important political role of the steel sector made the industry‘s development very sensitive to the rapid and dramatic changes in the political environment. In particular, the distinction between leaders who felt that the socialist goals of income equalisation and heightened political consciousness should take priority over material progress, and those who believed that industrialisation and general economic modernisation were prerequisites for the attainment of a successful socialist order, has determined the growth in the industry's output level in different periods. The proceeding development in the steel industry reflects this tendency.

The 1950s with the first Five-Year-Plan (1953-57), was a period characterised by close cooperation and guidance from the Soviet Republic. With Soviet help, the basis for the iron and steel industry was laid and modern technologies such as blast and open-hearth furnaces were introduced. The industry was substantially developed and modernised during this decade, and the production level rose steadily.

The period of stable development was soon disrupted by "The Great Leap Forward" (1958-60)[2]. Growing differences between the productivity in the agriculture and the industry made the economic focus shift from industry in particular, to both industry and agriculture. The need for capital in order to be able to invest in two sectors instead of one, was immense and this resulted in, among other things, an enormous mass mobilization of surplus labour to support the local industry. This phenomenon was especially evident in the steel production. All families were induced to have their own furnace in their backyard so to say, or at least in the farm unit. Mills were built and plants expanded in large scale. This period naturally experienced an impressive production growth, but the quality of both inputs and outputs was low, and especially outputs tended to be over-reported. In the end "the Great Leap Forward" was, if anything, a great leap backwards. In 1961 the industry practically broke down. Small plants were mostly closed, the "backyard production philosophy" was abolished, and the total amount produced sank to the half of the amount reported the year before.

The years to follow created a much-needed improvement in stabilising the environment for growth. The government's first priority in this period was

[2]The period of the late fifties, marked by the leadership's adoption of an approach that relied on spontaneous heroic efforts by the entire population to produce a "great leap" in production for all sectors of the economy simultaneously.

to restore the agricultural production and the light industries, but also the steel industry had its share of investments. Old furnaces and other equipment were repaired and new technology (basic oxygen and electric furnaces) was imported from Austria and Japan. Production fell again, however, in 1967 and 1968 during the period of the Cultural Revolution[3], but recovered relatively quickly, and there was another period of steady growth in the first years of the decade. In the mid-1970s the country again experienced a period of political upheaving and instability. The general hostile business climate created in the cultural revolution led to another decline in production. But, as usual, recovery came relatively prompt after a more peaceful climate was reintroduced.

In addition to the political upheaving in the 70s, one factor of a more natural kind severely affected the Chinese steel industry. The earthquake in Tangshan in 1976 almost ruined the Tangshan steel plant and the Kailuan coal mines, which were the major source of coking coal. The damages were repaired, however, and the production recovered relatively quickly.

Even though the economy has been modernized substantially during the last two decades, we can still see important traces of the first 30 years of the People‘s Republic (1949-1979). This is especially evident in the geographical distribution of the steel plants. In contrast to economic theory, which recommends locating production where a comparative advantage can be achieved, like locating near other related enterprises in order to enjoy agglomeration effects or centralising production in order to enjoy economies of scale, almost every region in China has its own steel industry.

3.3 Economic Reform

At the milestone Third Plenum of the National Party Congress's Eleventh Central Committee in December 1978, the party leaders in China decided to

[3] Primarily a political upheaval in the late sixties set forth by Mao‘s attempt to get rid of what he saw as sneaking capitalism and political enemies within the party structure.

implement fundamental economic restructuring, involving a gradual transition from a centrally planned economy to a socialist market economy. The thought was not to abandon the socialist system, but rather to improve it by adjusting to a number of market principles, and in this way strengthen the support in favor of the socialist regime. More market-based price structures were introduced and the managers were given more autonomy, especially on the control with the planning and strategy of their enterprises.

The first period of economic reform, the "Period of Readjustment" (1979-1981), was dedicated to correcting key imbalances in the economy and forming the foundation for a well-planned modernisation drive. The major goals of the readjustment process were to expand exports rapidly; overcome key deficiencies in transportation, communications, coal, iron, steel, building materials, and electric power; and redress the imbalance between light and heavy industry by increasing the growth rate of light industry and reducing investment in heavy industry. The steel industry was, however, a vital part of both light and heavy industry, and remained in a central position with relatively easy access to capital.

The period of readjustment produced promising results with higher incomes and a general growth in the economy. This success story made the political leadership with Deng Xiaoping continue and broaden the line of "reform and opening", beginning in 1982. A cluster of policies based on greater flexibility, autonomy and market involvement significantly improved the opportunities available to most enterprises. It also generated high rates of growth and increased efficiency.

As far as the foreign trade is concerned, the control with traded products, quantities and potential traders had traditionally been quite strict. For the industry to be more flexible and able to import important goods such as certain raw materials and technology, the reform program recommended that all these restrictions were relaxed. Apart from the need of imported goods and foreign capital, showing the socialist state as an international economic power was probably another driving force behind the relaxation of the foreign trade rules, even though it was never explicitly stated.

The role of foreign trade under the continuing economic reforms increased its importance far beyond that of any previous period. Unlike earlier periods, when China was committed to achieving self-sufficiency, under Deng Xiaoping foreign trade was regarded as an important source of investment funds and modern technology. As a result, restrictions on trade were loosened further in the mid-1980s, and foreign investment was legalised although still severely restricted. In addition, special economic zones were established in Shenzen, Zuhai, Shantou, Xiamen and Hainan, all coastal cities or provinces. These zones enjoyed privileges like special tax levels and low or non-existing export tariffs. In 1984, 14 coastal cities were granted the status of open economic zones, and by the end of 1993 there existed about 2000 different types of open economic zones all over China.

State ownership has traditionally been the dominating ownership structure in the steel industry. During the last decades however, the Chinese leaders have promoted other models like private or local ownership, and on some occasions also foreign ownership. As a result of these changes, the production and ownership structures in the 1990s have changed dramatically [Wu(2000)]. The state sector is divided into two parts, the local enterprises and the key enterprises. The local enterprises are owned by the provincial governments while the key sector enterprises are centrally owned and under direct control of the national political leaders. Although strong central control has been an important characteristic of the Chinese steel industry, the trend is decentralisation of power. There are now far more local enterprises than only a decade ago as a result of the reform program, and all in all there has been a decline in the number of state-owned enterprises. In spite of this trend, the central government still dominates the crude steel production as they see this sector as strategically important for building a modern, fully industrialised state. On the other hand, in closely related sectors such as the iron ore sector and the processing sector, the central ownership is no longer encouraged, and as a result we see a significant growth in the number of a wide range of private enterprises in these sectors.

One of the more recent institutional changes closely related to the opening up for private ownership, is the market orientation in the production. China has over the last couple of years seen a wave of corporatisation of its enterprises encouraged by the economic reform program, and according to Wu [Wu(2000)], 33 enterprises was listed on national or international stock exchanges between 1997 and 2000. This development has led to prices being set according to market conditions, and has reduced the extent of mandatory purchases by the state.

3.4 WTO Accession

In 1986, China sent appliacation for membership to the General Agreement of Trade and Tariffs organisation (GATT), and after years of negotiations, the People's Republic was finally submitted into the World Trade Organisation (WTO) the 1st of December 2001. During the negotiation years, China has, as we have seen, as a consequence of both inner pressure and the wish to enter the WTO, restructured its economy substantially. This long period of both intended and not so intended adjustments to the WTO trade policy, has made the Chinese economy quite well prepared for the final entry.

One of the implications of China entering the WTO, was committment to stop all kinds of subsidies to the state owned sector as well as basing all sale and buying decisions on commercial interests only. As the crude steel industry is still largely state owned, this will indeed affect the Chinese steel production pattern.

China has developed to be one of the most important steel producers in the world, and it is likely that other producers will try to stop China from gaining their market shares. It is therefore more and more vital for the Chinese steel industry to have an arena where they rightfully can take up the fight with policies that hinder competition. WTO has proved to be very important in this regard.

Chapter 4

China's Role in the World Steel Market

4.1 Consumption

China has one of the largest populations of the world, 1 288 million people by the end of 2002 [The World Bank(2005)], and the country obviously has a great consumption potential. This potential is only partly reflected in the national steel consumption numbers. According to the International Iron and Steel Institute [IISI(2003)], China has been the leading consumer of crude steel since the end of 1998, and the country experienced a growth in the consumption of crude steel from 87 010 000 tons in 1992 to 196 350 000 tons in 2001, which gives an impressive average annual consumption growth rate of 10.6%. As can be seen in Figure 4.1, this picture differs from that of China's serious competitors, which have experienced a decline, or at least a stagnation, in their respective consumption growth rates. The level of industrialisation may well explain some of these differences. History tells us that there has been a great need for steel in the early and middle stages of the industrialising process, and that this has lead to an expanded demand for steel and steel products. As a country reaches the stage of full industrialisation, however, the need for steel normally stabilises at a certain level. The majority of the other large steel consumers are more or less fully industrialised, and as expected, their steel demand is not increasing like that of China, where the industrialisation process has not yet reached its peak.

Figures 4.1 and 4.2 confirm that China is the world's leading steel consumer, with as much as 25% of the total world steel consumption. Both the population size and the industrialisation level are likely to be determinants of a country's consumption share. In China's case, the population level is probably the main reason behind the high numbers, whereas in the case of the USA, which consumes about 14% of the world's total steel reserves, the overall high industrialisation level is more likely to be the driving force behind the steel consumption.

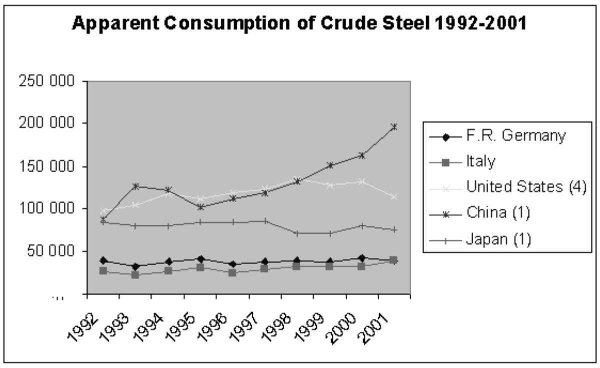

Figure 4.1: Source: Steel Statistical Yearbook 2002
Apparent consumption = production - exports + imports
All numbers in thousand tons

The Chinese consumption numbers are truly very high. However, the per capita consumption gives a slightly different picture of the consumption level. China is a country in the middle of an industrialisation and modernisation process, with relatively low steel consumption per capita, and the consumption trend is positive. Figure 4.3 provides a picture that serves as an indication of the enormous increase in steel consumption that China has yet to experience. In 2001, consumption per capita was 152.8 kg. Although slightly above the world average of 139.7 kg, the Chinese steel consumption per capita in 2001 was still far below the ones of the other important steel

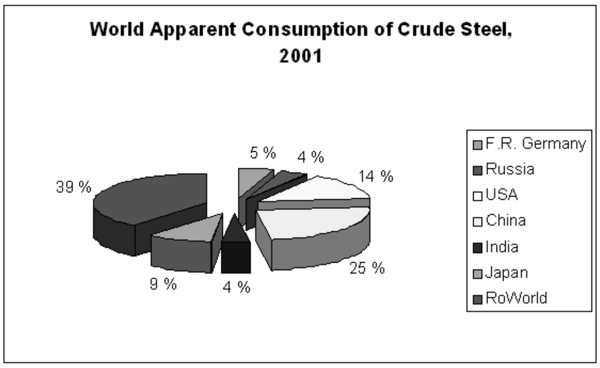

Figure 4.2: Source: Steel Statistical Yearbook 2002
Apparent consumption = production - exports + imports

producers like Japan for example, with a consumption per capita of 598 kg, or the USA at 401.3 kg. The industrialised countries have experienced a stagnation of the per capita steel consumption between 400 kg and 800 kg, while China's per capita consumption has increased from 73.5 kg in 1990 by 9.6% annually to 152.8 kg in 2001. However, the average annual per capita growth rate of 9.6% in the period from 1991 to 2001 is, unlike that of the total steel consumption growth, not outstanding.

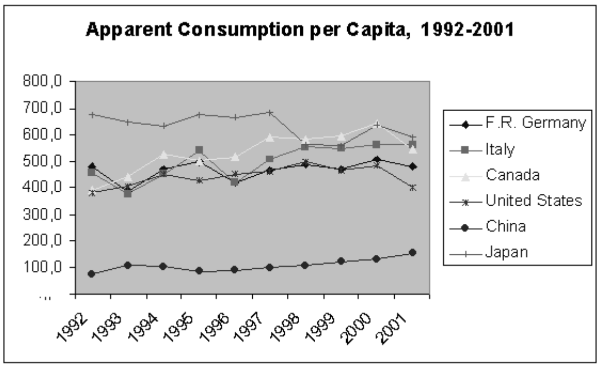

Figure 4.3: Source: Steel Statistical Yearbook 2002
Apparent consumption = production - exports + imports
All numbers in Kilo

All in all, there has been, and still is, a substantial growth in the Chinese steel consumption. The realisation of the potential for further growth in steel demand is, however, exposed to several challenges as China‘s political, economic and social reality is in constant dramatic change. Some of these issues are discussed in section 4.5.

4.2 Production

According to the International Iron and Steel Institute [IISI(2003)], China had a gross production of crude steel of 152 260 000 tons in 2001, and has since 1996 been the largest crude steel producer in the world. The USA and Japan have traditionally been the world giant steel producers, and are indeed still among them, with a production of respectively 90 104 000 and 102 866 00 tons of crude steel in 2001. Since 1996, however, their production growth has more or less stagnated (Japan has had an average growth of 1% since 1996 and the USA have actually had a negative average growth of 1% in the same period). This is in stark contrast to the impressive production growth that China has experienced (an average growth of 9%). Figure 4.4 illustrates the fact that the USA have experienced a decline in production between 1992 and 2001. In the same period China has manifested its position as the leading steel producer of the world, with 18% of the global production in 2001, see Figure 4.5.

Technology There exist a number of steel production facilities with different environment, efficiency and quality profiles in China today. Strong central control, long periods of politically induced lack of contact with communities with modern production technologies, a continuing shortage of capital and a frequent change of focus on economic development are among the reasons why we find the Chinese steel industry characterised by a wide spread among the plants as far as technology and efficiency are concerned.

In 2001 65.7% of China's total steel was produced in Basic Oxygen Furnaces, see Table 4.1. This number is in itself not very different from those

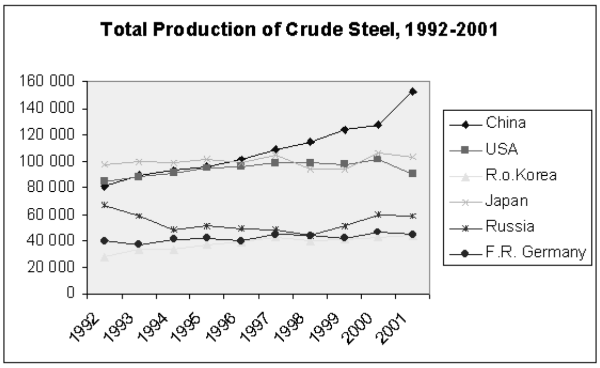

Figure 4.4: Source: Steel Statistical Yearbook 2002
All numbers in thousand tons.

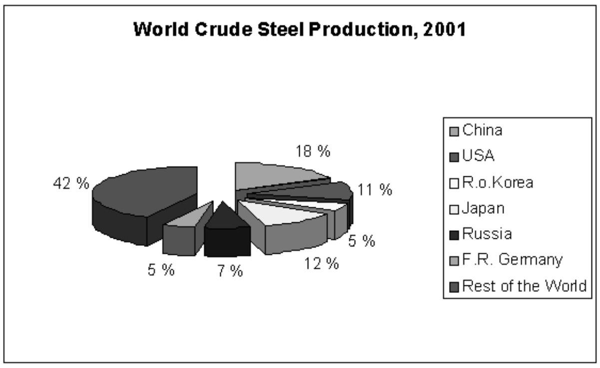

Figure 4.5: Source: Steel Statistical Yearbook 2002

of many other countries, e.g. Japan with 72.4% or South Korea with 56.4%. However, there does exist a great difference in the composition of the rest of the production. While both Japan and South Korea report that the rest of their production was done with the help of EAF technology, China reports that 17.7% of its crude steel is made in open hearth furnaces and with other old fashioned and polluting technologies.

Wu [Wu(2000)] found in one of his articles that the share of electric arc method in China's steel making in 1998 (about 16%) was substantially lower than the world average (about 33%). In China, most electric arc furnaces

Crude Steel Production Process, 2001				
% of total production				
	OHF	**BOF**	**EAF**	**Other**
F.R. Germany	-	70,7	29,3	-
Russia	26,3	58,7	15,0	-
United States	-	52,6	47,4	-
Brazil	-	78,0	20,2	1,8
China	1,2	65,7	16,6	16,5
Japan	-	72,4	27,6	-
South Korea	-	56,4	43,6	-

Table 4.1: Source: Steel Statistical Yearbook 2002
All numbers in %.

are part of great integrated or semi integrated plants, in contrast to the majority of steel-making countries, where a combination of EAF and continuous casting technologies forms a distinct segment in the steel market, the so called mini mills. As a consequence, China has not really been able to enter this market segment, and has yet to experience the full advantages of the EAF technology. As can be seen from Table 4.1, the picture of China as a technologically unsophisticated producer like it is described by Wu in 1998 [Wu(1998)], has not changed very much over the recent years. The USA and South Korea top the list of EAF producers, while only Russia among the great steel producers accompanies China at the bottom of the list. The same two countries are as can be seen in Table 4.1, characterised by a disappointingly slow development in the direction of more environmental technologies.

Production structure Turning the attention from volumes and technology to the production structure of the industry, illustrated in Table 4.2, one finds that the steel production in China is dominated by the production of long products like wires and sections and ordinary rolled steel products.

Total Steel Production, 2001		
Product	**2000**	**2001**
Pig Iron (10 000 tons)	13101.5	15554.3
Steel (10 000 tons)	12650.0	15163.4
Steel Products (10 000 tons)	13146.0	16067.6
Heavy Rail	116.9	126.4
Ordinary Rolled Steel, Large	161.5	226.2
Ordinary Rolled Steel, Medium	518.1	663.1
Ordinary Rolled Steel, Small	3336.5	4389.7
High Quality Section Steel	756.8	928.6
Wire Rod	2635.4	3109.7
Heavy Steel Plate	76.0	90.9
Medium Steel Plate	1636.8	2008.8
Steel Sheet	1903.8	1922.1
Silicon Steel Sheet	130.0	177.0
Seamless Steel Pipe	414.83	535.7

Table 4.2: Source: China Statistical Yearbook 2002

The Chinese production structure differs quite a lot from that of other important steel producing countries. The Chinese rate of long to flat hot rolled products was in 2001 1.45 [IISI(2003)], while the USA had a ratio of 0.39 and Japan 0.52.

The long products are traditionally mainly demanded from the heavy industries and from the construction sector, sectors which in China have experienced continuous growth the last decades. Historically, a modernisation process develops a vital and expanding manufacturing sector. The manufacturing sector, contrary to the construction sector, mainly demands flat steel products of high quality such as sheets and tubes. It is therefore likely that both long and flat steel products will be highly demanded in China for the next decades. The future growth of the Chinese steel sector will, among other things, rely heavily on the industry‘s ability to restructure in order to meet the relatively new demand for flat products.

4.3 Growth

Demand As a rule of thumb, growth in the whole of the economy leads to a more or less proportional expansion in demand for steel and steel products. This fits neatly in with the Chinese reality where the annual average GDP growth rate has been 9.85% the last decade, and the demand both for crude steel and for finished steel products has increased continually (10.6% annually from 1992-2001)[1] [IISI(2003)].

Production In 2002 China manifested its position as the leading steel producer of the world. The country increased its crude steel production by 20.3% from the previous year to 181.6 million tonnes [IISI(2005)]. Figure 4.6 shows that the growth in production output leading up to 2002 has also been substantial; actually, since 1980 the gross output has been growing at an average rate of 11.8% per annum [Wu(2000)]. These high growth rates may partly be attributed to the Chinese industrial policy over the last decades, a policy that has strongly supported the steel industry financially as well as politically.

Predictions A lot of studies have been done in an attempt to forecast the Chinese growth rate. ZhiDong [ZhiDong(2003)] e.g., has come up with an interesting econometric model to estimate the growth rate up to year 2030. In his model, the development of macroeconomic variables as well as the energy consumption pattern and the environmental aspects, especially the emissions of SO2 and CO2, are taken into consideration. From his baseline scenario he concludes that the GDP growth is expected to surpass 6% annually. He predicts that the annual average growth rate will be 7.4% from 1999 to 2010, 6.1% from 2010 to 2020 and 5.2% from 2020 to 2030, with about one percentage point decline every decade. According to ZhiDong,

[1]When studying Chinese growth statistics, one should be aware of the possibility of over-reporting of aggregate numbers. Several studies have concluded that the Chinese GDP statistics are overstated and with them possibly also the growth rate. Meng and Wang for example [Meng and Wang(2000)], find that the growth rate from 1992 to 1997 should be about 6%, more than 2.5 percentage points under the officially reported GDP growth rate.

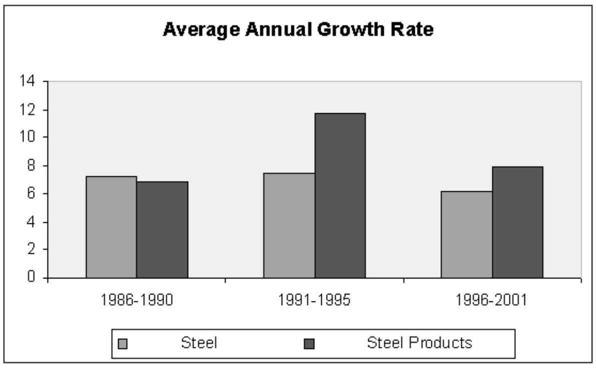

Figure 4.6: Average annual growth rate of output in the steel industry.
Source: China Statistical Yearbook 2002

this forecast positions itself right in the middle of other known forecasts of the Chinese growth rate, see for example [OECD/IEA(2000a)] [Li(2000)] or [Wang(2000)]. In addition to the GDP growth, it is possible to predict the development in steel production from ZhiDong's model. Chinese steel production is predicted to be 197 million tons (Mt) in 2010, 208 Mt in 2020 and 235 Mt in 2030, and continuous growth in the whole of the economy combined with an expected boosting private vehicle market, are identified as the main driving forces. However, ZhiDong stresses that the projected development of the Chinese economy and its energy composition is hardly sustainable. China will be highly dependent on imports of oil and gas from the Middle East and the former Soviet states. The projected increase in energy consumption will by necessity lead to higher production of SO2 and CO2. Most likely this production will reinforce environmental problems related to emissions of these gases. Abatement of the environmental damages will be costly. Substantial investments in new technology will be necessary and lost production possibilities can be expected as it is difficult, maybe impossible, to restrict the CO2 emissions in other ways than by reducing the use of fossil energy.

4.4 Trade

Steel

The many different types of steel and steel products have been, and are still, subject of a variety of tariffs. A study by Hildegunn Kyvik Nordås from 2002 [Nordås(2003)] calculates the simple average ad valorem tariff rate of iron and steel by the time of China's WTO accession (December 11th, 2001) to be 6.2%, and expects it to sink to 5% by the end of 2004. For iron and steel products, the tariff rates were, and will most likely continue to be, somewhat higher at 10.8% by the time of accession and an expected simple average of 10% by the end of 2004. It is noteworthy that the reduction of tariffs on steel products is very small compared to the reduction of tariffs on crude steel.

Volumes China was the largest producer of steel in 2001, and despite the official goal of self sufficiency, the republic was also a net importer of crude steel with 44 090 000 tons imported the same year. On top of this, China's steel product imports reached its highest level ever at almost 27 Mt in the first eleven months of 2002 [International Steel Statistic Bureau(2003)]. All in all, iron and steel products represented more than 5% of the total value of imports to the country in 2001, while exportation of the same type of products only constituted around 1% of the country's total exportation value [IISI(2003)].

According to Figure 4.7, the European Union was the main exporter of steel in 2001 with 106.9 Mt exported. Most of this trading was, however, intra-regional and only 31.3 Mt were exported to regions outside the EU. The former states of USSR as well as a group of Asian countries like South Korea, India and Japan, with respectively 56.7 and 31.2 Mt exported, also stand out as important traders. North America and the rest of Asia are among the most important importers with respectively 33.9 and 52.9 Mt imported. The Asian region like the European, seems to have a well developed intra-regional trade system. China's main trading partners are, according to the Iron and Steel Institute [IISI(2005)], North America, Japan, the former

Exporting Region / Destination	European Union (15)	Other Europe	former USSR	North America	Latin America	Africa & Middle East	China	Japan	Other Asia	Oceania	Total Imports	of which: extra-regional imports*
European Union (15)	75.5	13.7	7.7	0.2	1.7	1.6	0.4	1.8	1.5	0.1	102.7	27.7
Other Europe	13.0	4.0	7.1	0.0	0.1	0.0	0.1	0.3	0.4	0.0	24.9	20.9
former USSR	2.4	2.3	4.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	9.0	4.7
North America	6.3	1.9	2.4	7.9	7.1	0.7	1.0	2.4	4.2	0.1	33.9	26.0
Latin America	1.6	0.8	3.1	1.8	2.3	0.3	0.1	1.3	0.7	0.1	11.9	9.6
Africa	2.6	1.4	4.6	0.1	0.1	1.7	0.1	0.4	0.2	0.1	11.1	9.4
Middle East	1.9	3.0	8.5	0.1	4.6	0.2	0.2	1.5	1.1	0.0	21.0	20.3
China	0.7	0.5	9.0	0.0	0.3	0.5	-	4.4	10.1	0.0	25.6	25.8
Japan	0.1	0.0	0.1	0.0	0.0	0.0	0.3	-	3.6	0.0	4.0	4.0
Other Asia	2.6	1.1	10.0	0.3	2.4	3.3	5.0	17.8	10.0	0.3	52.9	42.9
Oceania	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.5	0.5	0.3	1.7	1.4
Total Exports	106.3	28.6	56.7	10.5	18.6	8.5	7.2	29.5	32.1	1.0	298.8	193.1
of which: extra-regional exports*	31.3	24.6	52.4	2.6	16.3	6.5	7.2	29.5	22.0	0.7	193.1	
Net Exports (exports-imports)	3.6	3.7	47.6	-23.4	6.7	-23.7	-18.4	25.5	-20.8	-0.7		

* - excluding intra-regional trade marked

Figure 4.7: Steel trade by region, 2002. Source: Steel in Figures, 2003
All numbers in Million tons.

USSR and the rest of Asia. Exports mostly go to the surrounding countries except Japan, which is itself a net exporter, and to North America, while a dominant share of the imports comes from the former USSR, Japan and the rest of Asia.

Composition China mainly exports long steel products and unfinished or semifinished products of relatively low quality. The main product group imported is finished steel products as the domestic producers have a limited capacity to produce high quality products. Flat products are also in short, and these are to a large extent imported[2].

Iron Ore

Iron ore is an essential ingredient in the steel production process, but the initial allocation seems to have little influence on production decisions. The result is that there is a large scale world trade in this input factor. In fact, the iron ore trade totally dominates the dry bulk market. According to Figure 4.8, the main exporters of iron ore in 2002, were Central and South America (174.6 Mt), where Brazil and Mexico stand out as especially important countries, Oceania (158.5 Mt) dominated by Australia, and some states of the former USSR (50.0 Mt). The imports on the other hand, are mostly by the European Union (120.2 Mt), a region which has an extended production of steel but virtually no iron ore reserves, by Japan (126.3 Mt), which has exactly the same problem, and by China (92,4 Mt). The USA, or at least the NAFTA countries as a whole, are more or less self-sustained when it comes to iron ore.

As far as China is concerned, the country imported 69.5 Mt of iron ore in 2000, of which most comes from Latin America and Oceania (more exactly; Brazil and Australia) [IISI(2005)]. In 2001 this number had in 2001 increased to 92.4 Mt, which gives a growth rate of 32% in one year! China actually possesses quite big reserves of iron ore itself, 45 700 Mt of ensured reserves in 2001 [The Chinese Bureau of Statistics(2002)], but unfortunately most of it is of poor quality. Accordingly, there is a great demand for high quality iron ore to be able to supply especially the fast growing manufacturing sector with high quality steel.

[2] In order to keep up with the demand in the economy as well as to compete with steel-producing neighbours, the Chinese steel industry is forced to restructure its production in the near future. This might well lead to a sinking demand for foreign flat and finished steel products, and as a consequence, the import pattern may change.

Destination \ Exporting Region	European Union (15)	Other Europe	former USSR	NAFTA	Central and South America	Africa & Middle East	Asia	Oceania	Total Imports	of which: extra-regional imports*
European Union (15)	10.1	0.9	4.1	11.9	60.7	16.3	1.0	15.2	120.2	110.2
Other Europe	0.9	-	24.4	0.4	6.4	1.2	0.8	1.4	35.4	35.4
former USSR	-	-	21.4	-	-	-	-	-	21.4	0.0
NAFTA	0.2	0.0	0.0	10.1	7.6	0.2	-	0.4	18.5	8.4
Central and South America	0.0	-	-	1.2	6.6	-	-	-	7.8	1.2
Africa and Middle East	2.4	-	-	0.1	11.1	0.2	0.6	-	14.5	14.3
China	-	-	0.1	0.6	30.3	9.4	13.9	38.0	92.4	78.5
Japan	0.0	-	-	0.9	31.7	5.6	19.9	68.3	126.3	106.4
Other Asia	0.0	0.1	-	1.5	19.8	1.2	3.7	35.2	61.4	57.7
Oceania	-	-	-	1.0	0.3	-	0.8	0.0	2.1	2.1
Total Exports	13.5	1.0	50.0	27.6	174.6	34.0	40.6	158.5	500.0	414.2
of which: extra-regional exports*	3.5	1.0	28.6	17.6	168.0	33.9	3.2	158.5	414.2	
Net Exports (exports-imports)	-106.7	-34.2	28.6	9.2	166.9	19.6	-20.8	156.4		

* - excluding intra-regional trade marked

Figure 4.8: Iron Ore Trade by Region, 2002. Source: Steel in Figures, 2003 All numbers in million tons.

Coal

From 2001 till 2002, the level of global coking coal[3] exports decreased with 8.2 Mt, falling to 188.2 Mt, see Figure, with China as the only exemption 4.9[4]. The Chinese government has over the last two decades been an eager agitator of exports and recent actions by the authorities to encourage

[3]Coking coal is mostly used in blast furnaces for steel production whereas the steam coal finds its use in the production of electricity and the processing industry. As it is sometimes difficult to find exact statistics for coking coal alone, it is sometimes referred to coking coal and sometimes to hard coal, a group which also includes steam coal.

[4]All numbers and facts referred to in this subsection stems from Coal Information 2003 [OECD/IEA(2003)].

coal exports include an increase in coal export rebates and a reduction in the export handling fees charged by China's four official coal export agencies. Between 2001 and 2002 China saw the export volume rise by 20.3%, to 13.8 Mt by the end of 2002. Australia has over the whole period been the largest coking coal exporter, and was in 2002 the source of 56% of the global coking coal exports.

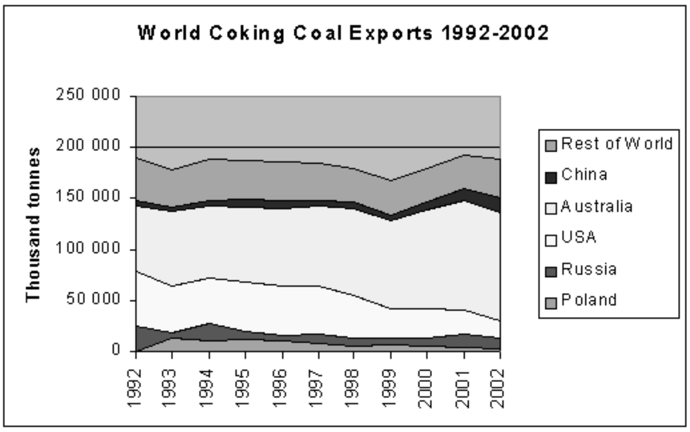

Figure 4.9: World Coal Exports 1992-2002. Source: Coal Information 2003

China is not an important importer of coal, and in 2002 the country was a net exporter. As Figure 4.10 shows, Japan, which has very few national coal reserves, is the dominant importer of steel with 65.8 Mt imported in 2002. India and the Western European producers are other important importers, but all together their imports only represented 29.2 Mt, less than half of the Japanese imports in 2002. The general level of imports has been relatively stable over the last decade, varying between 173 Mt and 190 Mt. The largest importers have imported more or less the same amount every year in this period, with Germany as an exception. Germany entered the picture of large importers in 1998, but since then also Germany has imported a similar amount of coal every year.

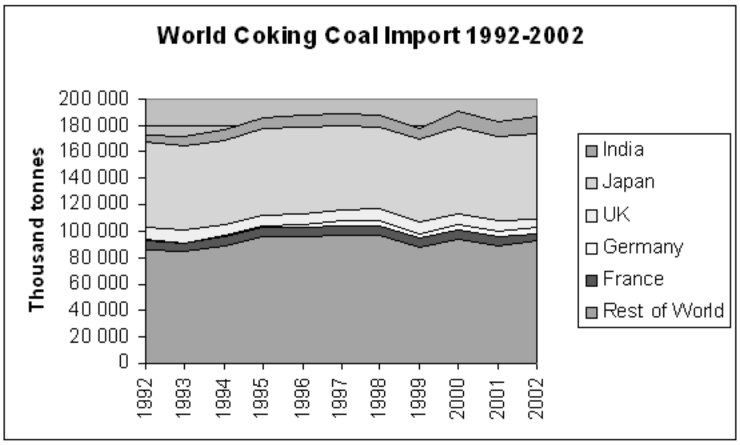

Figure 4.10: World Coal Imports 1992-2002. Source: Coal Information 2003

Scrap

Scrap is an essential and often scarce input factor in the steel making process. It is being extensively used in both the BOF and the EAF technology. It also represents an important cost component of the steel produced. Scrap is not an input factor that a country is initially endowed with. On the contrary, a country‘s supply of steel scrap depends on the level of industrialisation as this in many cases is an important premise for metal waste. Even a country which produces a large amount of steel scrap, is not necessarily assured access to suitable scrap for input in its steel production. The problem is that for the scrap to be suitable for recycling in steel production, it has to be of be a certain quality.

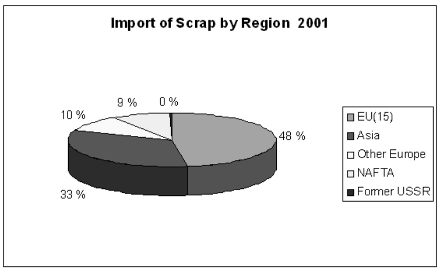

Figure 4.11: Source: World Steel in figures 2003

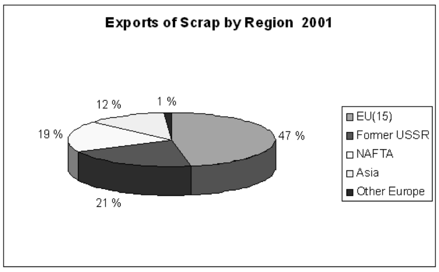

Figure 4.12: Source: World Steel in figures 2003

Intra-regional trade Figures 4.11 and 4.12 give us an interesting picture of the world scrap trade; it seems that it mostly consists of intra-regional trade. The EU stands for 48% of the world imports of scrap, while at the same time it is the main exporter with 47% of the world market. The other regions represented in the figure also seem to import and export quite similar amounts of scrap, with the former USSR as the second largest exporter (21%) and importer (33%). One should of course, based on these numbers alone, be careful with stating that the international scrap trade is mainly a matter of intra regional trade. It seems a likely conclusion to draw, however, that there is an extended intra-regional trade in the scrap market if one keeps in mind the cost and the more practical complications with transporting scrap over long distances.

In 2001 China was the dominant importer of scrap with a gross import of 9 787 Mt [IISI(2005)]. Actually, the net imports did not deviate much from this number as the exports only summed up to 10 Mt the same year. Asia as a whole was the largest net importer of the regions represented in the figure.

4.5 Challenges

The Peoples Republic of China with its system of market-based socialism as well as the republic's steel sector, faces great challenges in the near future. Listed below are some of them.

Diseconomy of scale The great, and to some extent artificial, spread of the Chinese steel industry has been a source of worry for the economic planners the last couple of years. The problem is that maintaining this spread has a great alternative cost because it reduces efficiency and prevents the enterprises from profiting from the potential advantage of economies of scale.

Infrastructure The electricity supply is far from sufficiently meeting household demand. In rural areas many households do not have access to electricity at all, and in the cities there are several restrictions on the use of electricity-intensive items like refrigerators and air-condition, so, the electricity supply of steel mills is in danger. The Railway System as well as the harbours also fail to meet the great need following the increasing internationalisation and general growth in many parts of the Chinese industry.

Political issues Several political issues need delicate and wise treatment in order to avoid reversing the development of a stable society and a socialistic market economy. Down-scaling of subsidies, a growing unemployment rate, reform of the social security system, and an increasing need for regional redistribution combined with a growing opposition are some of the most pressing concerns of the Chinese government. Especially the political treatment of formerly state-owned sectors will be of great importance to the development of the Chinese economic environment.

Biased production structure The observed rise in steel demand in China is mainly driven by the constant increase in the number of construction projects and the continuing expansion of the manufacturing industry. The expanding manufacturing sector in particular has a great need for flat steel products. Unfortunately, the Chinese steel industry has, as we have seen, a production structure which is biased towards long steel products. Another problem is the quality of the Chinese steel. The manufacturing sector as well as the private vehicle market is considered to be the engines of the domestic steel demand, but these sectors are dependent on high quality steel.

Environmental issues The sustained high growth rates in China have not only had positive impacts on the Chinese society. The environment is severely damaged by "modern" production and from many directions it is now argued that time has come to restructure in order to save the remains. The next chapters will look further into this topic and relate it to the steel industry in particular.

Chapter 5

Environmental Challenges

5.1 The Present Environmental Situation

According to *The Economist*, around half of the Chinese population, or 600 million people, have water supplies that are contaminated by animal and human waste [The Economist(2004)]. The World Bank reports that China has 16 of the world's 20 most polluted cities. Estimates suggest that 300 000 people die prematurely every year of respiratory diseases. China has the world's highest emissions of sulphur dioxide and a quarter of the country suffers from acid rain. In 2002, SEPA found that the air quality in almost two thirds of the 300 cities it tested failed World Health Organisation standards. Adding it all up, The Economist reports that, according to the World Bank, pollution is costing China an annual 8-12% of it's $1.4 trillion GDP in direct damage, such as the impact on crops of acid rain, medical bills, lost work from illness, money spent on disaster relief following floods and the impelled costs of resource depletion. The high growth rates have brought with them serious challenges for the environment e.g. the inevitable emissions related to increased demand for steel, an explosion of private energy consumption and a quickly expanding private vehicle market. Developing a cleaner steel production will be one of the necessary actions in order to rescue the Chinese environment.

Yang Jingling and Yue Qingrui, both from the China Metallurgical Institute (CMI), discussed the current situation of environmental protection of China's iron and steel industry and the development of the technology of environmental protection in China Metal Reports in February 2003 [China Metal Reports(2003)]. The rest of this section is based on this discussion.

Over the past ten years, China has doubled its output of iron and steel, but total energy consumption at the nation's many plants has increased by only 30%. This implies a gradual decline in energy consumption per ton of iron. Simultaneously, the discharge of waste water, the total discharge of waste gas, the discharge of waste water per tonne of steel, and the atmospheric dust content in factory areas have declined. These declines have been achieved through the strengthening of environmental management and waste treatment and the implementation of the ISO 4000 series of environmental standards.

Baosteel - China's steel industry leader - has, by adopting several technological innovations, and thereby setting an example for environmental protection in the whole domestic iron and steel industry, played an important role in the more environment-friendly development of the steel sector in China. Although Baosteel has reached international environmental protection levels, the whole industry still lags behind in many respects due to differences in geography, technology, skills and finance.

Environmental protection focus in China compared to the rest of the World According to the experts at the China Metallurgical Institute, the environmental protection focus in China differs from that of the rest of the World. The environmental protection in the iron and steel industry in China has its main focus on the following issues:

1. Waste water treatment
2. Smoke and dust disposal
3. Waste slag treatment and recycling

4. Reaching standard levels of discharge

In developed countries, however, environmental protection has reached the requirements for pollution and their environmental protection mainly focuses on:

1. Treatment of all poisonous and harmful gases like SO2 and NOX
2. Treatment of volatile chemicals
3. Treatment of dioxins
4. Treatment of heavy metals and radioactive substances
5. Installing technology with low noise and low CO2 emissions.

Energy consumption Energy consumption in steel production is relatively higher in China than in the rest of the world, Table 5.1 shows that China actually uses more electricity in both EAF production and BOF production than any other steel-producing region. The inefficient energy use combined with the fact that China has a high growth rate of both GDP and steel production, indicates a continuing growth in energy consumption related to the steel industry. The total CO2 emissions from energy consumption are in other words expected to increase. Indeed, the econometric model developed by ZhiDong [ZhiDong(2003)] that was referred to earlier, predicts that the total energy consumption in China will increase, and that China in 2030 will be responsible for emissions of CO2 equalling almost 96% of the total 1999 emissions from the USA and the rest of the OECD countries together!

Smoke and gas treatment The actual level of SO2 emissions was in 2000 close to 20 million tons and the government intends to reduce these emissions in the future. Currently, smoke desulfurisation is the most common way to control the emissions of SO2, but the method is inefficient and costly. As the situation is today, it will cost at least RMB 700 (USD 84.6) to

Region	El, BOF	El, Scrap EAF	El, DRI EAF
Western Europe	140.52	520.92	-
East Eur. & former SU	164.32	549.03	-
North America	171.81	535.99	728.41
South America	120.41	517.44	917.78
Japan	128.04	471.71	-
China	191.30	569.00	869.00
Rest of Asia	141.72	521.27	881.66
Australia	139.83	-	-
Rest of World	189.91	544.28	845.72

Table 5.1: Electricity use in different steel production technologies
Source: The SIM model

desulfurize one ton of $SO2$[1], and some companies seem to prefer paying fines rather than investing more money in the necessary technologies. According to Yang Jingling and Yue Qingrui, the problem lies in state policies and corresponding regulations and laws, as well as in the economic weakness of many enterprises.

5.2 What Can Be Done?

Two groups of actors in the Chinese steel market can in principle initiate the necessary actions needed to abate pollution from the steel industry. When examining what can be done with the environmental degradation, one could start with taking a closer look at the instruments one of these groups, namely the national and local governments, has at hand. It is also interesting to examine the extent of the government's political power and their will to make use of the available instruments.

[1]These numbers were given to the two representatives from the China Metallurgical Institute by an anonymous analyst, and their validity is impossible for me to check. I do, however, assume that they can give us an indication of how costly it is for the steel producers to introduce greener technologies.

The government cannot solve the problem of pollution on their own, however; cooperation from the other main group of actors, namely the polluting enterprises, will be essential. It will therefore be interesting to explore the ways the enterprises can restructure their production process to avoid unwanted pollution effects. It is also necessary to look at the enterprises' readiness to meet these challenges, an issue that depends on information, national pressure, international pressure and, not least, the costs of changing the production structure.

The Enterprises

Given the increased international trade and the resulting contact with international trends in production, quality demands and environmental awareness, it seems likely that the Chinese enterprises will feel a certain pressure, but also a great incentive in the form of money and expertise, to improve their production processes.

Based on the many ways of making steel, several quite different restructuring processes designed to meet environmental challenges have been held out as the right way to go. There may be substitution among technologies, but there may just as well be substitution among input factors. The adoption of new technologies or different attempts to increase environmental efficiency within the existing ones, can take a variety of forms - and they may all well be sensible and good strategies. Below are listed some of the most important potential improvement areas.

Energy efficiency Improving efficiency in the already existing production facilities is perhaps the most obvious first step in the process of developing a "greener" steel production. Although the energy efficiency according to Chinese authorities has improved during the past ten years, China still reports a strikingly low energy efficiency in production compared to other leading producers in the world, and there is obviously a lot to learn from steel producers in especially the USA, Japan and EU [China Metal Reports(2003)].

Cleaning technologies The implementation of traditional clean coal technologies (like coal washing, screen and briquette) may have the potential to produce a somewhat better local environment although it gives very small CO2 emission reductions. High-tech coal technologies such as Integrated Coal Gasification Combined Cycle (IGCC), on the other hand, can contribute to a cleaner local environment, reducing CO2 emissions and the energy security.

Structural changes in production A third possibility is to go through with more structural changes of the production processes. There exists a variety of possibilities to change the production structures the Chinese producers make use of, but to ease the discussion they will be divided into two broad groups:

1. A change in the input mix in the BOF process.
2. A complete shift in technology from BOF production to EAF production.

These two groups of structural changes will form the basis of the analysis later on, but first a broad picture of what can be done on the government's hand will be sketched.

The Government

Unfortunately, it seems very difficult, maybe impossible, for the Chinese authorities to find a strategy to resolve the sustainability issues (air protection, climate change and energy security) simultaneously and perfectly as the costs and immediate consequences of sufficient reactions would most likely overturn the Chinese economy. A need for making priorities between the different areas of environmental improvements as well as between economic and social interests on the one hand and the environment on the other hand will force itself through. Why then could the green restructuring not be left to the industry itself, why is it not likely that the enterprises would go through with reforms without the government interfering? One argument for the government to act is the fact that there do not exist other adequate solutions to the CO_2 problem than a mere reduction of the emissions. While everyone will be better off if the total emissions are reduced, in a free market situation the single enterprises lack incentives to reduce their own emissions. From their point of view it can be argued that it would be a rational thing to do, and it certainly would be tempting, to let the others take the burden of reducing emissions and enjoy the position of a free-rider. If one agrees that governmental action in one way or another is needed, the next question will be, what instruments does the government have at hand?

Green taxes The government has several instruments they can make use of in order to reduce negative external effects like pollution. They could for example introduce a fee or even criminal penalties on all actors if they produce (or cause) emissions over a certain threshold. The idea is to give the steel producers (and/or consumers) an extra cost proportional to their emissions (direct or indirect) so that they are more likely to make production (buying) decisions in line with the interest of the society at large. Taxes like this would be a cost-effective way of reducing unwanted emissions as the producers with the lowest abatement costs are expected to reduce their emission the most (up to the level where the abatement costs exceed the fee). It will, however, be difficult to forecast exactly how big the reduction of emissions will be. Taxes are in general relatively easy to implement, but it may be difficult to decide on the right level of taxes (the level that minimises the sum of social costs coming from the emissions and the abatement costs).

Non-tradeable emission standards Another possibility is to regulate the amount of emissions from each single polluter directly by implementing a system of emission standards. The government then designates each producer with a certain amount of allowed emissions, and in this process, they have the possibility of adjusting for relevant differences between the producers. The problem with the standard system is that it is very costly to collect enough information to make the right decisions about sizes of quotas, and when considering the size of the Chinese steel industry, it will probably never be possible to achieve full information about the producers' cost structures. A common solution to the information problem is to give every producer the same emission standard, but this ”equal” treatment turns out to give very unequal implications on the different producers as they face different cost structures and different markets. It will, in other words, not be cost effective to make every producer reduce their emissions by the same amount, but on the other hand the government gets control with the actual amount emitted.

Tradeable emission standards The system of tradeable emission standards has the advantage of both fees and non-tradeable emission standards. The government can set the wanted level of emissions when fixing the number and size of the emission standards. As the quotas can be traded, market mechanisms are expected to ensure cost-effective reductions by allocating the most quotas to those with the highest marginal abatement costs and vice versa. The problem with tradeable emission permits is that such a system will demand a lot of resources and organising to function well. There is also the problem of how the initial permits should be distributed. This subject will probably be politically engaging - a fact that has the potential to affect the policymaking in both positive and negative ways.

Focus on renewable energy The instruments discussed above are all some kind of punishment for or direct regulations of emissions. The government will, if they make use of them, induce extra costs on the producers and the short term consequences can be downsizing of activity, loss of jobs and reduced social security. On the other hand, the government also has a golden opportunity to reward and encourage research and development of new alternative technologies based on renewable energy sources. Such research is often costly, and building new plants based on new untested technologies, will for many enterprises be far too risky. The government can help the risk-willingness by taking over some of the risk and providing grants, or they can give direct subsidies to those willing to implement new technologies. This type of reward policy will probably give the best results if it is combined with some of the instruments listed above.

Agenda 21 and SEPA The Chinese government seems willing to spend time and money to overcome some of its most pressing environmental problems, at least if we can trust their official statements on the subject of environmental protection. They claim to be ready to make priorities which gain total welfare more than profitability at the corporate level as long as it does not disturb order in the society. The Chinese government has, according to China's Agenda 21 [The Administrative Center for China's Agenda 21(1994)], since the 1980s considered environmental protection fundamental to socialist modernisation.

In June 1992, the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, adopted five important documents, including the Rio Declaration and Agenda 21. Agenda 21 calls for all nations to develop and put into effect their own national strategies, plans and policies for sustainable development, and to be prepared to deal with the common challenges facing humanity. China's Agenda 21, the white paper on China's population, environment and development in the 21st century [The Administrative Center for China's Agenda 21(1994)], is quite substantial - it contains 20 chapters and 78 programme areas, and states that:

"In order to achieve sustainable economic and social development, China cannot follow the old path of "polluting first and cleaning later" or "damaging first and repairing later", but must rely on full use of economic measures and market mechanisms to promote sustainable development."

The Chinese Government claims to attach great importance to the UNCED. The Chinese Premier Li Peng attended the conference and made a commitment to conscientiously implement resolutions adopted there. China's Agenda 21 was approved by the Chinese government and often functions as a guide document for drawing up medium and long term plans on economic and social development. Its goals were embodied for the first time in the Ninth Five Year Plan(1996-2000), and are also embodied in the present Five Year Plan (2001-2005).

In 1998 Mr Zhu, the then prime minister, elevated the State Environmental Protection Agency (SEPA) to ministerial rank, and three years later the 10th Five-year Plan for Environmental Protection set ambitious emission-reduction targets and boosted environmental spending to 700 billion yuan ($85 billion) for 2001-2005 - equivalent to 1.3% of GDP. A legal framework has been created. Also the rhetoric has changed; Hu Jintao and Wen Jiabao, the current president and prime minister, now stress balanced development rather than economic growth. Unfortunately, while the tasks of SEPA are numerous and complicated, the ministry is under-resourced, with little money and only about 300 people in the central staff. Their situation is further complicated by the rivalry with other ministries with overlapping mandates and the counteraction by ministries and powerful lobbies whose main concern are economic growth and employment. On top of this, the policies decided upon in SEPA are supposed to be implemented at the local level by the Environmental Protection Bureaus. However, their loyalty often goes to the local authorities, which are naturally concerned about the employment and prosperity of their region, rather than to the central office in Beijing. As Ma Jun, an environmental scholar interviewed by *The Economist* puts it: "The Bureaus depend on the local governments to pay their salaries and pensions. How can they enforce regulations against the local government?" [The Economist(2004)].

The Kyoto Protocol In 1992 most of the world's countries joined an international treaty called "the United Nations Framework Convention on Climate Change" (UNFCCC) to begin considering what can be done to reduce the problem of global warming. In 1997 governments agreed to an addition of the treaty, called the Kyoto Protocol, which has more powerful and legally binding measures. The Kyoto Protocol came into operation on the 16th of February 2005, after Russia's final ratification of the Protocol in December 2004.

China signed the protocol in May 1998, and finally approved the protocol in August 2002. *Peoples Daily* [Peoples Daily(2005)] reported in relation to the signing that the Chinese Premier, Zhu Rongji, said: "The approval manifests China's positive stance towards international environmental cooperation and world sustainable development" He also stated, however, that "China is a low income-country with a large population, and that poverty eradication and economic development are the top priorities. Notwithstanding the foregoing, the Chinese government does attach great importance to climate change."

As a developing country, China is not required to reduce emissions in the initial stage of the agreement. But at some point, for example when the first stage is over in 2012, it might be. Experts and government officials have acknowledged that the treaty will have broad implications for China, noting that it will present both opportunities and challenges. As a signatory to the Kyoto Protocol, China is likely to commit certain obligations years ahead of the requirements. Provided the per-capita greenhouse emissions exceeds 4 tons in China, it will cost the country 50 billion yuan ($6.04 billion) to implemnt the Kyoto protocol every year, warned Pan Yue, Vice Minister of SEPA. The protocol is expected to have most immediate impacts on companies engaded in thermo-power generation, iron and steel and petrochemical industries. *Beijing Review* [Beijing Review(2005)] reports, however, that according to Qiu Baoxing, Vice minister of Construction in China, The Kyoto protocol is actually believed to give strong impetus to the development of cleaner industries in China. In addition to imposing emission reductions on developed countries, the protocol helps countries reduce greenhouse gases on the global scale through a clean development mechanism (CDM). Under the CDM, developed countries cooperate with developing countries by assisting emissions reduction projects with capital investment and technology. The reduction achieved in the developing countries is calculated and counted as part of the developed countries' commitment to the Kyoto protocol. "The CDM is a win-win cooperation mechanism", said Zhu Guangyao, another Vice Minister of SEPA, and he estimated that China's annual emission reductions through CDM programs could add up to more than $1 billion.

To conclude: The intentions of the Chinese are apparently the best, but there are many serious obstacles to overcome. There is also a question of how painful the unavoidable restructuring of the steel sector will be, and how it will affect welfare, growth rates and political support in the short run. These questions are a subject of continuous discussion and are not examined in this report.

China's Agenda 21 documentation lists a number of important research areas that have to be further examined in order to be able to wisely direct the Chinese economy on to the path of sustainable development. Among these are "Investigating the impact of economic measures and market incentive mechanisms on competitiveness and international trade". The rest of this report is meant to be a contribution to this work.

Chapter 6

Effects of a "Green" Restructuring

6.1 Introduction

The previous chapters, especially chapters 4 and 5, showed that the Chinese steel industry has experienced an impressive growth over the last decades, and that the picture of increasing steel consumption as well as production, will most likely stay the same for at least another decade. This growth has made China a dominant actor in the global steel market, but also in the global markets for steel related goods. The previous chapters also called attention to another side of this story, however, namely the increasing emissions of polluting gases. International organisations and business partners, as well as local governments and national authorities, were identified as driving forces for a movement in the direction of more environmentally friendly production of steel in China, and such a development was in chapter 5 argumented to be more or less inevitable.

There exists, as mentioned in Chapter 5, a variety of reforms that may lead to reduced emissions from the steel sector. However, two broad groups of changes of the industry stand out as especially interesting to examine in a static general equilibrium model like SIM; 1) a change in input factors from pig iron to scrap metals in the BOF process, and 2) a change in production technologies from BOF production to EAF production. The aim of this chapter is to answer a number of questions concerning these two changes in the steel production. First of all, do the reforms work? Or, in other words; to what extent do the reforms reduce emissions? After both sets of reforms have been analysed, it will be examined which one is the better reform when emission reduction is the main focus. The second set of questions will concentrate on what happens to the global steel and input factor markets. How the general activity level as well as the distribution among regions and technologies is affected will be of vital interest in this matter. In advance of the analysis, based on the knowledge from chapters 4 and 5, a few conjectures about the results can be made:

- Both reforms will lead to reduced emissions, at least in China.
- Ceteris paribus, green taxes in China will place an extra constraint on the producers and lead to reduced output.
- There will be more global steel trade as China reduces its supply of steel while the demand is not decreasing.
- The reform that concerns substitution of input factors conforms with the government's goal of "improving technical facilities through technological renovation and expansion of existing enterprises" and is therefore a reform likely to be implemented.
- The reform concerning substitution of technologies will be very costly and may be less likely than a substitution of input factors.

In the following, a steel industry model (SIM) will be manipulated in order to analyse the consequences of the two different types of changes. This particular model, presented in more detail in the next section, is chosen mainly due to its ability to show the global consequences from a Chinese restructuring, but also due to its simplicity and ability to separate different economic effects. As China is an important actor in the global steel market, national actions meant to change the local environment will necessarily have some sort of global effects. Such effects will be in the interest of competitors, input suppliers, transport suppliers and other involved parties to monitor closely.

Also environmental organisations and institutions of different kinds should be interested in clarifications of the possible consequences of a "necessary" Chinese restructuring. The SIM model is well suited for such a global analysis, its strength being in the ability to cast a clearer light on global effects. On the other hand, the model only monitors the effects on the CO2 emissions. It is not developed in order to examine the particular local Chinese effects, and it is based on rather few Chinese data sources. A thorough analysis of the Chinese effects of a Chinese restructuring is therefore not possible. However, as long as there is reason to believe that other types of pollution with effects of a more local character are reduced proportionately with the CO2 emissions, the model is still suited to say at least something about the direction of the environmental effects in China in particular.

The structure of the rest of this chapter will be as follows; First, the SIM is introduced. Second, an analysis of a change in the direction of the most developed steel producing regions, namely from BOF production to EAF production, is provided. Third, a possibly cheaper and more likelier change, the change from pig iron to scrap metals in BOF production, is examined. Finally, the implications of the restrictions of the SIM, as well as the simulation results, are discussed.

6.2 The Steel Industry Model

The model developed by Lars Mathiesen and Ottar Mæstad [Mæstad and Mathiesen(2002)] at the Institute for Research in Economics and Business Administration, has nine regions: Western Europe, Other Europe and Former Soviet Union, North America including Mexico, Central & Southern America, Japan, China, Rest of Asia, Australia, and the rest of the World.

Total steel demand in each region is represented by an aggregate, constant elasticity of demand function. Two types of steel are produced and consumed in each region; oxygen blown steel and electric arc produced steel. These are treated as imperfect substitutes, because the steel quality as well as the input mix differs between integrated steel mills and mini mills. Steel demand is normally considered to be relatively irresponsive to changes in steel prices.

Steel from different regions are treated as imperfect substitutes. The degree of substitutability between steel from different regions is, however, quite high. The import price of steel is the sum of producer prices in the exporting region, export taxes, transport costs and import duties.

In each region, steel may be produced by three technologies: Basic Oxygen Blowing (based on a mix of pig iron and scrap), Standard Electric Arc Furnace (based on scrap) and DRI based Electric Arc Furnace (based on a regional specific mix of DRI and scrap). The outputs of the two EAF processes are treated as perfect substitutes. The substitutability between the two main steel types (BOF steel and EAF steel) is relatively little, especially in the short run.

The production of oxygen blown steel is modeled in several stages. At the first stage, coal and iron ore 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 produced. DRI based production of EAF steel has a similar structure to that of the BOF steel, except that natural gas is used in the place of coal in the iron making stage of the process. The standard EAF has a simpler structure, with only scrap and electricity as the major inputs. The model also accounts for some additional fossil fuels such as coal powder in the EAF process and heavy fuel oil and natural gas in the blast furnace. These inputs are used in fixed proportions.

The model allows for substitution between pig iron and scrap in the BOF. The technological possibilities to substitute between scrap and pig iron are reasonably good, but the energy balance of the process does not allow the amount of scrap to increase much beyond 30%. In the other processes and process stages, inputs are used in fixed proportions. The actual input mix per ton steel may, however, differ between the regions. Some differences may be explained by relative input prices that differ between regions. Other may result from managerial competence, experience and different vintages of capital. Such differences are taken as given.

Due to differences in input mix and input prices, production costs vary across regions. Production costs also vary within each region due to variations in productivity across plants. The profile of production costs for a given technology within a region, is described by an industry cost curve. This cost curve is treated as additively separable in output and factor prices. This formulation implies that a shift in factor prices will have an equal effect on all firms with a given technology in a given region. All observed differences in production costs are thus, somewhat arbitrarily, ascribed to factors that are not explicitly modeled, such as labour, maintenance, administration etc.

There are global markets for iron ore, coal and scrap. The world prices of these goods are determined by world supply and demand. The supply of scrap is relatively insensitive to price changes because of a more or less fixed amount existing, whereas the coal supply is very price sensitive due to large global reserves. Local input prices may however 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 policies.

Steel producers take steel prices as given. Steel prices are calibrated under the assumption that marginal cost pricing applies. 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.

The model is a short to medium term equilibrium model. 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 demand. The transport demand 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. A freight rate index, and thus the amount of transportation, is determined by the equalisation of aggregate transport demand with the supply of dry bulk transport services.

Parameter	**Value**
Price elasticity of steel demand	-0.3
Subst. el., BOF/ EAF	0.5
Subst. el., steel from different regions (Armington)	8.0
Subst. el., pig iron/scrap in BOF	1.5/0.5
Price elasticity of steel supply	
BOF steel:	0.7
EAF steel:	1.2
Price elasticity of supply of major inputs	
Scrap:	0.5
Coal:	2.0
Iron ore:	1.0
Transport:	0.27

Table 6.1: Key parameter values in the SIM

Figure A.1 in Appendix A gives a broad picture of how the model is constructed. For more information on the data and methods used in the SIM, see [Mæstad and Mathiesen(2002)] and [Mathiesen(2000)].

6.3 Simulations

The following analysis rests upon the assumption that the Chinese government has decided to somehow force the steel industry to make substantial reductions of emissions that damage the environment. As pointed out earlier, such a forced reduction will be controversial and and it can certainly be discussed whether or not it will be likely at the extent used in our simulations. However, in order to be able to clearly illustrate the effects of governmental intervention, this report will make use of a progressive goal of an emission reduction of 25% driven through by adequate taxes or the use of other economic instruments. This progressive goal seems to be close to reality although it is difficult to imagine the immediate implementation of for example the tax rates used in some of the simulations. Taking the government stated intentions as a staring point, however, the conclusions in this work are valuable. In the SIM the only emissions observable are the CO2 emissions, and for convenience the CO2 emissions are therefore used as the indication on whether the government has reached their goal of substantial emission reductions or not.

In China's Agenda 21 [The Administrative Center for China's Agenda 21(1994)], which earlier in the thesis has been established as an important directive for policy formulation, certain areas of economic policy are given special attention. Major activities outlined for the near future include:

- Removing or reducing those subsidies that do not conform with the objectives of sustainable development
- Reforming or adjusting the existing economic and fiscal incentives to conform with environmental and development objectives
- Establishing a policy framework that encourages the creation of a new system of pollution control and environmentally sound resource management
- Establishing a pricing system consistent with the objectives of sustainable development

Also considered important is the use of economic measures and market mechanisms to promote the development, introduction and popularisation of environmentally sound technologies in fields which have close links to the environment, and natural resources such as energy production, transportation and the steel industry.

The SIM allows for an introduction of market based instruments in the form of taxes and subsidies. It is assumed to be impossible to implement direct quantitative restrictions on the steel production or the emissions. The simulations in this report will therefore be based on taxes and subsidies on particular input factors as well as technologies. The use of these instruments seems to be well in accordance with the official statements from the white paper.

The Chinese steel market is special; factors such as size, history, culture and economic conditions jointly form a relatively different internal market with a somewhat different character from the other important steel markets in the world. Combined with the general difficulty of making perfect estimates of elasticities and costs for a steel model, this fact makes it worthwhile doing a sensitivity analysis to see how the simulation results vary with especially the elasticities that are taken as preconditions. Finally, I will examine what happens if the Armington elasticity, the elasticity of substitution between technologies, and the elasticity of substitution between inputs vary.

6.4 Substitution between BOF Production and EAF Production

Present conditions and likelihood of substitution As mentioned before, a shift from BOF to EAF technology will demand heavy initial investments. The attractiveness of implementing totally new technology will, however, increase if the variable costs decrease. An extended access to electricity, without the price reaching too high levels, may also boost the interest in EAF technology although Valrie Reppelin-Hill [Reppelin-Hill(1998)] found that input prices surprisingly enough have little influence on the diffusion of EAF technology. On the other hand, as discussed in Chapter 4, the demand for flat products and high quality steel products is supposed to increase more than the demand for other steel products. This may not make substitution of BOF with EAF very feasible, as it is normally regarded bad business to make heavy investments in production for a market that is declining. But, new technologies and methods are continually developed, and plants that are based on EAF technology and at the same time are able to make flat products more efficiently than earlier, are coming!

China already imports a great amount of scrap as there is a domestic shortage of high quality scrap. The government has traditionally encouraged the industry to make use of internal resources rather than becoming more dependent on international supplies, a fact that points against the development of new EAF production facilities and related increased amounts of imports. Another impediment to the development of EAF technology is the poorly developed infrastructure, which, among other negative effects, hinders large scale importation. On the other hand, China can refer to a very low degree of domestic recycling of scrap metals, and the potential in this area is great. Possession of natural gas combined with iron ore reserves points to the fact that if China shifts some production to EAF technology, it will more likely be to DRI based EAF, not scrap based EAF. But then again, the quality of iron ore is low and the infrastructure (energy) is poorly developed, so imports of both gas and high quality iron ore will most likely be a necessity for many years to come. In the following simulations it is therefore assumed that the distribution among DRI based and scrap based EAF steel remains the same.

Table 6.2 shows that China has relatively little EAF production compared to other steel producing regions. North America and Western Europe make the most extensive use of clean technologies, with scrap based production accounting for over 40% of the total production. South America, China and Australia on the other hand, bottom the statistics with 5% and 11% respectively. The three latter regions make some use of the DRI technology, South America the most with 28% of total production, while China and Australia follows with 5% and 4% respectively - a pattern that reflects the initial input reserves of the different regions and gives a hint about the importance of initial resources for the production decisions.

Region	BOF share	DRI share	Scrap share
Western Europe	0.60	0.00	0.40
East Eur. & former SU	0.80	0.00	0.20
North America	0.51	0.09	0.40
South America	0.65	0.28	0.07
Japan	0.71	0.00	0.29
China	0.84	0.05	0.11
Rest of Asia	0.34	0.19	0.47
Australia	0.85	0.04	0.11
Rest of World	0.38	0.47	0.15

Table 6.2: Production shares of BOF steel, scrap and DRI based EAF steel
Source: Steel statistical yearbook 2002 [IISI(2003)]

Expected consequence 1: The Chinese scrap demand will increase.

The relative scrap demand in China is expected to increase. China is, as discussed in Chapter 4, a grand net importer of high quality scrap and a natural consequence of increased scrap demand is that the imports of scrap increase. Because the world scrap supply is relatively constant, an increase in world market scrap prices will most likely follow the increased demand.

Expected consequence 2: Decreasing demand for iron ore and coal in China lead to lower relative prices of these input factors.

A decrease in Chinese BOF production will lead to a decrease in coal demand from the Chinese steel producers, ceteris paribus. The effect on the total Chinese coal demand, is however, more dubious. Increased demand for electricity will indirectly surge the demand for coal as much of the Chinese electricity production is coal based. Anyhow, none of these effects are likely to be of great importance for the world market as China is more or less self sufficient of coal. One could of course imagine that the surplus of coal reserves were exported to the rest of the world, and that this possibly could affect the world market. In the shorter term, however, this is not very likely as the Chinese coal in general has a low quality and is in relatively low demand. The poorly developed infrastructure supports the expectation of little or no increase in coal exports from China. In the longer term the picture may look different. The Chinese authorities are eager to export more of their large coal reserves, and may well be willing to invest in infrastructure and refining of the coal to be able to export more in the future. Although the use of coal in China is expected to decrease, a more immediate and indirect effect of a restructuring, however, is the change in relative prices. The prices of coal decrease relative to the scrap prices as the scrap demand increases. This may lead to substitution of scrap with pig iron and increased demand for coal in other steel producing regions than China. The same argumentation holds for the iron ore market. China is highly dependent on imports of high quality iron ore, and a decrease in Chinese iron ore demand is expected to have direct effects on the global iron ore market. Exports to China will certainly decrease, but the net effect on the global demand is not so clear. Supposing that the scrap prices will increase as a result of substitution in the Chinese steel production, the iron ore prices will fall relative to scrap prices, a fact that may lead to substitution to pig iron and thereby an increased demand for iron ore in steel production in the rest of the world.

Expected consequence 3: The EAF production in China will increase.

How will a more fundamental change in production technologies in China affect the world pattern of production technologies? There will hopefully be an increase of EAF production in China, and, as discussed above, this EAF production will probably be scrap based, at least in the short run. The amount of EAF production in the rest of the world, however, will probably remain more or less unaffected by the restructuring in China. Even though the scrap prices are likely to increase, the substitution elasticity between technologies is quite small, and it is not likely that EAF producers will abandon their modern cost effective production facilities due to a small rise in scrap prices. Following the rise in EAF production, a decrease in Chinese BOF production is likely. As the scrap prices are expected to increase, it is possible that the world BOF producers will substitute scrap with pig iron. In China however, the scrap content in the BOF process is already so low that the scrap prices may well have little influence on the input mix decisions. It is therefore difficult to predict the Chinese net effects of increased EAF production on the BOF production.

Expected consequence 4: The emission level in China will decrease.

The final goal of a fundamental change of production technologies is to reduce local pollution and emissions of climate gases related to steel production. The remaining question is therefore whether such positive results from the outlined restructuring can be expected or not. The local effects of more EAF production at the expense of BOF production, are probably positive, especially when assuming that the EAF production will be scrap based. It has to be added, however, that the local effects depend highly on how the extra electricity needed is generated[1]. It is more difficult to estimate the global emissions of climate gases. The expected general increase in global scrap based EAF production indicates a reduction in absolute emissions as long as the BOF production is not increased simultaneously. The possible substitution of scrap in the BOF process will, however, unavoidably lead in the other direction.

Simulation results

In order to examine the consequences of a shift from BOF to EAF technology, the SIM model is manipulated by adding an output tax on BOF production and/or a subsidy to the EAF production in China. A number of simulations with different combinations of taxes and subsidies have been tried out, and it seems like only subsiding EAF production gives very small or ignorable effects on the amount of EAF steel produced versus the amount

[1]The exact composition of the energy production in each region is unfortunately not incorporated in the model, and will not be subject to discussion in the report.

of BOF steel produced. The rest of this section will therefore focus on the effects of adding an output tax to the BOF production. Environmental taxes will mean an extra cost for the producers and can be expected to result in reduced production. In an attempt to neutralise this effect, however, the government can choose to give subsidies to production with cleaner technology, in this case EAF. The fact that the initial idea of this paper was to stimulate EAF production rather than punish BOF production also points in the direction of some sort of subsidising of EAF, and the last simulation will accordingly contain a subsidy to EAF production in addition to the BOF tax. The effects of two different output taxes, 20% and 30%, on BOF production are also simulated, while the basic scenario, the scenario to which all the other simulations will be compared, contains neither output taxes nor subsidies. In short, the analysis is based on the following simulations:

Simulation 1a Output tax on BOF production: 20%

Simulation 1b Output tax on BOF production: 30%

Simulation 1c Output tax on BOF production: 20% and subsidy of EAF production: 20%

Result 1: The global emissions are reduced by 5-7%, mainly due to reduced BOF production.

Table B.1, with up to almost 35% reductions of CO2 emissions in China as well as substantial global emission reductions, does indeed give a quite encouraging picture of the potential for emission reduction. All simulations give a reduction in global emissions of CO2. The size of the reductions span, however, from under 5% to well over 7%. Simulation 1b, with the highest tax on BOF production and no subsidies to the EAF production, gain the best results on global emission reduction. Following are simulation 1a and 1c with a reduction of about 4.5%. Note that these two different approaches, simulation 1a with medium high taxes on BOF production, and simulation 1c with medium high BOF taxes combined with some subsidies to the EAF production, give about the same result as far as emissions are concerned. An interesting observation is also that all emission reductions can be traced to the reduction of BOF production, whereas the two other technologies, scrap based EAF and DRI based EAF, are responsible for almost ignorable emission increases. These increases are highest when EAF production is subsidised.

Result 2: Emission reductions in China vary between 22% and 35%, and are caused by reductions of the production volume, especially of BOF steel.

The pattern is the same for China as for the world in general, only multiplied several times. Total emission reductions span from nearly 22% to close to 35%, with simulation 1b representing the most effective reduction policy followed by simulation 1a and simulation 1c with reductions of about 22%. As was the case for global emission reductions, the reductions in BOF production and thereby emissions from this technology, are responsible for the total reductions as the emissions from both types of EAF production in China are increasing. In simulation 1c where EAF production is subsidised, emissions from EAF production are increasing by over 13%, but this effect is by far outpaced by the reductions in BOF emissions. While the a priori expectations of reduced emissions were based on EAF production taking over for the Chinese BOF production, it turns out that the driving force behind emission reductions, is the reduction in total production volumes.

Result 3: Steel production volumes are in general reduced, particularly in China.

In general, a tax on BOF production will impose an extra cost on the producers that make use of this exact technology, and lead to less production of BOF steel. The question is how such a tax will affect the total amount of steel produced. The overall impression given by Table B.2, is that all simulations result in a reduced steel production volume, in China as well as on the world market. Especially in China this effect is evident, with total reductions up to 31%, while the highest reduction in global production is 2.8%. The reductions in BOF production are responsible for this trend as production of EAF steel is increased in all simulations. This picture confirms the a priori expectations about redistribution between technologies in China as well as the rest of the world. The increase in EAF production is however a relative measure, and does not represent substantial absolute amounts of extra steel produced, except maybe in simulation 1c where, in addition to the tax on BOF production, a subsidy was given. The absolute reductions in BOF production are in other words, not even close to being evened out by increased EAF production, neither in China nor in the rest of the world.

Like the case with the CO2 emissions, simulation 1b always gives the highest total production reductions at about 31.2% in China and 2.8% in the global market. Simulation 1a and simulation 1c follow behind with about 20% reductions in China and 1.7% in the world in total. Simulation 1a has the advantage of minimising the damages of reduced production in existent facilities, as it decreases the BOF production by "only" 24%. In simulation 1c, however, where a subsidy is given, the reduction of BOF production is evened out by the increase of EAF production, and simulation 1c ends up giving the lowest total production reductions. The policy in simulation 1c may therefore be preferable if the general production level is considered the most important decision factor.

Result 4: The global supply of input factors is reduced as a consequence of the reduced demand from BOF producers in China.

Table B.3 shows the global effects of the policy experiments on the input supply. Although almost ignorable, 0.4% at the most, the global supply of scrap is, contrary to expectations, reduced in all three simulations. The tax on BOF production has lead to reduced demand for scrap from the BOF producers in China. The absolute reduction in BOF production in China is exceeding the country's absolute growth in EAF production, a result that actually seems to lead to reduced demand for scrap in China and thereby decreasing scrap prices (from 0.3% to 0.8%, depending on the simulations). As expected, there is a slight increase in scrap demand for EAF production due to the low scrap prices, but this effect is surpassed by the reduced demand from BOF producers all over the world. The prices of iron ore and coal decrease more than the prices of scrap (from right under 2% to 4.5%), however, and Table B.4 shows that all BOF producers, including China, substitute pig iron for scrap, a fact that could lead to an increased demand for iron ore and coal. A general increase in BOF production in other parts of the world than China seems to support this expectation. The global supply of iron ore and coal, however, do decrease as a result of the reduced BOF production in China. Both reductions of iron ore and coal are most extensive in simulation 1b (iron ore: -4.359% and coal: -9.320%), and the effect on coal supply is in general stronger than that on the iron ore supply.

Result 5: The trade in finished and semi finished steel is increased.

By far the most dramatic consequences of the simulations for steel trade are, as shown above, reduced Chinese production of steel and a surging need for imported steel in order to meet domestic demand. The steel transport matrixes from simulations 1a-1c, as shown in Tables B.6, B.7, and B.8, confirm this. China increases imports of steel with as much as 90% from Australia in simulation 1b. The increased exports to China vary widely between the exporting regions, however. In simulation 1b, for example, China does indeed increase its import from all regions, but the increase varies between 37% from the rest of Asia and 90% from Australia. Simulations 1a and 1c represent the smallest changes in steel trade between China and the various regions with 12-54% increased imports, while showing about the same level of difference in export increases between the exporting regions. As Chinese imports of steel increase, the exports of steel from China decrease. Again, simulation 1b gives the most dramatic results with decreases varying between 61% to the rest of Asia and 67% to both South and North America. In the case of imports of Chinese steel, on the contrary to exports to the country, all regions experience about the same relative change in volumes. All regions simultaneously increase their exports to and reduce their imports from China. Most regions also experience a general increase in exports and decrease in imports. Excepted are China's closest neighbours, Japan and rest of Asia, where exports are reduced and imports are increased like in China. In the case of China, however, the changes are of a much more substantial character than in the case of the two latter regions. The global transport of steel increases in all simulations, most in simulation 1b (7.058%). Global steel trade will, in other words, according to the SIM, increase as a result of a fundamental restructuring in China.

Result 6: The trade in input factors is reduced.

As pointed out in Chapter 4, China does not initially export iron ore and the model accordingly predicts no effect on Chinese exportation of a restructuring of the domestic steel production. However, Tables B.10, B.11 and B.12 show that imports of iron ore to China are reduced substantially in pace with the reduction of BOF production. Simulation 1b stipulates as much as a 35% import reduction while simulations 1a and 1c suggest a 20% reduction. Imports to China are reduced by about the same relative amount from all its trading partners (South America, Australia and the rest of Asia). All initially exporting regions increase their exports to importing regions other than China. Especially Japan and Eastern Europe and former Soviet Union increase their imports of iron ore. However, the substantial reduction of Chinese iron ore imports dominates the changes in the picture of global iron ore trade, as the global iron ore transport is reduced by 1.705% in simulation 1c, 1.734% in simulation 1a, and 2.736% in simulation 1b.

Tables B.14, B.15 and B.16 show that all simulations give increased coal trade for all regions involved. Most of the initial exporters export more (between 1 and 5%) and most of the initial importers import more (between 1 and 5%). The only exception is Australia which, unlike other importers, does not experience any significant increases in its coal imports. Among those increasing their exports are China, Australia and North America, while Japan, south America, the rest of Asia and Eastern Europe and former Soviet Union increase their imports substantially.

Simulation 1b gives the largest increase in total steel related trade, with 0.963%, an increase that can hardly be called substantial. Although a restructuring in China seems to increase steel exports from other regions and simultaneously increase the total amount of coal traded, the initially substantial iron ore trade is reduced. The result is that the total trade volume related to steel does only increase marginally.

6.5 Substitution of Pig Iron with Scrap in the BOF Process

The present situation and likelihood of substitution Today, most of the Chinese steel is produced in basic oxygen furnaces (BOF). An improvement of this process will for many steel producers be the most affordable way to restructure to greener production as it does not involve heavy investments in new production facilities[2].

The usefulness of substitution of pig iron with scrap in the BOF process depends heavily on the availability of high quality scrap and the energy balance. The higher the quality of scrap, the higher share of scrap in the metal input is possible without disturbing the energy balance. At any rate, a scrap share of about 30% is considered the maximum limit. Normally, the share of pig iron in the metal input in the BOF process varies between 65% and 90% with scrap or scrap substitutes accounting for the rest. As can be seen from Table 6.3, North America is the region that has been able to exploit the potential of scrap as an input factor in the BOF process, with an average share of scrap in metal input of 25%. "Eastern Europe and the former Soviet Union" also stand out with 23% scrap in the total metal input. At the other end of the scale, we find especially the Asian steel producers; Japan has the lowest scrap share, 5%, and China is hardly any better with a scrap share of 8%, whereas "Rest of Asia" makes slightly more use of scrap in its production (13%). In sum; China seems to have a great potential in

[2]The variable production costs are, however, lower in the EAF production, so whether an enterprise chooses substitution of inputs or a more fundamental substitution of technology, depends partly on the ability to raise investment funds.

substituting pig iron with scrap.

Region	Pig Iron share	Scrap share
Western Europe	0.82	0.18
East Eur. & former SU	0.77	0.23
North America	0.75	0.25
South America	0.87	0.13
Japan	0.95	0.05
China	0.92	0.08
Rest of Asia	0.87	0.13
Australia	0.84	0.16
Rest of World	0.85	0.15

Table 6.3: Input share of pig iron and scrap in the BOF process
Source: CRU International
Ltd. [CRU International Ltd.(2001)] [CRU International Ltd.(1999)]

Expected consequence 1: The demand for scrap in China will increase.

The scrap demand in China is expected to increase. As discussed in Chapter 4, China is a grand net importer of high quality scrap and a natural consequence of increased scrap demand is that the imports of scrap increase. Because the world scrap supply is relatively constant, an increase in world market scrap prices will most likely follow the increased demand.

Expected consequence 2: Lower relative prices of iron ore and coal will stimulate the demand for these input factors in other regions than China.

Ceteris paribus, an increased use of scrap in the BOF process in China implies a decrease in the use of both iron ore and coal. China is more or less self sufficient with coal, and the reduced Chinese coal demand will therefore probably have insignificant direct effects on the world coal market (see discussion in the case with technology substitution). When it comes to the effects on iron ore and scrap of restructuring to more EAF production in China, the predictions will be of the same character as those from the case with input substitution. The increased scrap demand in China will probably lead to higher world market prices and the Chinese imports of iron ore are likely to decrease. The decrease in relative prices of coal and iron ore compared to those of scrap metals, may lead to substitution of input factors in other steel producing regions, and as a result, the total effects on the world market seem unclear before the simulations are done.

Expected consequence 3: There will be few changes in the global distribution of production among technologies; if anything, a slight decrease in EAF production is expected.

How will the change in inputs in the Chinese steel production affect the world pattern of production technologies? An abundance of coal reserves suggests an increased possibility of providing cheap electricity for the Chinese EAF production. It is questionable, however, whether more supplies of coal will improve the present electricity supply. The insufficient development of electricity production facilities may be a true impediment for the supply of Chinese electricity. The electricity situation illustrates well the fact that the effect on the Chinese technology pattern of a restructuring is difficult to tell in advance. Substantial scrap subsidies are more likely to increase the Chinese EAF production. The foreseen increased scrap prices are on the other hand likely to have a negative influence on the amount of world EAF production, as this kind of steel production becomes less profitable. However, Valrie Reppelin-Hill [Reppelin-Hill(1998)] finds in his article that the input prices have little influence on the diffusion of EAF technology. A safe guess is that, if any effect at all, a modest decrease in the global amount of EAF production can be expected. The total effects on the use of BOF technology are difficult to estimate. A reasonable guess is however, that the BOF producers in China will make use of relatively more scrap and that at least some of the BOF producers in the rest of the world will substitute to pig iron as a result of the increase in scrap prices relative to pig iron prices.

Expected consequence 4: The emissions in China will decrease.

As in the case with substitution of technologies, the motivation behind restructuring in the first place, was to reduce the negative effects of steel production on the environment. The desired effects from changing the input mix in BOF production are reduced emissions of climate gases as well as reduced local pollution. Due to substitution of pig iron with scrap in China, it seems like the local pollution level will decrease with such a restructuring. It is, however, unclear whether the effect on world emissions of climate gasses will be negative or positive. This depends on the degree of substitution between inputs in other parts of the world.

Simulation results

The substitution of input factors in the BOF process can be simulated by adding a subsidy to the use of scrap. China has been able to provide, or rather make use of, very little local scrap compared to other steel producing countries. It is difficult to think of a reason why China should not be able to recycle its scrap metals like other countries do, and it seems reasonable to believe that China has a great potential in this area. It is therefore assumed that the Chinese government at some time will, or at least could, stimulate production and use of scrap metal by providing financial and technical assistance to the production of it. This policy can in the SIM model be apprehended as a subsidy to the Chinese scrap users. Different levels of subsidies are simulated in simulations 2a and 2b.

Subsidies alone have never been a preferred policy in order to stimulate production of a certain kind of or wanted good. It is also possible, however, and probably necessary, to implement taxes on the use of coal and iron ore in order to reduce the level of those input factors compared to the use of scrap metals. The already scarce use of scrap metals in BOF production in China is mainly a supply problem, there has not been a tradition of recycling metals. Taxes on coal and iron ore alone may therefore well lead to a lower production level rather than a substitution of pig iron with scrap, but this possibility will not be closer examined in the following analysis. In order to gild the pill, it is assumed that the authorities will, or at least consider to, make use of subsidies in addition to taxes. A somewhat progressive attempt to reduce emissions could be to both tax the use of coal and/or iron ore (indirectly the use of pig iron) and at the same time provide subsidies for the use of scrap metals. If the subsidies and the tax level were set so that the total tax revenues equalled the total amount of subsidies, this policy would be very much like a Pigou tax[3]. Unfortunately, such a policy is very difficult to simulate in the present version of the SIM. It would probably be possible to extend the model, but such an extension is not carried out in this thesis. However, an attempt to capture the combination of a green tax with subsidies, is done in simulation 2c.

When using the SIM model as it is originally constructed, it turns out that taxes on pig iron as well as scrap subsidies give, if any, only marginal effects on the emission level. The authors of the SIM model had little information on the Chinese elasticities and simply set the elasticity of substitution between the input factors in China to 0.5, the same as North America, Rest of Asia and Rest of World. For all other steel producing regions the elasticity in question is set to 1.5. The following simulations are, however, based on an elasticity of 1.5 also in China, as it seems wrong to assume such a small ability to substitute scrap for pig iron in a production process where the potential of scrap use is hardly exploited at all. Technology may of course be an impediment to exploiting this potential, but investments to update the existing production facilities need not be of such a size that the substitution elasticity should be as low as 0.5. The analysis is in sum based on the following simulations:

Simulation 2a Elasticity of substitution between inputs in the BOF pro-

[3] According to the Penguin Dictionary of Economics [The Penguin Dictionary of Economics(1998)], Pigou is the "founder" of the polluter-pays-principle. His idea from 1932 was to tax pollution rather than banning it. The advantage of such a policy is that if the tax rate covers the damage or suffering caused by the pollution, it will pay firms to pollute only if the benefits of them so doing outweigh the costs. The tax will also generate revenue that can be used to compensate those who suffer most

duction: 1.5, subsidy of the input factor scrap: 50%

Simulation 2b Elasticity of substitution between inputs in the BOF production: 1.5, subsidy of the input factor scrap: 30%

Simulation 2c Elasticity of substitution between inputs in the BOF production: 1.5, subsidy of the input factor scrap: 30%
Tax on the input factor pig iron: 10%

The basic scenario, the scenario to which all the other simulations will be compared, contains neither output taxes nor subsidies and is based on an elasticity of substitution between input factors of 0.5. Simulation 2c is probably the most realistic simulation as a subsidy of 50% well may be too substantial and costly in terms of both market distortions and finances. The national government does not have inexhaustible funds, and a policy that can show to a certain amount of incomes as well as large expenses, will probably gain more support.

Result 1: There are insignificant changes on the global emission level, but reductions in China are amounting to up to 5%.

A reform in China was expected to reduce Chinese emissions. Substitution effects in the rest of the world may point in the direction of redistribution of emissions among the remaining regions, and not necessarily a global reduction of emissions, but the hope was still that there would be a positive global effect of the main actor's environmental friendly reforms. The general impression by looking at Table C.1, is unfortunately that our simulated tax/subsidy policies have little or no effect on the global emissions of CO2. At the world level all simulations give reduction of emissions, but they are so small, well under 1%, that they are almost ignorable. Most of these reductions stem from the reduced emissions in the BOF production, while the emissions from scrap based EAF production and DRI based EAF production, remain more or less the same. Simulation 2a, with 50% scrap subsidies always gives the largest reductions, whereas simulation 2c, with 30% scrap subsidies and a 10% tax on iron ore, gives the next best result as far as emissions are concerned.

As was expected, however, this depressive picture changes when examining the local Chinese effects. The general pattern is the same, there are reduced emissions from BOF production, but the size of the reductions are far higher in China than are the global ones. The reductions of local emissions are as high as 5% in simulation 2a and almost 4% in simulation 2c. Also in simulation 2b the reductions are substantial. Although it does not make sense to talk about local effects of CO2 reductions, there is, as mentioned earlier, reason to believe that other types of local pollution with local effects are reduced proportionately. The policy of subsidising scrap will in other words, most likely give highly desired effects on the local Chinese environment and confirms the expectations formed in advance of the simulations.

Result 2: Both EAF and BOF production increase in China, while there are no global changes in technology distribution.

When a subsidy of an input factor in BOF is given, it is natural to expect increased production with that technology. This expectation seems to be confirmed in Table C.2, where the effect of the simulations on total steel production in China is always reported to be positive or neutral. Not surprisingly, simulation 2a, where the subsidies are at the highest, exhibits the highest production increase. Although the initial idea was to increase the use of scrap in the BOF process, the national subsidising of scrap use also seems to have increased the Chinese scrap based EAF production substantially, with more than 13% in simulation 2a, and more than 9% in simulations 2b and 2c. However, the initial production level with this technology in China is not extensive, the increase does not represent a great absolute amount, and it is impossible to trace this effect on the global level. On the other hand, there is no reduction of global EAF production like expected in advance of the simulations, a fact that can be taken to support the mentioned findings of Valrie Reppelin-Hill [Reppelin-Hill(1998)]. Similarly, the tax on iron ore has made the DRI production less profitable in China and in simulation 2c, the Chinese production with this technology is reduced although there is no such effect on the world market. The production of BOF steel in China is increased in all simulations except simulation 2c where the negative effect of the iron ore tax dominates the positive effect of scrap subsidies and reduces the total amount of produced BOF steel. There is little or no global effect, however, either on the distribution among the technologies or on the total production level. This implies that other producers than the Chinese have reduced their scrap based EAF production and increased the production of BOF steel and in some cases DRI based EAF steel.

Result 3: China increases the scrap use with up to 65% while the rest of the world substitutes scrap with pig iron.

As the Chinese demand for scrap is increasing, the scrap prices are, as supposed in advance, increasing as well, from 2% in simulation 2b to 5% in simulation 2a, making it more expensive for producers in the rest of the world to use scrap in their production. Not surprisingly, Table C.4 shows substitution of scrap with pig iron in all regions but China. The table is based on changes related to simulation 2c where an iron ore tax is combined with scrap subsidies, but the result would be similar if it was based on the simulations with no taxes. In China, the use of pig iron is reduced by 4.7% while the use of scrap is increased with 67.5%. This increase seems substantial, but remember that the initial levels of scrap use in Chinese BOF production were among the lowest in the world. In order to reach the level of for example North America, an increase of almost 200% would be necessary, but still, simulation 2c brings China up to the level of the rest of Asia, which is not bad after all. Scrap demand is increasing in China, but decreasing in the rest of the world as a result of the simulations. How does this affect the global supply of scrap metals? Table C.3 actually shows that it is the increased demand from China that dominates the picture, and the prices are accordingly high. Even though the scrap supply is relatively inelastic, it is increased in all simulations, most in simulation 2a and second most in simulation 2c, while both the prices and the supply of coal and iron ore are reduced. The effects are very small however, a 2.515% increase of scrap supply at the most, so their importance should not be overestimated.

Result 4: A higher steel production level in China leads to lower imports and a reduction in the global steel trade.

The SIM model predicts a reduction of Chinese steel imports as the domestic steel production increases in all simulations, see Tables C.6, C.7 and C.8. Simulation 2a, which gives the highest production increases, predicts the highest import reduction, between 4 and 11% from the various exporters, while simulation 2c with the lowest production increase, indicates an import reduction of maximum 5%. The extent of the relative import reduction varies highly between the exporters. Australia seems to be the less affected exporter in relative terms, while "rest of Asia" and "rest of World" are most severely affected by China's increased independence. Exports from China are increased simultaneously with the diminishing imports. All importers gain more or less the same from this, no region increases its relative imports from China significantly more than the others. Simulation 2c gives the lowest Chinese export increase with 1% to all importing regions, while simulation 2a gives the highest ones with increases amounting to between 7 and 8%. In most regions, however, both imports and exports are extended as a result of the Chinese restructuring. China and "rest of Asia" are exceptions as they reduce imports and increase exports, although China at a much greater scale than "Rest of Asia". Western Europe also represents an exception as the region either reduces or freezes its steel exports in the simulations. The Chinese import reduction seems to dominate the global picture as the total volume of steel traded is, if anything, reduced (reductions are very small, and vary between 0.418% in simulation 2c and 0.936% in simulation 2a).

Result 5: The total amount of iron ore and coal traded remains the same. China imports less while other regions import more.

As far as the iron ore concerns, the trade pattern is very little affected by the Chinese restructuring, see Tables C.10, C.11 and C.12. Chapter 4 pointed out that China is not an exporter of iron ore, on the contrary, the Chinese steel producers are highly dependent on imports of high quality ore. Simulations 2a-2c show that as the use of iron ore in Chinese steel production is reduced, the imports sink accordingly. The relative reductions of Chinese ore imports are affecting all trade partners (South America, Australia and "Rest of Asia") equally, with a decrease varying between 3% in simulation 2b and 7% in simulation 2a. Both Eastern and Western Europe experience a marginal increase in imports as a result of input substitution, about 1% from all exporting regions, while Japan and "Rest of Asia" see no changes in their ore import pattern at all. In all three simulations the Chinese import reduction ends up dominating the total change in global iron ore trade, as the total amount traded is reduced by 0.354% at its most in simulation 2a. The total amount of iron ore traded is in other words almost the same as before a Chinese restructuring, but the pattern has changed.

The same conclusion goes for the coal trade; the total amount traded is more or less unchanged while the trade pattern changes slightly. In all simulations there are a couple of changes, although in sum they never represent more than 1%, see Tables, C.14, C.15 and C.16. The a priori assumption of little or no increases of Chinese coal exports, seems to be confirmed. Eastern Europe, Western Europe and South America all seem to be importing slightly more coal, and their import increases are distributed equally among the exporting regions. China is, as discussed in chapter 4, not an important part of the global coal trade, and the consequences of a restructuring were therefore not expected to have direct effects on the world market. Changes in relative prices of the other input factors could on the other hand lead to an increased use of coal and iron ore. This may have been the case in our simulations, where the scrap subsidies in China have lead to increased scrap prices and some substitution of scrap with pig iron in other producing regions. The simulations give only weak support for this theory, however, as total coal trade is increased by only 0.852% at its maximum in simulation 2a.

In sum, none of the simulations result in more than marginal changes in the total amount of steel related trade. While China and the "rest of Asia" have reduced their purchases on the world market, the remaining steel producing regions have increased their trading and more or less evened out the negative effects from China and its neighbours. If anything, there is a marginal reduction in trade, representing only 0.237% at its highest in simulation 2a.

6.6 China Specific Issues and Shortcomings of the Model

The model is based on data on the cost structure of billets & blooms and slabs, which are all mainly continuously casted. As shown in Chapter 4, in China there is still an extended production of ingots, a fact that results in different input and output patterns from the continuously casted products. In addition to this, there are very few observations from China. Plants that do not make use of the continuous casting technology typically experience lower productivity, more energy intensive production, higher costs and inferior quality on their output. This fact is not reflected in the model, and is likely to especially imply the following modifications of the simulation results: First, the results coming from the SIM model may well determine steel prices that are too modest when the fact that the Chinese production costs probably are higher than the baseline in the model is taken into consideration. Second, the demand pattern for important input factors such as iron ore and coal may be different from that determined in the model; less productivity and higher energy intensity probably lead to higher demand and higher local prices of these factors. Third, lower quality than assumed indicates lower real exports (as low quality steel is less demanded) and higher imports (as there is a substantial need for high quality steel in China). Fourth, the prices of Chinese steel are possibly higher because of less efficient (and more costly) production methods. Fifth, the environmental damages and the CO2 emissions made by steel production in China are probably higher than those projected by the model due to the energy intensity in particular, but also due to the use of technology that is less focused on being environmentally friendly than that of continuous casting. Total abatement costs (in order to achieve the same absolute emission reductions) are therefore probably higher than projected by the model.

The model does not differentiate between flat and long products. As they have different trade patterns, costs, and final demand patterns, this is important. It is, however, possible to trace some of the differences by looking at the different profiles of the EAF steel and the BOF steel. Both long and flat products can be made from both types of steel, but long products are more commonly made by EAF.

China has traditionally not been able to provide the high quality needed for sophisticated use, a fact that hinders the country in exploiting the full potential of internal as well as external steel demand. The SIM model does not take this fact into consideration. No distinction between different qualities of steel is made, only the distinction between EAF steel and BOF steel is embodied in the model. This does probably not have any notable effects on the analysis later on in this report, it simply means that the model is not suited to analyse aspects of steel quality.

Although there still exist many steel production facilities based on open hearth furnaces and other outdated technology in China, these technologies are not part of the steel industry model. For most countries and regions, this fact does not have any consequences of interest, but when it comes to China, IISI [IISI(2003)] reported that in 2001, as much as 17.7% of their crude steel production was in open hearth furnaces or other old-fashioned and polluting technologies. It must necessarily have an impact on both the level of production and the level of emissions that such an amount of steel is considered to be BOF steel (as it is in the model) when it really is of a much more polluting and inefficient kind. The estimates of total emissions from Chinese steel production should therefore be treated with care, they are most likely understated. In our simulations later on, the effects from changing the input mix in BOF production as well as from putting a tax on BOF production, should also probably be considered to be a little over estimated.

The Armington elasticity (the elasticity of substitution between regions) in the model is set to 8. On the one hand, this elasticity may be too low for the steel market as in many aspects it is a market of more or less free competition and one could therefore expect that increased prices of steel from one region would lead to immediate substitution to steel from other regions. When it comes to China, however, the elasticity may well be too high as China is a low cost producer with a certain "extra cost margin" compared to the majority of other steel producers. A small raise in costs in China may therefore not necessarily lead to higher prices and consequently does not necessarily mean as high a substitution to steel from other regions as the model implies. Later on, sensitivity analyses will be used in order to examine how the Armington substitution elasticity affects the simulation results.

The SIM model exhibits the trade pattern through its transport matrixes which are based on observed trade flows and transport distances. Steel, ore, and coal transport matrixes are presented, but due to restricted access to data, the model has not incorporated the scrap metal trade flow, but simply kept to stating that the price is set at the world market. It is therefore not possible to examine the effects of the restructure simulations on the scrap trade.

The model can only give an indication of whether the environmental consequences are as intended. The problem is that the model only gives an estimation of changes in CO2 emissions related to the restructuring of production, it does not give any information about the local air quality, the emissions in water or the waste situation. Neither does it give any information about the extent of recycling in the process. It is however, possible to assume that a restructure resulting in reduced CO2 emissions simultaneously will help mitigate other environmental problems related to the steel production. The CO2 emissions are, however, a global factor where the other damages have more of a local character and it is necessary to be careful when using the CO2 emission level as a measure for total environmental improvement.

An important assumption in the SIM model is that the market mechanisms function properly so that increased production costs lead to increased consumer prices. The special history of the economic system in China has, however, not inhibited such mechanisms, and there is no tradition of increased production costs leading to increased consumer prices. In order to be able to reduce emissions from the industry, it will probably be necessary, but difficult, to implement such mechanisms, especially in the minds of the corporate leaders. Things change quickly in China at the moment, however, so such an implementation may well be realistic and in place in relatively little time. Anyhow, the SIM model just assumes that they already are in place and may therefore indicate greater effects of a restructuring than will necessarily be the reality.

6.7 Sensitivity of the Simulations

Table 6.1 showed that the elasticity of substitution between EAF steel and BOF steel was initially relatively small in the sim model (0.5). This is partly due to the huge initial investments necessary to start producing with a completely new technology. Subsidising scrap and at the same time implementing a tax on input factors that are important only in the BOF production, like it is done in the second set of simulations, will in other words lead to a relatively small amount of substitution to EAF production. Similarly, a direct tax on BOF steel production has relatively little direct effect on the production of EAF steel. According to our simulations, the extra push towards EAF production that the government may have hoped for when implementing the BOF tax, seems not to have appeared. However, that already existing EAF production facilities have the capacity to produce more than present numbers show, and that the elasticity of substitution between the steel types should be somewhat higher, is a plausible suggestion. If this was the case, one could expect to see the simulation results moderated slightly. More steel producers may shift to EAF production and the demand for coal and iron ore would probably sink together with the emissions. Simulations where the elasticity of substitution between technologies is changed to 0.75 and 0.9, are run in order to examine closer the sensitivity of this elasticity.

As discussed earlier, the Armington elasticity (the elasticity of substitution between regions) is set to 8 in the model. On the one hand, this elasticity was argued to be too low for the global steel market, as it in many aspects is a market of more or less free competition. In the case of China, however, the elasticity was argued to be too high as China is a low cost producer with a certain "extra cost margin" compared to the majority of other steel producers. Two simulations are done in order to test the sensitivity of the results of the Armington elasticity. The first is programmed with an Armington elasticity of 16, while the second uses an Armington elasticity of 4.

In the case with input substitution in the BOF process, the argument that China probably should have a higher input elasticity than 0.5 in the BOF process, was presented. Following this way of thinking, a simulation with the input elasticity in the BOF process of 1.5 is done in the simulations of substitution of technologies.

All the simulations that are done in order to examine the importance of the mentioned initial premises, will be compared to one particular simulation from each of the two reforms. In the first case, where a substitution from BOF production to EAF production was the intended consequence, simulation 1c, with an output tax of BOF production of 20% and a subsidy of 20% to the EAF production, will be the benchmark. The benchmark in the second case, where a substitution between input factors in the BOF production was the intention, will be simulation 2c, with an input tax of 10% on pig iron and a subsidy of 30% on scrap metals.

The results of the sensitivity analysis are shown in Tables C.17, C.18, B.17 and B.18. There are a few general patterns recognisable in the two tables. First, there were in general very small or even insignificant changes to the original simulation results from changing the values of the sensitivity parameters. Second, the effects are always more significant in the case with technology substitution than in the case with input substitution. This is probably a result of the fact that the BOF production reductions in China are more extensive in the case with substitution of BOF with EAF than in the case with substitution between pig iron and scrap. These substantial reductions of production volumes create more opportunities for substitution, of technologies and/or of production regions, depending on Armington elasticities and technology substitution elasticities, than does the last case. Third, the effects on China are, not surprisingly as the policies were implemented i China, always bigger than the global effects. Fourth, when examining closer the results of the different sensitivity simulations, it seems clear that the original results are only slightly changed due to higher elasticities of technology substitution. To be more precise; in the case of an input tax (or subsidy), there are hardly any effects at all, while the technology tax case naturally (as the tax works directly on the variable in the elasticity in question) is more affected by the changes of the elasticity. Fifth, only when looking at the results from changing the Armington elasticities is it possible to trace any substantial changes compared to the original results. Again, the technology tax case is the most affected. Especially when the Armington elasticity is 4 and the possibilities of substitution between regions are more restricted, the effects do stand out. The Chinese emissions are reduced by as much as 12 % compared to simulation 1c, while the global emissions are reduced by 2%. The production is reduced accordingly, and can be traced mainly to the reductions of BOF production, which again lead to reduced demand for iron ore and coal. In sum, the broad picture is that both benchmark simulations are little affected by changes of the premises in the model. Simulation 1c shows the greatest sensitivity, especially to changes in the Armington elasticity.

6.8 Discussion

Which policy seems most suitable in the first set of simulations? To recapitulate: the first set of simulations contains different attempts on taxing one of the most polluting technologies, namely the BOF technology, in order to force the producers to substitute to EAF production. In China, as well as in the rest of the world, simulation 1a gives lower emission reductions from the BOF production than simulation 1c. This effect is evened out by the growth in EAF production and an associated emission increase in simulation 1c, however, and the latter ends up giving the lowest total emission reductions of the two. Simulation 1a is in addition the simulation that is closest to matching a goal of 25% reduction of emissions in China. However, simulation 1c does give emission reductions very close to those of simulation 1a, but simulation 1c does at the same time provide stimulating support for EAF producers and may therefore be preferred by authorities as well as producers. All involved parties wish for an increased steel production in China as the demand is literally exploding. This may point in the direction of giving some subsidies to EAF production combined with the output tax on BOF production. The policy in simulation 1c may therefore be preferable if the production level together with the emission level are considered the most important decision factors[4]. Simulation 1a, on the other hand, has the advantage of demanding less administration and being less distortive on the steel market.

Which policy seems most suitable in the second set of simulations? The second set of simulations consists of different attempts to tax highly polluting input factors in the BOF process. The Chinese authorities have, in addition to setting goals of emission reductions, expressed a great need for expanding the national steel production volume. The policy in simulation 2c, which is suggested to be the more likely earlier in this thesis because of its capability of reducing emissions, leads to a more or less unchanged amount of Chinese steel produced. The policy in simulation 2a, however, shows a production increase of more than 3% and may be more tempting to those who stress increased production levels. One could, however, argue that extensive use of subsidies, as is the case in simulation 2a, can hardly be a sound and lasting way of increasing the production level[5].

[4]The SIM is a static model and the analysis of simulations done in SIM will necessarily confine itself to comparative statics. Market forces that are not incorporated in the model, and therefore assumed exogenous to the analysis in question, e.g. a general growth in the economy, may well indicate increased production of steel and compensate for the reduction caused by environmental taxes. In its turn, this may lead the authorities to make different policy choices than the ones indicated from the isolated case of the SIM.

[5]Again, the evaluation of the suitability of the various policies must be handled with care as forces exogenous to the model may lead the authorities to judge differently about

A comparison of the two sets of reforms. The global steel-related trade volume does never change dramatically as a result of a Chinese restructuring. Both experiments show only marginal changes in the total volume traded. The importance of the various trading regions as well as the traded goods does, however, change as a result of the Chinese restructuring. In the second case, where an input substitution is simulated, the Chinese steel imports are reduced by up to 11% caused by domestic production increases, while the global trading of input factors remains about the same. All exporters of steel seem to suffer equally from the steel import reductions in China and they increase their exports to other importing regions only marginally. In the first case where substitution between technologies is simulated, the changes are more distinct and with a different sign. Substantial production cuts in China lead to up to 85% increase in Chinese steel imports, and larger shares of the other regions' exports are directed to China. The Chinese iron ore import decreases while all other regions trading with iron ore reinforce their initial positions as exporters and/or importers by increasing imports and/or exports by up to 5%. When it comes to coal trade, all initial trade positions are reinforced, with increases of imports and/or exports of up to 5%.

Both groups of simulations lead to, assuming it possible to read this out of the model, reductions of the local pollution in China. Although the extent of the reductions is varying, it seems clear that all six simulations are able to reduce pollution in China. The global reduction of emissions of CO2, which can be read directly from the model are disappointingly small in all simulations. This is mainly a result of regions other than China substituting scrap with pig iron. In some cases there is also substitution of EAF steel production with BOF production. However, the model does not make use of emission restrictions of any kind in regions other than China. This is not entirely realistic as many of the regions actually practice different kinds of restrictions. This fact probably has the effect of moderating the substitution

the different policies simulated.

of input factors in the BOF process as well as the substitution of technologies in the simulations. The global effects of a Chinese restructuring may, in other words, be of a slightly more positive kind (actual emission reductions) than expressed by the simulations.

The attempts to form tax policies in order to induce substitution between technologies give the best results in terms of emission reductions. The local emissions in China are reduced by up to 35% whereas the case with input substitution in the BOF process only gives up to 5% reductions. On a global basis, the picture is the same even though the effects are smaller - the simulations with substitution of technology give up to 7% global emission reductions, while the other case only exhibits marginal reductions, close to 1% at the most. The premise of all simulations was that the Chinese authorities wish to reduce the polluting emissions coming from the steel sector. Having this in mind, the analysis suggests that a policy aimed at making the producers substitute between technologies will be the most preferable. The policy implications are, however, not so straight forward as they may seem. The substitution of technologies will necessarily lead to severe cuts in Chinese steel production in the short and medium term, and implicates either large import increases or reduced industrial activity in China. A policy which reduces domestic production will most certainly be extremely controversial and probably not entirely realistic.

The instruments implemented in the two sets of simulations are in many aspects very different. In the first case, there was an extensive use of scrap subsidies. This kind of economic instrument implicates a great amount of public funds transferred from the consumers, the Chinese people, to the producers of steel, which in an increasing number of cases are private enterprises. In the second case, with a tax on the BOF technology, there was a transfer of funds the other way round, from the producers to the public funds. The sets of experiments are therefore not one-to-one comparable, a fact supported by the very different results exhibited in the various tables in Appendices 2 and 3. It is consequently important to keep in mind that the differences in outcomes from the two policy experiments are a result of both the different instruments in use and the underlying premises of the steel market. Simply implementing a tax on the input factors in the BOF process was not evaluated as a likely approach to the problem, and a possible subsidising of EAF production on the other hand, seemed like a very expensive policy with indistinguishable effects. However, it is reasonable to believe that the main results, or at least the direction of the movements resulting from the two sets of experiments, can give important, if not exact and directly comparable, insight about possible consequences from some of the Chinese authorities' attempts to reduce the emission level in the Chinese steel production.

Chapter 7

Concluding Remarks

The GDP growth rate in China has been persistently high in several decades. Parallel to an impressive general growth, the steel industry has reinforced its position, and the industry has experienced an annual growth rate of as much as 10.6% over the last decade. The other side of this promising picture is, however, characterised by extensive emissions of CO2 gases and other related environmental problems. The need for doing something about this highly undesirable and damaging effect of increased steel production is pressing. The effects of a possible restructuring to "greener" steel production in China will be of vital interest for policy makers, environmental organisations and the actors in the various markets related to steel. This report has tried to identify some of the possible measures that can be actuated in order to deal with the environmental challenges of steel production. In particular, two such measures have been modeled with the help of a steel industry model (SIM), in order to examine more closely the effects on emissions, on the production pattern and on the trade pattern.

The various simulations carried out in this report give no clear policy advice, their value is rather that they help structure the thoughts around a green restructuring of the Chinese steel production. Policies attempting to change the input structure in the BOF production seem to have very modest effects compared to policies aimed at substitution of technologies. The Chinese authorities will most likely have to decide which is the more important, production growth or pollution reductions. The simulations that substitute BOF technology with EAF technology, show especially that Chinese authorities will be forced to face this serious dilemma when deciding for an emission reduction policy. The authorities do, of course, wish the reductions to be as extensive as possible given the resources expended, they do in short want the reduction policy to be as efficient as possible. On the other hand, the continuous growth of the Chinese economy does depend on increased domestic production or imports of steel as the demand is virtually exploding. Chinese authorities, which have traditionally strongly encouraged self sufficiency, will most likely prefer the increasing demand to be met by domestic production. With the instruments available in the SIM model, it seems difficult, or maybe impossible, to construct a tax policy that reduces emissions effectively without severe reductions in production. The good news, however, are that although the simulations with input substitution in the BOF process hardly give any global emission reductions and the local effects are much smaller than those of the other simulations, they actually result in much needed local emission reductions. And, because the SIM is a static general equilibrium model, market forces that are not incorporated in the model, e.g. a general growth in the economy, may bring a general increase in steel production which can compensate for the reduction caused by environmental taxes. The choice between production and emissions that the authorities are assumed to be forced to make may therefore not be as difficult as predicted.

The use of the SIM model in order to analyse the Chinese steel market does, as discussed in section 6.5, present a few problems. Firstly, it would be interesting to develop the model a bit further in order to be able to distinguish between long and flat products and see how this affects the prior analysis. In this study, it has only been possible to make a few guesses about the direction of development based on an assumption that long product follow the development of EAF production and flat products the development of BOF production. Secondly, it has not been possible to say much about the reactions of the scrap market to the Chinese restructuring. Programming of the scrap market is not included in the model due to scarce access to information, but such information would definitely represent an improvement for the model as well as for the analysis. A related problem is the lack of data on Chinese steel plants. Scarce data material may give a wrong impression of the Chinese steel industry, in this case probably in the form of a more modern industry than the one that actually exists. Improved access and use of Chinese data would consequently give the model and the analysis a valuable upgrading. Furthermore, an implementation of other regions' emission restrictions could give valuable information about whether a Chinese restructuring will just shift the emissions to other regions or whether it represents a real reduction of emissions.

The problems discussed above are all problems related to the actual content of the SIM model. Areas for further research do, however, also consist of problems not incorporated in the model. There are, for example, available a series of instruments, economic and political, not applicable in the SIM model, to reduce emissions from the steel production. Technological improvements of a less fundamental and costly character, e.g. implementing cleaning technologies or improving the energy efficiency, may be a solution, but such initiatives are not a topic in this analysis.

Since the forming of the SIM model and the beginning of this thesis, the development in China and the Chinese steel sector has taken place very rapidly. The data forming the base of the thesis are already old news and may be misguiding. It can be argued, however, that, if anything, the tendencies described in chapters 4, 5 and 6 have only been reinforced during the last two or three years. The results from the preceding simulations should accordingly not be directly misguiding, rather pointing too moderately in the right direction. It would, however, naturally be highly useful to update the data on which the SIM model is based, especially those on production numbers and emission profiles.

Appendix A

The Steel Industry Model

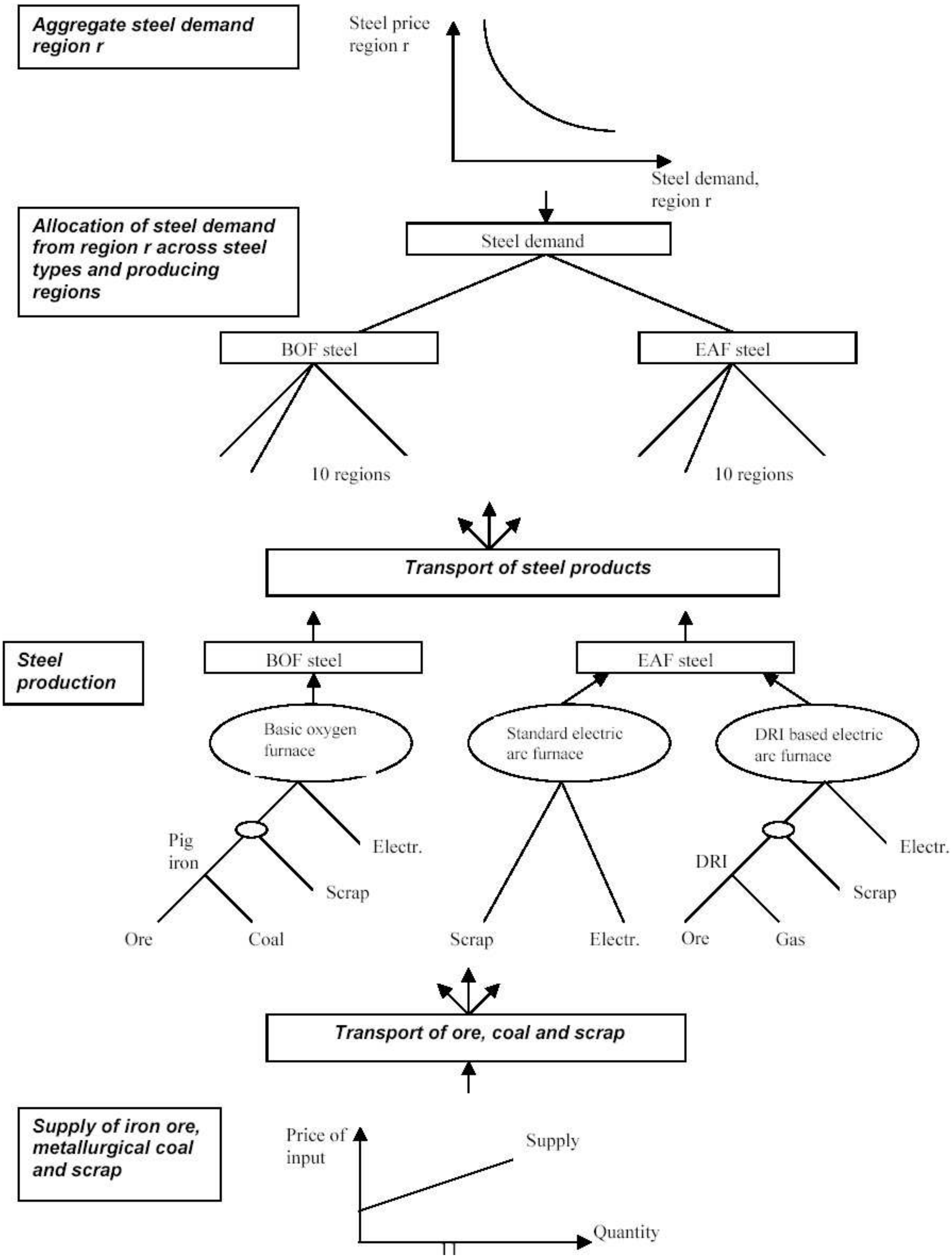

Figure A.1: The steel industry model
Source: Mæstad & Mathiesen 2002 [Mæstad and Mathiesen(2002)]

Appendix B

Results from Simulating Substitution between BOF Production and EAF Production

	China			
	BOF	**Scrap**	**DRI**	**Total**
Basic scenario	424.908	19.186	10.878	454.972
Simulation 1a	322.155 (-24.122%)	19.389 (1.014%)	10.971 (0.824%)	352.515 (-22.52%)
Simulation 1b	266.692 (-37.185%)	19.508 (1.632%)	11.026 (1.328%)	297.226 (-34.67%)
Simulation 1c	321.089 (-24.373%)	21.768 (13.408%)	12.314 (13.162%)	355.171 (-21.94%)

	World			
	BOF	**Scrap**	**DRI**	**Total**
Basic scenario	1364.773	185.003	74.665	1624.441
Simulation 1a	1285.858 (-5.78%)	186.136 (0.61%)	75.136 (0.63%)	1547.13 (-4.678%)
Simulation 1b	1243.296 (-8.90%)	186.761 (0.95%)	75.395 (0.98%)	1505.449 (-7.246%)
Simulation 1c	1284.976 (-5.85%)	187.63 (1.42%)	76.165 (2.01%)	1548.770 (-4.577%)

Table B.1: **Changes in emissions** from different levels of output taxes and subsidies (tons)

	China			
	BOF	**Scrap**	**DRI**	**Total**
Basic scenario	107.126	14.354	5.838	127.318
Simulation 1a	81.162 (-24.176%)	14.471 (0.77%)	5.888 (0.816%)	101.521 (-20.26%)
Simulation 1b	67.162 (-37.255%)	14.539 (1.249%)	5.917 (1.315%)	87.618 (-31.18%)
Simulation 1c	80.890 (-24.430%)	16.243 (13.112%)	6.608 (13.149%)	103.741 (-18.52%)

	World			
	BOF	**Scrap**	**DRI**	**Total**
Basic scenario	531.761	233.544	53.49	818.75
Simulation 1a	515.408 (-2.986%)	234.477 (0.409%)	53.75 (0.488%)	803.635 (-1.790%)
Simulation 1b	506.582 (-4.647%)	234.996 (0.633%)	53.893 (0.755%)	795.471 (-2.787%)
Simulation 1c	515.079 (-3.048%)	235.062 (0.660%)	54.239 (1.400%)	804.380 (-1.699%)

Table B.2: **Changes in supply** of steel from different levels of output taxes and subsidies (million tons)

World			
	Scrap	**Ore**	**Coal**
Basic scenario	346.910	974.306	493.806
Simulation 1a	345.910 (-0.256%)	946.160 (-2.801%)	463.635 (-6.020%)
Simulation 1b	345.419 (-0.398%)	930.994 (-4.359%)	447.358 (-9.320%)
Simulation 1c	346.251 (-0.158%)	946.949 (-2.720%)	463.575 (-6.033%)

Table B.3: **Changes in input supply** due to input price changes from different levels of output taxes and subsidies (million tons)

	Pig Iron	**Scrap**
Western Europe	0.415%	-1.881%
E.Europe & former SU	0.463%	-2.126%
South America	0.290%	-0.613%
North America	0.539%	-2.472%
Japan	0.137%	-2.126%
China	0.087%	-1.015%
Rest of Asia	0.144%	-0.703%
Australia	0.670%	-2.387%
Rest of World	0.104%	-0.764%

Table B.4: **Changes in input use in the BOF process** due to output taxes and subsidies in simulation 1c

Steel transport matrix(tonmiles)									
Export/Import	**WEurope**	**EEfU**	**NorthAm**	**SouthAm**	**Japan**	**China**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe		7.878	42.210	6.703	1.500	8.198	35.106	3.347	21.327
E.Europe & former SU	37.506		50.033	15.812	1.348	124.569	167.340		54.270
North America	2.957			9.927			5.394		
South America	12.003	1.045	38.492			1.997	26.375		1.547
Japan	7.448	2.331	33.739	14.695		5.187	23.302	2.714	12.829
China	8.171	2.853	23.285	1.049	0.521		9.789		1.661
Rest of Asia	29.829		67.916	6.490	5.585	7.518		2.866	6.225
Australia	1.888		5.965	0.612	0.399	0.797	4.001		
Rest of World	9.352		5.993	2.476		3.012	17.197	1.015	

Table B.5: Initial **steel trade pattern** in the SIM

Steel transport matrix									
Export/Import	**WEurope**	**EEfU**	**NorthAm**	**SouthAm**	**Japan**	**China**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe		3	0	0	6	49	10	5	3
E.Europe & former SU	-5		-6	-6	1	45	5		-2
North America	2			2			14		
South America	1	4	1			48	11		4
Japan	-6	-3	-7	-7		40	3	-3	-3
China	-50	-48	-51	-51	-47		-45		-48
Rest of Asia	-6		-7	-6	-3	23		-4	-4
Australia	-6		-7	-7	1	54	6		
Rest of World	-2		-2	-2		32	5	1	

Table B.6: Changes in steel trade from simulation 1a, all changes in %

				Steel transport matrix					
Export/Import	**WEurope**	**EEfU**	**NorthAm**	**SouthAm**	**Japan**	**China**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe		5	-1	-1	9	85	15	7	5
E.Europe & former SU	-9		-10	-9	0	74	6		-3
North America	3			3			23		
South America	2	7	1			85	17		7
Japan	-10	-5	-12	-11		66	3	-4	-5
China	-66	-64	-67	-67	-63		-61		-64
Rest of Asia	-9		-10	-10	-5	37		-6	-6
Australia	-10		-11	-11	1	90	8		
Rest of World	-3		-4	-4		55	7	2	

Table B.7: Changes in steel trade from simulation 1b, all changes in %

Steel transport matrix									
Export/Import	**WEurope**	**EEfU**	**NorthAm**	**SouthAm**	**Japan**	**China**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe		3	o	o	5	44	9	4	3
E.Europe & former SU	-5		-5	-5	1	41	4		-2
North America	2			2			14		
South America	1	4	2			42	10		4
Japan	-6	-3	-6	-6		35	2	-3	-3
China	-48	-47	-48	-48	-45		-43		-47
Rest of Asia	-4		-4	-4	-2	12		-3	-3
Australia	-6		-7	-7	1	54	6		
Rest of World	-1		-2	-2		22	4	1	

Table B.8: Changes in steel trade from simulation 1c, all changes in %

Ore transport matrix(tonmiles)							
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**Japan**	**China**	**RoAsia**	**RoWorld**
Western Europe			0.387				
North America	48.560	1.463	10.880	7.649		10.660	
South America	324.010	39.164	15.439	356.097	196.286	200.115	84.624
Rest of Asia	8.132	6.640		79.584	50.726		10.288
Australia	205.998	17.321	6.696	287.185	142.804	125.051	
Rest of World	85.611	4.715	0.646	41.444		6.150	

Table B.9: Initial **ore trade pattern** in the SIM

Ore transport matrix							
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**Japan**	**China**	**RoAsia**	**RoWorld**
Western Europe			2				
North America	2	3	2	3		2	
South America	2	3	2	3	-23	2	2
Rest of Asia	2	3		3	-23		2
Australia	2	3	2	3	-23	2	
Rest of World	2	3	2	3		2	

Table B.10: Changes in ore trade from simulation 1a, all changes in %

Ore transport matrix							
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**Japan**	**China**	**RoAsia**	**RoWorld**
Western Europe							
North America	3	5	3	4		3	
South America	3	5	3	4	-35	3	2
Rest of Asia	3	5		4	-35		2
Australia	3	5	3	4	-35	3	
Rest of World	3	5	3	4		3	

Table B.11: Changes in ore trade from simulation 1b, all changes in %

Ore transport matrix							
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**Japan**	**China**	**RoAsia**	**RoWorld**
Western Europe			2				
North America	2	3	2	3		2	
South America	2	3	2	3	-22	2	1
Rest of Asia	2	3		3	-22		1
Australia	2	3	2	3	-22	2	
Rest of World	2	3	2	3		2	

Table B.12: Changes in ore trade from simulation 1c, all changes in %

Coal transport matrix(tonmiles)								
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe							0.010	
E.Europe & former SU	5.608		0.822	10.539	33.933	2.730	0.009	0.605
North America	89.849	26.481		37.336	174.380	29.615		11.158
South America	4.854		1.719		1.627			
China	1.486	1.832		0.589	2.064	1.001		
Rest of Asia	2.635				2.021			
Australia	157.043	41.313	0.081	36.893	127.024	46.079		10.616
Rest of World	7.872			3.529	26.339	2.818		

Table B.13: Initial **coal trade pattern** in the SIM

Coal transport matrix								
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe							0	
E.Europe & former SU	2		2	2	3	3	0	3
North America	2	3		2	3	3		3
South America	2		2		3			
China	2	3		3	3	3		
Rest of Asia	2				3			
Australia	2	3	1	2	3	3		3
Rest of World	2			2	3	3		

Table B.14: Changes in coal trade from simulation 1a, all changes in %

Coal transport matrix								
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe							0	
E.Europe & former SU	3		3	4	4	4	0	4
North America	4	5		4	4	4		4
South America	4		3		4			
China	3	5		4	4	4		
Rest of Asia	3				4			
Australia	4	5	2	4	4	4		4
Rest of World	4			4	4	4		

Table B.15: Changes in coal trade from simulation 1b, all changes in %

Coal transport matrix								
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe							0	
E.Europe & former SU	2		2	2	3	2	0	3
North America	2	3		2	3	2		3
South America	2		2		2			
China	2	3		3	3	2		
Rest of Asia	2				3			
Australia	2	3	1	2	3	2		3
Rest of World	2			2	3	2		

Table B.16: Changes in coal trade from simulation 1c, all changes in %

Sensitivity analysis of simulation 1c

	Emission red.		Production				
	Global	Chinese	Global	Chinese	BOF	Scr.based	DRI based
tech.subst.el: 0.75	0.02	0.12	-0.33	-0.01	0.00	-1.14	-0.01
tech.subst.el: 0.9	-0.19	-0.95	-0.03	-0.77	-0.27	0.37	0.44
Armington.el: 16	-0.28	-1.42	-0.05	-1.15	-0.4	0.55	0.64
Armington.el: 4	-2.00	-11.69	-0.74	-10.00	-1.23	0.10	0.17
input.subst.el: 1.5	0.02	0.12	-0.33	-0.01	0.00	-1.14	-0.01

Table B.17: % Changes on Simulation 1c from changing the initial elasticities

Sensitivity analysis of simulation 1c

	Input			Trade			
	Scrap	Coal	Iron Ore	Scrap	Coal	Iron Ore	Total
tech.subst.el: 0.75	-0.02	0.03	0.01	0.00	-0.01	0.01	0.00
tech.subst.el: 0.9	0.11	-0.29	-0.13	0.00	-0.02	-0.09	-0.05
Armington.el: 16	0.16	-0.43	-0.19	0.00	-0.02	-0.13	-0.08
Armington.el: 4	-0.11	-2.62	-1.18	2.30	0.99	-0.77	0.36
input.subst.el: 1.5	0.09	2.14	0.94	-1.76	-0.88	0.59	-0.29

Table B.18: % Changes on Simulation 1c from changing the initial elasticities

Appendix C

Results from Simulating Substitution of Pig Iron with Scrap in the BOF Process

	China			
	BOF	**Scrap**	**DRI**	**Total**
Basic scenario	424.908	19.186	10.878	454.972
Simulation 2a	401.333 (-5.473%)	19.934 (3.851%)	10.839 (-0.396%)	432.106 (-5.03%)
Simulation 2b	413.875 (-2.518%)	19.976 (4.070%)	10.785 (-0.890%)	444.636 (-2.27%)
Simulation 2c	406.612 (-4.229%)	19.887 (3.606%)	10.477 (-3.715%)	436.976 (-3.96%)

	World			
	BOF	**Scrap**	**DRI**	**Total**
Basic scenario	1364.773	185.003	74.665	1624.441
Simulation 2a	1348.081 (-1.22%)	184.542 (-0.25%)	75.413 (1.00%)	1608.035 (-0.925%)
Simulation 2b	1356.608 (-0.60%)	185.143 (0.08%)	74.836 (0.23%)	1616.587 (-0.398%)
Simulation 2c	1351.174 (-1.00%)	185.154 (0.08%)	74.628 (-0.05%)	1610.956 (-0.745%)

Table C.1: **Changes in emissions** from different levels of input taxes and subsidies (tons)

	China			
	BOF	**Scrap**	**DRI**	**Total**
Basic scenario	107.126	14.354	5.838	127.318
Simulation 2a	109.314 (2.125%)	16.288 (13.426%)	5.898 (0.985%)	131.5 (3.28%)
Simulation 2b	108.323 (1.199%)	15.686 (9.232%)	5.833 (-0.125%)	129.842 (1.98%)
Simulation 2c	106.908 (-0.123%)	15.688 (9.245%)	5.672 (-2.868%)	128.268 (0.75%)

	World			
	BOF	**Scrap**	**DRI**	**Total**
Basic scenario	531.761	233.544	53.49	818.75
Simulation 2a	533.259 (0.374%)	232.627 (-0.382%)	53.744 (0.475%)	819.630 (0.165%)
Simulation 2b	532.603 (0.251%)	233.465 (-0.024%)	53.514 (0.046%)	819.583 (0.159%)
Simulation 2c	531.731 (0.087%)	233.499 (-0.009%)	53.401 (-0.166%)	818.631 (0.043%)

Table C.2: **Changes in supply** of steel from different levels of input taxes and subsidies (million tons)

	Scrap	**Ore**	**Coal**
Basic scenario	346.910	974.306	493.806
Simulation 2a	355.521 (2.515%)	968.510 (-0.505%)	485.889 (-1.510%)
Simulation 2b	350.556 (1.083%)	971.075 (-0.241%)	489.944 (-0.688%)
Simulation 2c	350.956 (1.199%)	968.952 (-0.459%)	487.783 (-1.126%)

Table C.3: Global **changes in input supply** due to factor price changes from different levels of input taxes and subsidies (million tons)

	Pig Iron	**Scrap**
Western Europe	0.736%	-3.319%
E.Europe & former SU	0.872%	-3.973%
South America	0.343%	-0.722%
North America	0.593%	-2.714%
Japan	0.220%	-3.412%
China	-4.695%	67.470%
Rest of Asia	0.182%	-0.885%
Australia	0.662%	-2.358%
Rest of World	0.162%	-1.180%

Table C.4: **Changes in input use in the BOF process** due to input taxes and subsidies in simulation 2c

				Steel transport matrix(tonmiles)					
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**China**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe		7.878	42.210	6.703	1.500	8.198	35.106	3.347	21.327
E.Europe & former SU	37.506		50.033	15.812	1.348	124.569	167.340		54.270
North America	2.957			9.927			5.394		
South America	12.003	1.045	38.492			1.997	26.375		1.547
Japan	7.448	2.331	33.739	14.695		5.187	23.302	2.714	12.829
China	8.171	2.853	23.285	1.049	0.521		9.789		1.661
Rest of Asia	29.829		67.916	6.490	5.585	7.518		2.866	6.225
Australia	1.888		5.965	0.612	0.399	0.797	4.001		
Rest of World	9.352		5.993	2.476		3.012	17.197	1.015	

Table C.5: Initial **steel trade pattern** in the SIM

	Steel transport matrix								
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**China**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe		0	0	-1	-1	-8	-2	-1	-1
E.Europe & former SU	1		0	0	0	-7	-1		0
North America	0			0			-1		
South America	1	0	0			-8	-1		0
Japan	1	1	1	0		-7	-1	0	0
China	8	8	8	8	7		7		8
Rest of Asia	2		2	1	1	-11		1	1
Australia	1		1	1	0	-4	-1		
Rest of World	1		1	0		-11	-1	0	

Table C.6: Changes in steel trade from simulation 2a, all changes in %

				Steel transport matrix					
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**China**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe		0	0	0	0	-5	-1	-1	0
E.Europe & former SU	0		0	0	0	-4	-1		0
North America	0			0			-1		
South America	0	0	0			-5	-1		0
Japan	1	0	1	0		-4	0	0	0
China	5	4	5	5	4		4		4
Rest of Asia	1		1	1	1	-7		0	1
Australia	1		1	0	0	-2	0		
Rest of World	1		1	0		-7	-1	0	

Table C.7: Changes in steel trade from simulation 2b, all changes in %

Steel transport matrix									
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**China**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe		0	0	0	0	-3	0	0	0
E.Europe & former SU	0		0	0	0	-2	0		0
North America	0			0			0		
South America	0	0	0			-3	0		0
Japan	0	0	0	0		-2	0	0	0
China	1	1	1	1	1		1		1
Rest of Asia	1		1	0	1	-5		0	0
Australia	0		0	0	0	0	0		
Rest of World	1		0	0		-5	0	0	

Table C.8: Changes in steel trade from simulation 2c, all changes in %

Ore transport matrix(tonmiles)							
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**Japan**	**China**	**RoAsia**	**RoWorld**
Western Europe			0.387				
North America	48.560	1.463	10.880	7.649		10.660	
South America	324.010	39.164	15.439	356.097	196.286	200.115	84.624
Rest of Asia	8.132	6.640		79.584	50.726		10.288
Australia	205.998	17.321	6.696	287.185	142.804	125.051	
Rest of World	85.611	4.715	0.646	41.444		6.150	

Table C.9: Initial **ore trade pattern** in the SIM

Ore transport matrix							
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**Japan**	**China**	**RoAsia**	**RoWorld**
Western Europe			1				
North America	1	1	1	0		0	
South America	1	1	1	0	-7	0	1
Rest of Asia	1	1		0	-7		1
Australia	1	1	1	0	-7	0	
Rest of World	1	1	1	0		0	

Table C.10: Changes in ore trade from simulation 2a, all changes in %

Ore transport matrix							
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**Japan**	**China**	**RoAsia**	**RoWorld**
Western Europe			0				
North America	1	1	0	0		0	
South America	1	1	0	0	-3	0	0
Rest of Asia	1	1		0	-3		0
Australia	1	1	0	0	-3	0	
Rest of World	1	1	0	0		0	

Table C.11: Changes in ore trade from simulation 2b, all changes in %

Ore transport matrix							
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**Japan**	**China**	**RoAsia**	**RoWorld**
Western Europe			1				
North America	1	1	0	0		0	
South America	1	1	0	0	-5	0	1
Rest of Asia	1	1		0	-5		1
Australia	1	1	0	0	-5	0	
Rest of World	1	1	0	0		0	

Table C.12: Changes in ore trade from simulation 2c, all changes in %

				Coal transport matrix(tonmiles)				
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe							0.010	
E.Europe & former SU	5.608		0.822	10.539	33.933	2.730	0.009	0.605
North America	89.849	26.481		37.336	174.380	29.615		11.158
South America	4.854		1.719		1.627			
China	1.486	1.832		0.589	2.064	1.001		
Rest of Asia	2.635				2.021			
Australia	157.043	41.313	0.081	36.893	127.024	46.079		10.616
Rest of World	7.872			3.529	26.339	2.818		

Table C.13: Initial **coal trade pattern** in the SIM

Coal transport matrix								
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe							0	
E.Europe & former SU	1		0	1	0	0	0	0
North America	1	1		1	0	0		0
South America	1		1		0			
China	1	1		1	0	0		
Rest of Asia	1				0			
Australia	1	1	0	1	0	0		0
Rest of World	1			1	0	0		

Table C.14: Changes in coal trade from simulation 2a, all changes in %

Coal transport matrix								
Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe							0	
E.Europe & former SU	1		0	0	0	0	0	0
North America	1	1		0	0	0		0
South America	1		0		0			
China	1	1		1	0	0		
Rest of Asia	1				0			
Australia	1	1	0	0	0	0		0
Rest of World	1			0	0	0		

Table C.15: Changes in coal trade from simulation 2b, all changes in %

Coal transport matrix

Export/Import	**WEurope**	**EEfSU**	**NorthAm**	**SouthAm**	**Japan**	**RoAsia**	**Austr.**	**RoWorld**
Western Europe							0	
E.Europe & former SU	1		0	1	0	0	0	0
North America	1	1		1	0	0		0
South America	1		0		0			
China	1	1		1	0	0		
Rest of Asia	1				0			
Australia	1	1	0	1	0	0		0
Rest of World	1			1	0	0		

Table C.16: Changes in coal trade from simulation 2c, all changes in %

Sensitivity Analysis of simulation 2c

	Emission red.		**Production**				
	Global	Chinese	Global	Chinese	BOF	Scr.based	DRI based
tech.subst.el: 0.75	0.00	-0.10	0.00	0.00	0.00	0.00	0.01
tech.subst.el: 0.9	0.00	-0.01	0.00	0.00	0.00	0.00	0.02
Armington.el: 4	0.00	0.04	0.00	0.11	0.00	-0.03	0.12
Armington.el: 16	0.00	-0.06	0.00	-0.14	0.00	0.04	-0.16

Table C.17: % Changes on Simulation 2c from changing the initial elasticities

Sensitivity Analysis of simulation 2c, continuing.

	Input			Trade			
	Scrap	Coal	Iron Ore	Scrap	Coal	Iron Ore	Total
tech.subst.el: 0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tech.subst.el: 0.9	0.00	-0.01	0.00	0.00	0.00	0.00	0.00
Armington.el: 4	-0.01	-0.01	0.00	0.01	0.00	0.01	0.01
Armington.el: 16	0.01	0.00	-0.01	0.03	0.00	-0.01	0.00

Table C.18: % Changes on Simulation 2c from changing the initial elasticities

Acknowledgements

I am grateful for the very competent and patient advisory I have received from my advisor Kjetil Bjorvatn. I also wish to thank Ottar Mæstad for an informative introduction to the SIM, Jørund Buen for help with information about environmental protection in China and Bjørn Bodding for giving me an indication of whether the subject of this thesis had any interest for other people than myself.

Bibliography

[Beijing Review(2005)] Beijing Review. What will the Kyoto Protocol mean for the largest developing country in the world? *Beijing Review*, May 2005. http://www.bjreview.com.cn/En-2005/05-11-e/11-china-2.htm.

[China Metal Reports(2003)] China Metal Reports. Environmental Protection in China's Iron and Steel Industry. *China Metal Reports*, February 2003.

[CRU International Ltd.(1999)] CRU International Ltd. Billets and Blooms Cost Model - Version 1999, 1999.

[CRU International Ltd.(2001)] CRU International Ltd. Hot strip Cost Model - Version 2001, 2001.

[IEA(2004)] IEA, 2004. Extracted 12 May, 2004 from www.iea.org.

[IISI(2003)] IISI, editor. *Steel Statistical Yearbook 2002*. International Iron and steel Institute, 2003.

[IISI(2005)] IISI. Steel in Figures 2003. Technical report, The International Iron and Steel Institute, 2005. www.worldsteel.org.

[International Steel Statistic Bureau(2003)] International Steel Statistic Bureau. ISSB headlines, February 2003. www.issb.co.uk.

[Jones(2005)] J. A. T. Jones. Electric Arc Furnace Steelmaking. Technical report, Steelworks Learning Center, American Iron and Steel Institute, 2005. www.steel.org.

[Kozak and Dzierzawski(2005)] B. Kozak and J. Dzierzawski. Continuous casting of steel: Basic principles. Technical report, Steelworks Learning Center, The American Iron and Steel Institute, 2005. www.steel.org.

[Li(2000)] S. Li. Prospects for China's economic development in the next 20 years, 2000. Summary Report of the Workshop on Social, Economic and Energy Development and Carbon Emission Scenario Analysis in Beijing, China, May 2000.

[Mæstad and Mathiesen(2002)] O. Mæstad and L. Mathiesen. Climate policy and the steel industry: Achieving global emmision reductions by an incomplete climate agreement. *SNF Working Paper No63/02*, 2002.

[Mathiesen(2000)] L. Mathiesen. A Steel Industry Model. *SNF Report No81/00*, 2000.

[Meng and Wang(2000)] L. Meng and X. Wang. Estimation of the reliability of the Chinese growth statistics. *Economic Research Journal*, (10), 2000.

[Nordås(2003)] H. K. Nordås. Direction of trade following China's accession to the WTO. *SNF Working Paper No4/02*, 2003.

[OECD/IEA(2000a)] OECD/IEA, editor. *World Energy Outlook*. China Statistical Press, 2000a. Electronic version, www.iea.org.

[OECD/IEA(2003)] OECD/IEA, editor. *Coal Information 2003*. China Statistical Press, 2003. Electronic version, www.iea.org.

[OECD/IEA(2000b)] OECD/IEA. *Emission Baselines: Estimating the Unknown*, chapter Iron and Steel Case Study, pages 239–279. OECD, 2000b.

[Peoples Daily(2005)] Peoples Daily. Premier Zhu Announces China's Approval of Kyoto Protocol. *Peoples Daily*, May 2005. http://english.people.com.cn/200209/03/eng20020903$_1$02567*.shtml*.

[Reppelin-Hill(1998)] V. Reppelin-Hill. Trade and Environment: An Empirical Analysis of the Technology Effect in the Steel Industry. *Journal of Environmental Economics and Management*, 38:283–301, 1998.

[Stubbles(2005)] J. Stubbles. The Basic Oxygen Steelmaking (BOS) Process. Technical report, Steelworks Learning Center, American Iron and Steel Institute, 2005. www.steel.org.

[The Administrative Center for China's Agenda 21(1994)] The Administrative Center for China's Agenda 21. China's Agenda 21, 1994.

[The Chinese Bureau of Statistics(2002)] The Chinese Bureau of Statistics, editor. *China Statistical Yearbook 2001.* China Statistical Press, 2002.

[The Economist(2004)] The Economist. A great wall of waste. *The Economist*, pages 55–57, August 21st 2004. Special report on China's environment.

[The Penguin Dictionary of Economics(1998)] The Penguin Dictionary of Economics. Polluter-pays-principle, 1998. Retrived 26 May 2005, from xreferplus. www.xreferplus.com/entry/446025.

[The World Bank(2005)] The World Bank, editor. *Little Data Book 2005.* 2005.

[Wang(2000)] T. Wang. Challenges and Opportunities facing China in the 21st century, 2000. Summary Report of the Workshop on Social, Economic and Energy Development and Carbon Emission Scenario Analysis in Beijing, China, May 2000.

[Worden et al.(1987)Worden, Savada, and Dolan] R. L. Worden, A. M. Savada, and R. E. Dolan, editors. *China - a Country Study.* Federal Research Division, Library of Congress, 1987. www.loc.gov/rr/frd/.

[Wu(1998)] Y. Wu. *The Economics of the East Asia Steel Industries*, chapter China's Metals Industry. Ashgate Publishing, Aldershot, 1998.

[Wu(2000)] Y. Wu. The Chinese Steel Industry: Recent Developments and Prospects. *Resources Policy*, (26):171–178, 2000.

[ZhiDong(2003)] L. ZhiDong. An econometric study on China's economy, energy and environment to the year 2030. *Energy Policy*, 31:1137–1150, 2003.