Industrial growth and emissions in emerging economies

Decomposition of manufacturing CO_2-emissions from fuel combustion

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Abstract

Global climate change has become a key issue. Since the 19th century, greenhouse-gas emissions have increased dramatically, mainly through the burning of fossil fuels from the energy and industrial sectors. While capital-intensive industrialisation remains a synonym for development worldwide, few studies have so far analysed branch-level industrial emissions in developing countries. This research applies a divisia index decomposition for analysing the behaviour of carbon-dioxide emissions in the manufacturing sectors of Brazil, China, India and Mexico from 1985 to 2005. For that, a database was constructed with manufacturing branch-level data on value-added and carbon-dioxide emissions from fuel combustion. The literature on the environmental Kuznets curve (EKC) assumes the existence of a 'clean' development trend for the maintenance of a supposed inverted "U" relationship. Using a case-by-case approach, this paper addresses the existence of such a trend, as well as the adequacy of the 'pollution haven' hypothesis. The estimates for Brazil, China and Mexico are consistent with the 'clean' development trend hypothesis; however, for Brazil the covered branches saw a contraction in real value added and the trend does not seem to be a 'cleaner' one. The results for India seem inconsistent with that hypothesis. This indicates that not all countries may become less pollution-intensive as economic development proceeds. The 'pollution haven' hypothesis may apply to some branches in Brazil, China and India, particularly regarding the branches 'iron and steel' and 'non-metallic minerals'. If it does, however, 'dirty' industrial relocation seems to have contributed to reducing manufacturing emission intensity in most cases. These results suggest that 'dirty' industrial relocation from developed to developing countries may have positive environmental impacts. Direct investment in the expansion of production capacities may have stimulated the adoption of more fuel-efficient technologies and processes than those already in use, leading to a positive impact in terms of lower emission intensity. Similar to the results obtained in related decomposition studies concerning industrial countries, in China, India and Mexico technological change was the most important determinant in the emission-output ratio variation. In spite of that, the results indicate that structural changes are also important sources of change in emissions, which is consistent with the literature questioning the EKC in this regard.

Keywords: carbon-dioxide emissions, divisia decomposition, manufacturing, sustainability.
JEL classification: L6, O1, O2, Q5.

Kurzzusammenfassung

Die Bedrohung durch den Klimawandel hat sich zu einer bedeutenden Frage entwickelt. Seit dem 19. Jahrhundert sind die Emissionen von anthropogenen Treibhausgasen, hauptsächlich durch das Verbrennen von fossilen Brennstoffen in den Energie- und Industrialsektoren, drastisch gestiegen. Obwohl kapitalintensive Industrialisierung allgemein als Synonym für Entwicklung gilt, hat erst eine geringe Anzahl von Studien die industriellen Emissionen einzelner Branchen in Entwicklungsländern erforscht. Die vorliegende Studie bedient sich der Divisia-Dekompositionsmethode für die Untersuchung der Eigenschaften von Kohlendioxidemissionen in den Fertigungssektoren Brasiliens, Chinas, Indiens und Mexikos von 1985 bis 2005. Eine Datenbank wurde hierfür mit Daten zum Mehrwert und zu den Kohlendioxidemissionen durch Brennstoffverbrennung von einzelnen Branchen der Fertigungsindustrie angelegt. Die Literatur über die Umwelt-Kuznets-Kurve (EKC) geht von der Existenz eines „sauberen“ Entwicklungstrends aus, um den angenommenen umgekehrten U-Verlauf zu erhalten. Anhand einer Einzelfallanalyse behandelt diese Arbeit sowohl einen solchen Trend als auch das Zutreffen der Hypothese einer emissionsintensiven Industrieverlagerung. Die Ergebnisse für Brasilien, China und Mexiko stimmen mit der Hypothese eines „sauberen“ Entwicklungstrends überein. Die Ergebnisse für Indien scheinen diese Hypothese indes zu widerlegen. Dies deutet darauf hin, dass nicht alle Länder im Laufe ihrer Entwicklung eine geringere Umweltverschmutzung aufweisen. Die Hypothese einer emissionsintensiven Industrieverlagerung trifft vermutlich auf einige Branchen in Brasilien, China und Indien zu, insbesondere auf die Industriezweige „Eisen und Stahl“ und „nicht-metallische Mineralien“. Trifft dies allerdings zu, scheint in den meisten Fällen eine „schmutzige“ Industrieverlagerung zur Verringerung der Emissionsintensität durch die Fertigungsindustrie beigetragen zu haben. Diese Ergebnisse lassen darauf schließen, dass „schmutzige“ Industrieverlagerung von Industrie- zu Entwicklungsländern auch einen positiven Einfluss auf die Umwelt haben könnte. Direktinvestitionen bei der Expansion von Produktionskapazitäten könnten die Nutzung von brennstoffeffizienteren Technologien und Prozessen angeregt und dadurch für eine niedrigere Emissionsintensität gesorgt haben. Vergleichbar den Ergebnissen ähnlicher Dekompositionsstudie mit dem Schwerpunkt Industrieländer war in China, Indien und Mexiko der technologische Wandel die wichtigste Determinante in der Veränderung der Rate des Emissionsausstoßes pro Produktionseinheit. Gleichwohl weisen die Ergebnisse darauf hin, dass Strukturwandel ebenfalls eine wichtige Quelle der Emissionsveränderung ist. Diese Feststellung deckt sich mit der Literatur, welche die EKC in diesem Punkt in Frage stellt.

Acronyms and abbreviations

BCA	Benefit-cost analysis
C	Carbon
CEF	Carbon emission factor
CEREN	Centre of Studies of the National Reality, Catholic University of Chile
CESO	Centre of Social Studies, University of Chile
CO_2	Carbon dioxide
ECLA	United Nations Economic Commission for Latin America
EKC	Environmental Kuznets curve
GDP	Gross domestic product
GHG	Greenhouse gas
GNP	Gross national product
IBGE	Brazilian Institute of Geography and Statistics
IEA	International Energy Agency
INDSTAT	Industrial Statistics Database
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard of Industrial Classification
ISI	Import Substitution Industrialisation
MT	Million or mega tons
MVA	Manufacturing value added
nat.	National
n.e.c.	Not elsewhere classified
NSO	National statistical office
OECD	Organisation for Economic Co-operation and Development
PDM	Parametric divisia method
R&D	Research and development
RSU	German Council of Experts on Environmental Issues
STAN	Structural Analysis Database
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Organisation
VAT	Value added tax
WCED	World Commission on Environment and Development

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List of figures and tables

1. Introduction

The threat of climate change has emerged as a major scientific and public policy issue. Since the 19th century, anthropogenic greenhouse gas (GHG) emissions have increased dramatically. According to the United Nations Intergovernmental Panel on Climate Change (IPCC), carbon dioxide (CO_2) is the most important anthropogenic GHG, and its primary source since the pre-industrial period has been the burning of fossil fuels, mainly from the energy and industrial sectors (IPCC, 2007: 2). Accumulated GHG emissions lead to warmer temperatures on the planet, which have significant impacts on the functioning of ecosystems, the viability of wildlife, and the wellbeing of humankind (Goulder and Pizer, 2006).

While capital-intensive industrialisation remains a synonym for development worldwide, developing countries are estimated to reach the same level of aggregate GHG emissions as industrialised countries within the next 30 years (Goulder and Pizer, 2006: 10). Emissions per capita in most developing countries remain, however far below the level verified in the so-called industrialised or developed countries[1]. Considering, on the one hand, the daunting challenge of overcoming poverty in developing countries and, on the other hand, the necessary economic development expected, the relationship between development-related and environmental indicators has received growing attention.

The literature on the environmental Kuznets curve (EKC) debates in part this relationship, however, focusing on growth. The EKC postulates that degradation and pollution increase in the early stages of economic growth. Beyond some level of income per capita, however, the trend reverses, so that at high income levels growth leads to environmental improvement (Stern, 2004: 1419).

Various studies (see Copeland and Taylor, 2004; Dasgupta et al., 2006; Caviglia-Harris, 2009) have reviewed the EKC and concluded that the theoretical and empirical work to date does not support the existence of a simple, predictable relationship between pollution and per capita income. One of the problems pointed out by Stern (2004) as well as by Dasgupta et al. (2006) concerns the fact that many structural factors affect this relationship, particularly in rapidly growing middle-income countries.

While economic growth intuitively increases pollution, evidence based on developed countries suggests that the branch-level structure of industry follows a ‘clean’ trend as development proceeds. This could reflect the domination of early industrialization by primary and heavy industries, which generate heavy pollution loads as they convert raw

[1] In 2007, the average amount of emissions per capita among the member countries of the Organisation of Economic Co-operation and Development (OECD) was equivalent to 10.97 tons of CO_2 per inhabitant. In contrast, emissions per inhabitant in that same year equalled 1.81 tons for Brazil, 4.57 for China, 1.18 for India, and 7.27 for South Africa (IEA, 2009a).

materials into primary inputs. During economic development, the industrial structure changes and primary industries may lose output share to cleaner industries, which together with technological development would decrease pollution per output, resulting in lower pollution intensity (Hettige et al., 2000: 451).

The EKC literature assumes the existence of such a ‘clean’ development trend for the maintenance of the inverted “U” relationship in the long run. However, this trend may be different from country to country depending on, for example, natural resource endowment and other determinants of comparative advantages in pollution-intensive industries.

Dasgupta et al. (2006) point at the argument of some critics that over time the EKC will rise again. After its decline, as globalization promotes a ‘race to the bottom’, poor countries become ‘pollution havens’ and environmental standards collapse in industrial countries as they defend their competitive position. The ‘pollution haven’ hypothesis has received considerable attention from researchers (see Antweiler et al., 2001; Cole and Elliot, 2003; Brunnermeier and Levinson, 2004; Copeland and Taylor, 2004; Levinson and Taylor, 2008). It basically argues that due to less strict legislation enforcement and differences in marginal compliance costs for emission reduction, industries may relocate to developing countries due to their comparative advantage in pollution-intensive industries.

This research uses a divisia decomposition method to discuss the existence of a ‘clean’ development trend, as well as the adequacy of the ‘pollution haven’ hypothesis for the case of carbon dioxide emissions in selected emerging economies. In contrast to the EKC, decomposition models may help disentangling the true relation between development and the environment (Stern, 2004). Due to its mostly cross-sectional econometric approach, the EKC literature has not accounted for particularities of individual development patterns. This provides a motivation for proceeding differently, using a case-by-case decomposition approach.

De Bruyn (2000) employs a time series divisia decomposition at the branch-level to investigate changes in industrial energy intensities in the Netherlands from 1980 to 1992 as well as in industrial heavy metal emissions in the German state of North Rhine-Westphalia from 1955 to 1988. His findings suggest that technological change determined the bulk of the decrease in these variables, and that structural changes played a marginal role.

Using a similar approach to carbon-dioxide emissions, this study investigates the manufacturing sectors in Brazil, China, India and Mexico at the branch-level. For that, a database from 1985 to 2005 was constructed with data on value-added (IBGE, 1996-2006; OECD, 2005; UNIDO, 2006; UNIDO, 2007) and emissions from fuel combustion (IEA, 2007a) of eight major manufacturing branches. Although there is a substantial literature applying decomposition analysis to CO_2 emissions from fuel combustion, most of it concentrates in high-income countries and focus at the country-level only.

The initial objective was to cover the manufacturing sectors of the so-called G+5 (group of five) countries[2], comprising Brazil, China, India, Mexico and South Africa, often referred to as 'emerging' economies. These countries have enjoyed growing economic relevance as well as political influence in the negotiation of international agreements, such as the Kyoto Protocol. However, the lack of branch-level emission data did not allow the coverage of South Africa.

The manufacturing sector was chosen because of its importance for economic development, as well as for the promotion of more sustainable technologies in terms of processes, products and services (Klassen and Whybark, 1999).

This introductory chapter describes the research context, objectives and questions, namely a) Did technological effects play a significant role in the emission-intensity variation during the specified period? b) Can a 'clean' development trend be found for the selected countries? and c) Are changes in the covered manufacturing sectors in line with the 'pollution haven' hypothesis or, on the contrary, inconsistent with a 'dirty' industrial relocation? In order to clarify the conceptual framework used, the second chapter presents the evolution of how sustainability and development have been understood in the economic theory. Based on that, it discusses some of the pros and cons concerning industrial policies and the role of the state in improving the conditions for sustainability.

The third chapter introduces the research methodology, including the used mathematical model, and describes the measurements and data. The decomposition results are presented in chapter four, based on different sub-periods depending on the availability and quality of data for each country. Chapter five discusses these results, laying emphasis on changes in fuel mixes and other complementary macroeconomic indicators.

[2] Although it has been common to refer to the so-called BRIC (Brazil, Russia, India and China) countries in discussions concerning emerging economies, Russia was not covered in the analysis, since its industrial sector experienced a contraction after the fall of the Soviet Union.

1.1. Research context

a. Climate change, industrial production and fossil-fuel emissions

Reports published by the German Federal Environmental Agency (Becker, 2006) and the British Finance Ministry (HM Treasury, 2006a) raise serious questions about the climate change process and its consequences for the global economy. According to the British study, published in 2006 and entitled *The Stern Review on the Economics of Climate Change*, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year in case no counter-action is taken. If a wider range of risks and impacts is taken into account, the estimates of the damage rise to 20% of GDP. Actions now and over the coming decades, claims the British Finance Ministry, could create risks of a major disruption of economic and social activity on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century (HM Treasury, 2006b).

For being the most abundant anthropogenic GHG, CO_2 has been considered a key indicator of the human pressure on the environment. Although CO_2 emissions derive mostly from the burning of fossil fuels, shares of fossil-fuel CO_2 relative to total GHG emissions vary considerably among countries (Table 1). Based on a sample of 70 developing and developed countries, representing together 95% of the global total CO_2 emissions from fuel combustion, the World Bank (2007: 10) concludes that for the majority of them fossil fuel CO_2 was responsible for more than 50 percent of the total GHG emissions in 2000. On the one hand, this share indicates the importance of fossil fuel combustion for climate policies. On the other hand, it helps contextualizing why some countries with a very small share such as Brazil (15.1%) may see an increase in emissions per unit of output despite the strongly debated issue of climate change.

Table 1. Ratio of fossil fuel CO_2 emissions to total GHG emissions in 2000 (World Bank, 2007)

Country	Fossil-fuel CO_2 to GHG Emissions (%)	Country	Fossil-fuel CO_2 to GHG Emissions (%)
Japan	89.1	Russia	76.9
United States	87.5	*China*	70.4
Czech Republic	86.2	Sweden	70.1
Korea, Rep. of	86.0	Norway	70.1
Portugal	83.8	Canada	70.1
Germany	82.4	France	68.7
Italy	81.5	Egypt	66.3
South Africa	81.2	Australia	65.7
Poland	81.1	Netherlands	65.1
United Kingdom	80.9	*Mexico*	60.6
Austria	80.3	*India*	56.8
Finland	78.9	*Brazil*	15.1

Globally, the manufacturing industry is the second major emitter of GHGs after the energy supply and fuel sector (Steinbach *et. al.*, 2006: 1). Energy supply, though, is an essential component of industrial production. Some studies forecast that from 2003 to 2030, the world will invest an estimated US$16 trillion in energy infrastructure, with annual carbon dioxide emissions estimated to rise by 60 percent (Goulder and Pizer, 2006: 11).

Figure 1 presents total emissions from fuel combustion in thousand MT (million tons) of CO_2 for the covered countries as well as for the world and the rest of the world, the latter defined as the world apart from the covered countries (IEA, 2009b). Annual growth rates from 1990 to 2005 lie above the world average in all covered countries, with emphasis to China (8.6%/year). According to the IEA (2009b), all the selected countries were among the world's top 20 countries in terms of CO_2 from fuel combustion in 2007. China leads the world ranking with 6,028 MT of CO_2, followed by the United States and the Russian Federation, respectively. India was in fourth position with 1,324 MT of CO_2, while Mexico was in 11^{th} position with 438 MT of CO_2 and Brazil in 17^{th} position with 347 MT of CO_2. Therefore, because of the weight of the selected countries and their considerable growth in terms of CO_2 emissions from fuel combustion, the annual growth rate of the category 'rest of the world' between 1990 and 2005 was half of the world's figures.

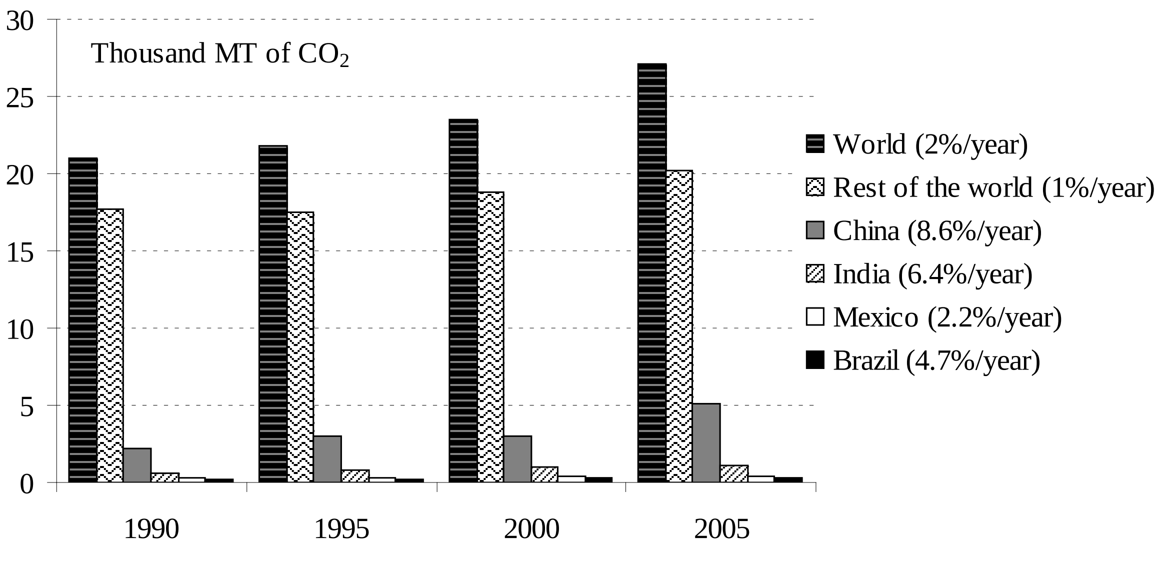

Figure 1. Total CO_2 emissions from fuel combustion (selected years)

Based on national accounts estimates (UNSD, 2009), Figure 2 presents gross manufacturing value added (MVA) at 1990 prices. Also here, manufacturing value added grew faster than the world average between 1985 and 2005, particularly for China, whose growth rate was nearly ten times higher than the world's rate. In 1985, the Chinese manufacturing value added represented around 80% of the Brazilian one, which was the largest at that time. In 2005, the Chinese MVA became nearly five times larger than the Brazilian MVA.

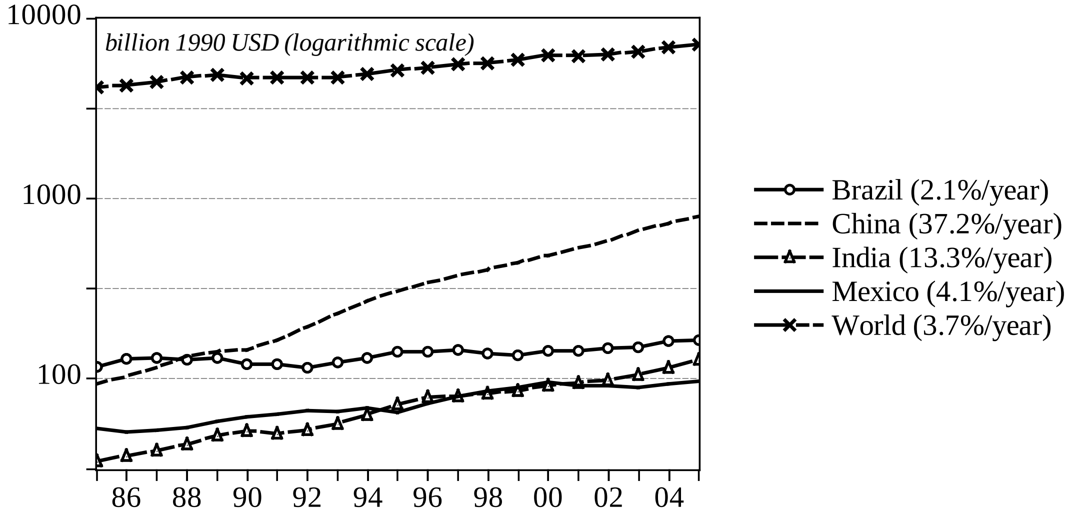

Figure 2. Gross manufacturing value added at 1990 prices - US dollars (1985-2005)

Brazil, China, India and Mexico seem to have experienced quite different dynamics in terms of manufacturing emissions and value added from 1985 to 2005. A common indicator to analyse such aspects is the so-called emission-output ratio, which gives the amount of emissions per output unit.

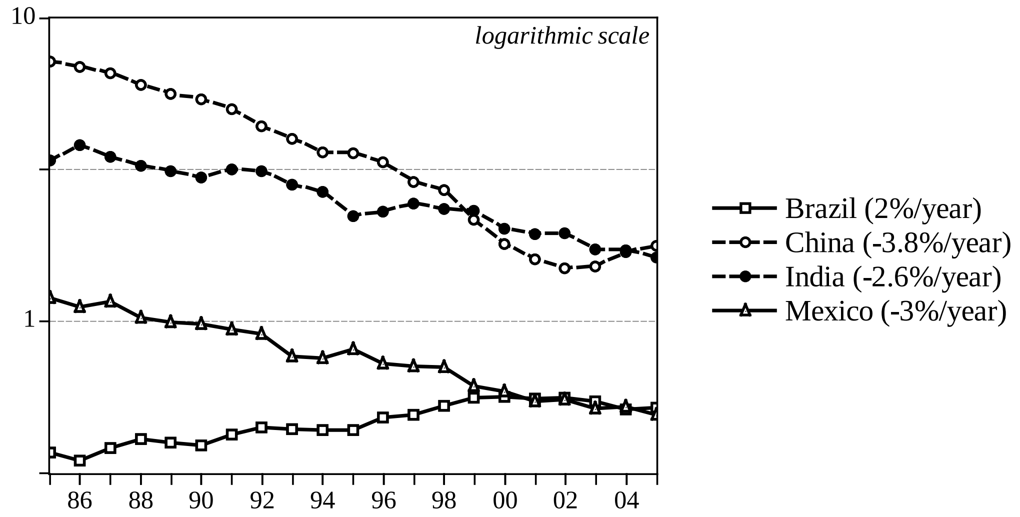

Figure 3. Manufacturing emission-output ratio / 1990 USD (1985-2005)

Figure 3 shows the behaviour of the emission-output ratio in the manufacturing sectors of the selected countries based on CO_2 emissions from fuel combustion (IEA, 2007a) and MVA at US dollars of 1990 (UNSD, 2009). Here, China and India have the most emission-intensive manufacturing sectors, which is important to take into account in the interpretation of the decomposition results. Brazil was the only country where this ratio increased during the period, which seems reasonable taking into account its very small share of CO_2 emissions from fuel combustion relative to its total GHG emissions (Table 1).

Considering the importance of the selected countries for the mitigation of global GHG emissions, as well as their different characteristics in terms of economy, society, governmental structures and policies, the focus on their cases may contribute for policy-making and provide a more representative picture of the relationship between industrial growth and the environment in developing countries than the analysis of high-income countries.

b. Developing countries and international climate policies

The Kyoto Protocol is a significant international effort to reduce global greenhouse gas emissions. It assigns emission limits to participating industrialised countries (or Annex I Parties – cf. footnote 3) for the period from 2008 to 2012, but offers flexibility in allowing these countries to alter their limits by buying or selling emission allowances from or to other industrialised countries, or by investing in projects that lead to emission reductions in developing countries. Unlike industrialised nations, developing countries have no specific obligations to abate greenhouse gas emissions under the Kyoto Protocol, and the Protocol provides no mechanism for developing countries to adopt emission commitments voluntarily (Aldy *et al.*, 2003: 380).

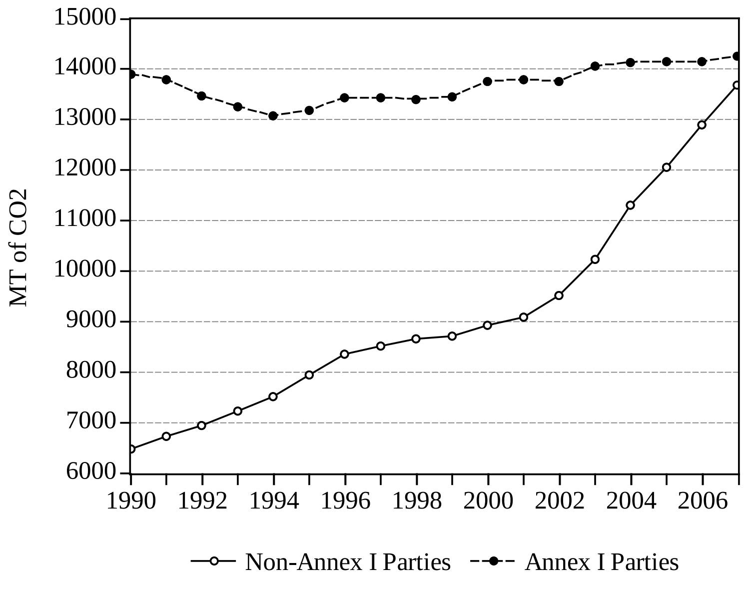

Figure 4. CO_2 emissions from fuel combustion / Annex I and Non-Annex I Parties (1990-2007)

Figure 4 presents the IEA (2009b) estimates for CO_2 emissions from fuel combustion of Annex I[3] and Non-Annex I Parties of the United Nations Framework Convention on Climate Change. From 1990 to 2007, the Non-Annex I Parties, which comprises most developing countries, have seen a growth rate in emissions of 6.6%/year during that period, while emissions from Annex I Parties have remained relatively stable. As a result, the sharp increase in developing countries' emissions, particularly as from 2000, has become a common topic in discussions about the impacts of globalisation, being often associated with cost-competitiveness issues as well as lowering labour and environmental standards.

Similar to the 1970's debate on a potential comparative advantage for developing countries in pollution-intensive industries, known as the *'pollution haven'* or *industrial relocation hypothesis* (cf. Copeland and Taylor, 2001; Antweiler et al., 2001; Cole and Elliot, 2003; Brunnermeier and Levinson, 2004; Copeland and Taylor, 2004; Levinson and Taylor, 2008), Aldy *et al.* (2003: 375) hold that if an international (but not fully global) climate policy results in differences in marginal compliance costs among countries, emissions may "leak" from participating high-cost countries to non-participating low- or zero-cost countries.

This could happen in two different ways. First, a policy may foster comparative advantages for low-cost countries (for example, countries without emission commitments) in the production of greenhouse-gas-intensive goods and services. Hence, GHG-intensive manufacturing plants may be relocated from countries with emission commitments (and hence higher energy costs) to countries without emission commitments. Second, the higher energy costs related to complying with the commitments could reduce the world's usual energy demand, depressing fuel prices until the re-establishment of the previous demand levels. In the meantime, countries without emission commitments would consume more fossil fuels, offsetting parts of the emission reductions accomplished by countries with commitments. Therefore, Aldy *et al.* argue that an agreement such as the Kyoto Protocol may, instead of significantly reducing net emissions, simply redistribute them.

Following the assumption that energy efficiency and environmental standards in most developing countries are lower than those in industrialised countries, this redistribution of emissions may lead to an increase in global emissions *ceteris paribus*.

[3] Annex I Kyoto Parties includes Australia, Austria, Belgium, Bulgaria, Canada, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein (not available in IEA, 2009b), Lithuania, Luxembourg, Monaco, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Ukraine and the United Kingdom. Membership in the Kyoto Protocol is almost identical to that of Annex I presented here, except for Turkey and Belarus which did not agree to a target under the Protocol and the United States which have expressed their intention not to ratify the Protocol.

1.2. Research questions

How did changes in branch-level structure and technological development contribute to variations in the intensity of production-related CO_2 emissions from fuel combustion of the manufacturing sectors in Brazil, China, India and Mexico between 1985 and 2005? In order to explore this overall research question, this study focused on the following, specific, questions:

a. Has technological development played a significant role in regard to changes of intensity in CO_2 emissions from fuel combustion in the selected countries?
b. Are changes in manufacturing branch-level composition, fuel mix and fuel-saving technological development in the selected countries consistent with the 'clean' development trend as output grows?
c. Are changes in the manufacturing structure and emission intensity of the selected countries consistent with the hypothesis of a 'dirty' industrial relocation between 1985 and 2005?

2. Theoretical framework

In order to lay the foundation for the analysis, this section describes the theoretical framework and clarifies the most important concepts used. It briefly reviews the evolution of the economic thought on development and sustainability with emphasis on the relationship between industrial growth and sustainable development.

2.1. Development, sustainability and industrialisation

The countries with which this study is concerned have been labelled many different terms. Almost all of these labels are intended to contrast their state or rate of change with those of the more advanced, developed countries. The more popular classifications are often found in pairs (i. e. developed and underdeveloped, more- and less-developed, developed and developing countries) and put all countries on a continuum based on their degree of development (Perkins *et al.*, 2001: 7).

The group of countries selected for this study, composed of Brazil, China, India and Mexico, are generally referred to in this study as *emerging economies*. While recognizing the degree of optimism implicit in this term, its use merely aims at applying a more specific term than the popular classifications mentioned above and those related to income levels only (ex.: low- and middle-income countries).

The following sub-sections present a historical review of the economic theory concerning the concepts of development and sustainability. Based on that, these sub-sections present a discussion about the role of the state in supporting sustainable as well as industrial development in the context of global climate change.

2.1.1. Economic growth and economic development

Despite several important insights from classical economists since Adam Smith as well as from neoclassical economists since the 1870s, it was only after World War II that the mainstream of economics began to focus on the discipline of economic development (Ingham, 1993; Lynn, 2002; Ranis, 2004). In spite of the vast literature on the issue nowadays, defining development and describing its processes remain complex and controversial tasks.

According to Perkins *et al.* (2001: 8-9), the terms *economic growth* and *economic development* have often been used as synonyms, but a fundamental distinction lies between them. Generally, economic growth refers to a rise, by whatever means, in national or per capita income. Economic development, however, implies economic growth with fundamental changes in the structure of the economy such as a rising share of industry along with a falling share of agriculture in national product, as well as in the extent and sophistication of capital goods used in production (Perkins *et al.*, 2001: 8; Lynn, 2002: 9).

Kenny and Williams (2001) review the growth literature and conclude that “the current state of understanding about the causes of economic growth is fairly poor”. The authors attribute this situation to a widespread denial of the complexity and heterogeneity of the process of economic growth which by and large assumes that components and processes of the economy are the same across countries and in the course of time. Nevertheless, Kenny and Williams agree that it is a near-universal phenomenon that the proportion of labour in agriculture declines as countries become richer and that manufacturing and services contribute to a larger extent to the GDP (Kenny and Williams, 2001: 12).

Sachs (1980: 21-22) argues that even though the industrial sector may account for only a small part of the national product in many developing countries, the pace and pattern of growth of this sector are likely to heavily influence the countries’ entire development strategy. According to Sachs, going beyond the relative share of manufacturing industries in the GDP and, instead, using as criteria the rates of growth, levels of and changes in productivity, diversification of the output mix, introduction of new techniques, and new forms of management, the industrial sector appears to be leading the process of economic development in nearly every case.

The idea that economies move in stages from subsistence to an industrialised state is an old one. The earliest economists saw society progressing from what Adam Smith in 1776 called “early, rude state” of hunting and gathering, to increasing specialisation and exchange, and then to modern industrial economies, with more capital accumulation and ever greater levels of production (Lynn, 2002: 43-47).

For the classical school, agriculture was subject to diminishing returns to labour on basically fixed land. The capacity of technological change to overcome the Malthusian (Malthus, 1815) and Ricardian (Ricardo, 1951 – originally published in 1817) “pessimism” remained controversial. The growth of non-agricultural activities was considered a consequence of the accumulation of fixed capital and labour drawn out of agriculture. The main fuel for the reallocation of labour as well as for the accumulation of industrial capital was seen as coming from the profits of agricultural capitalists. The government role in this dual-sector economy was not to promote particular industries but to permit individuals maximum opportunities to pursue their self-interest (Lynn, 2002: 43-47; Ranis, 2004: 2).

Some of the first modern theorists to build on *classical dualism*[4] were Rosenstein-Rodan (1943), Mandelbaum (1945) and Nurkse (1953). In general, these authors pointed to

[4] Sociological dualism is generally associated with Boecke (1953) and emphasised differences between a traditional, rural and a modern, urban sector in developing economies. Part of the debate over the dual economy

the existence of surplus labour as a potential resource, which once reallocated from agriculture to higher productivity pursuits in non-agriculture would constitute a major fuel for economic development. Lewis (1954) focused on the dualism in the labour markets, particularly concerning the determination of wages, and argued that labour reallocation would continue until all those whose remuneration exceeded their low marginal product had moved out of agriculture into commercialised non-agriculture (Ranis, 2004: 3).

In general, the theoretical discussion prevailing in the early post-WWII-period indicated that on the policy side there was an inclination to support state interventions for development, which was strongly associated with industrial growth. Import Substitution Industrialisation[5] (ISI), for example, was widely accepted as a component of the catching-up efforts of late developing economies until the 1960s and 1970s when it lost favour, reaching its utmost disfavour toward the end of the 1980s (Felix, 1989: 1455).

In this context, Rosenstein-Rodan (1943) advocated that development required a "big push", i.e. a major investment in order to create a set of complementary industries in the absence of an integrated national market. A similar idea was defended by Nurkse (1958), which became known as "balanced growth". Nurkse's balanced growth builds on the "big push" theory, but calls for a pattern of mutually supporting investments over a range of industries wide enough to overcome the frustration of isolated advance. While Rosenstein-Rodan's big push largely ignored agriculture in its focus on industrialisation, Nurkse recognised that agriculture should be part of a balanced approach (Lynn, 2002: 60-64; Ranis, 2004).

Along the lines of Rosenstein-Rodan and Nurkse, Hirschman (1958) thought of economic development as a massive coordination failure, in which several investments do not occur because other complementary investments are not made, and, similarly, in which the latter investments are not forthcoming because the former are missing. In contrast to these first authors, though, Hirschman proposed an "unbalanced growth", which meant to provide a boost to strategic or leading sectors that could create the linkages to bring others to existence. Hence, government officials should analyse the set of possible industries for those

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scenario in the 1950s and 1960s concerned how quickly progress in the modern sector would trickle down to the traditional sector, but many pointed to the integration and interdependence between these two sectors. Some authors focused on technological dualism (Higgins, 1956; Eckaus, 1955), but it was the classical dualism owing much to David Ricardo's *The principles of Political Economy and Taxation,* originally published in 1817 (Ricardo, 1951), that influenced the new emphasis on two-sector models in early post-World War II development theory (Lynn, 2002: 46; Ranis, 2004: 2-3; Perkins *et al.*, 2001: 88).

[5] Import Substitution Industrialisation consists of "a development strategy by which a technologically backward economy tries to accelerate industrial investment primarily for the home market prices through heavy reliance on government manipulation of market prices, barriers to entry and access to imports and finance". The inducements tend to be directed selectively, whereas the selection criteria vary between countries and may also shift through time. ISI is viewed as a transitional strategy, to be gradually superseded as the industrial sector matures technologically by lowering import barriers and increasing industrial exporting (Felix, 1989: 1455).

whose activities were most likely to create the most significant linkages for a particular country (Ray, 2000; Lynn, 2002: 59-60).

Primarily focused on explaining the relationship between growth and unemployment in advanced capitalist societies, Roy Harrod and Evsey Domar developed during the 1940s a well-known model which is usually seen as the earliest one dealing with growth, and referred to as the *Harrod-Domar model*. The Harrod-Domar model ultimately drew attention to the role of capital accumulation in the growth process and has been used extensively to examine the relationship between growth and capital requirements. Despite its original simplicity and rigid assumptions[6], this model was very influential, and eventually reinforced a tendency to equate development with growth, and growth with industrialisation (Perkins *et al.*, 2001: 45; Lynn, 2002: 50-52).

Mostly focused on industrialisation as a driver for economic development, the theoretical elements of the early post-war consensus concentrated on efficient resource allocation due to capital scarcity and savings-pushed growth, with relatively minor emphasis on technology change. In the mid-1950s, however, Robert Solow introduced a new growth model that represented an important step forward from the Harrod-Domar framework. Solow (1956) viewed technology as an exogenous factor directly enhancing the input of labour, and adopted a neoclassical production function which allowed for more flexibility and substitution between labour and capital (Perkins *et al.*, 2001: 52). His major contribution was to emphasise, for the first time since Schumpeter (1959 – originally published in 1912), the importance of technology in generating growth. This motivated a good deal of applied work on the role of research and development (R&D), technological choice, patents and other forms of scientific endeavour, leading to the emergence of the so-called *new growth theory* (Ranis, 2004: 3-6).

The early economic development and growth theory considered development as a economic technical problem. The solution to such a problem did not include any environmental preoccupation yet, and was mostly seen as a matter of increasing capital stock and improving resource allocation. Stiglitz (1998: 6) argues that by that time economists from the left and from the right agreed that development was a problem of improving resource allocation, but diverged strongly on the strategies to overcome this dilemma. While economists from the left attributed the underlying problems to market failures and sought to use governments to complement markets, economists from the right assumed that once governments could step out of the way, markets by themselves would lead to efficient

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[6] These assumptions mainly comprised: full employment as the initial condition, no allowance for substitution between factors of production, immediate transformation of savings into investment (requiring a well-developed financial system and functioning markets), and no allowance for monetary variables, prices or international trade.

resource allocation. It was argued that governments lacked the capabilities to undertake a major role in resource allocation, and that whatever capabilities governments had were often directed not at increasing national production, but at diverting rents to the politically powerful.

In the 1960s and 1970s, analyses about dependent relations among countries based on Marxist tenets, and particularly concerning the underdevelopment of Latin American countries, became internationally more popular, giving breath to what is usually referred to as dependency theory. The dependency school postulates that external political economic factors play an important role in the failure of development to occur in many countries (Palma, 1978: 911). In general lines, the dependency school considers the socio-political context to play a paramount role in the development process, which in developing countries (periphery) is largely driven by metropolitan or developed countries (centre). The central countries shape the periphery to suit their needs for material and labour power. Profits of companies from central countries are either sent home or used to create a dependent business class in the satellite country, making the development of the centre and underdevelopment of the periphery opposite sides of the same coin (Lynn, 2002: 48-49).

Together with research centres such as the CESO school (*Centro de Estudios Sociales – Universidad de Chile*) and the CEREN (*Centro de Estudios de la Realidad Nacional – Universidad Católica de Chile*), the United Nations Economic Commission for Latin America (ECLA) became a major source of inspiration for the dependency economics school. The core of the ECLA analysis was the critique of the conventional theory of international trade (as expressed in Hecksher-Ohlin-Samuelson model of Ricardo's theory of international trade). By doing that, it aimed to show that the international division of labour produced by world trade was of much greater benefit to the centre, where manufacturing production was concentrated, than to the periphery, which was destined to produce primary products. There were two reasons for this. Firstly, factor and commodity markets were more oligopolistic at the centre than in the periphery and, therefore, the benefits of trade were unequally distributed, leading to a long-term decline in the terms of trade for the periphery. Secondly, considering the role of externalities, there were a number of benefits associated with industrial production, which were needed in order to achieve accelerated and sustained economic growth in Latin America. This process of industrialisation could not be expected to take place spontaneously, for it would be inhibited by the international division of labour which the centre would attempt to impose, as well as by a series of structural obstacles internal to the Latin American economies (Palma, 1978: 882-898).

Structural obstacles to development have been a central point of the debate between neoclassical economics and structuralism, distinguished by Little (1982) as the two broad categories of development economics in the 1960s and 1970s. Based on the work of writers from the 1950s such as Paul Rosenstein-Rodan, Ragnar Nurkse, W. Arthur Lewis, Raul Prebisch, Hans Singer and Gundar Myrdal, proponents of structuralism argue that developing countries face large disequilibria and inflexibility of response to price incentives (Little, 1982: 20-21). These characteristics, in addition to the stronger immobility of resources and differences in the production structures of developing countries compared to developed ones, were considered important bottlenecks that inhibited change and adaptation. Structuralists advocated that in order to achieve development, it was necessary to change these aspects through direct administrative action (Arndt, 1985: 151).

In the early 1970s, Kuznets (1971) placed emphasis on the sources of structural change over time between agriculture, industry and services in developing countries (Ranis, 2004: 6). Chenery and Taylor (1968) as well as Chenery and Syrquin (1975) attempted to identify patterns of change in sectoral shares in various countries, and found no single well-defined pattern. Although average patterns found by Chenery and his co-authors presented a great variation around the trend, some planners used these patterns as benchmarks for the actual performance of their countries' industrial growth rates (Perkins *et al.*, 2001: 86).

Over the years there was a growing recognition that distortions in relative factor prices, overvalued exchange rates, low interest rates and biased internal terms of trade - all instruments of import substitution - not only discouraged agriculture and limited employment generation, but also created windfall profits for favoured elites long after such support was no longer necessary for infant industry reasons. In this context, the realisation that the enhanced use of the market needed to be complemented by institutional reforms and policy change was one indication of the gradual change in the development paradigm. Some of the basic ingredients of the new emerging consensus were the need for macro-economic stability together with the gradual rejection of structuralism (i. e. the belief in the non-response of agriculture and of export pessimism), focusing on an enhanced reliance on liberalising markets (Ranis, 2004: 7-9).

In the 1980s, spurred by the two international oil crises from 1973-74 and 1978-80, borrowing countries, especially in Latin America, began to have difficulty to generate sufficient government revenue and foreign exchange, whereas facing mounting debts and debt service. By 1987, after Mexico's moratorium on the payment of interest on its foreign debt in 1982, net resource flow to developing countries became negligible. For international commercial banks and countries which had borrowed from them the debt crisis was over by the mid-1990s. However, for countries (mostly low-income countries in sub-Saharan Africa, South Asia and Central America) which had borrowed from other governments and international financial institutions, the debt crisis was lingered unsolved through the end of the 20th century (Perkins *et al.*, 2001: 540-556).

In this context and following the gradual rejection of structuralism, the development policy focus changed from resource allocation to the "adjustment" of fiscal imbalances and misguided monetary policies, which did not allow markets to function well. John Williamson's compilation of ten policy areas for reform (Williamson, 1990), commonly referred to as the "Washington Consensus", reflects the new focus of the economic development policy at the time.

The original list of Williamson's ten areas for policy reform included fiscal discipline, public-expenditure priorities to fields with high-economic returns (e.g. income distribution, primary health care, primary education and infrastructure), tax reforms (including improved tax administration, broadening the tax base and cutting marginal tax rates), financial liberalisation, unified and competitive exchange rates, trade liberalisation, abolishment of barriers impeding the entry of foreign direct investment, privatisation, abolishment of regulations restricting competition as well as the entry of new firms, and enforcement of property rights. Although Williamson's "Washington Consensus" was originally thought of by himself as a report on the policy change occurring in Latin America in the 1980s, which he believed the Washington-based Breton Woods institutions[7] could agree with, it has been often interpreted as a "neo-liberal" or market-fundamentalist policy manifesto (Williamson, 1997: 48-60).

Ranis (2004: 9) argues that although not listed among the ingredients of the Consensus, the realisation that technological choice and the choice of the direction of technological change could be of major importance for successful development played an increasingly relevant role. The importance of state-sponsored research, particularly on export-oriented cash crops, had been long recognised but its role in basic food crops, in non-traditional agriculture and in non-agricultural exports emerged only gradually. It became increasingly clear that food-producing agriculture cannot be neglected, that rural producers and workers do respond to their economic environment and that industry cannot pull an economy into modern economic growth if agriculture remains stagnant.

The renewed attention to the role of technology in economics from the 1980s onwards is to a great deal related to the emergence of the so-called 'new growth theory', which, based on Solow's work, tries to incorporate technology as an endogenous factor through models of market externalities and, thus, explain the dynamics of growth. While Solow emphasised the role of technology in the maintenance of growth in per capita income,

[7] International Monetary Fund and International Bank for Reconstruction and Development, which today is part of the World Bank Group.

he did not specify how technological change took place or how it might be affected by the growth process itself. Although Arrow (1962) had already tried to endogenise technology by assuming learning by doing, Paul Romer's (1986) challenge of the Solow-type model is usually indicated as the point of departure for the new growth theory, also pioneered by Romer (1990), Lucas (1988), Grossman and Helpman (1991) as well as Aghion and Howitt (1998). These new models assume increasing returns to scale as well as a larger impact from investments in physical and human capital in the whole economy through positive externalities (De Loo and Soete, 1999: 1; Perkins *et al.*, 2001: 62; Ranis, 2004: 17-18). Positive effects of such investments on the environment did not receive much attention from the new growth theory at that time.

On the one hand, an important implication of the new growth theory is that economies with increasing returns to scale do not necessarily reach a steady-state level of income as in the Solow's framework; in other words, an increase in the saving rate can lead to a permanent increase in the rate of economic growth. On the other hand, another implication is that the gap between rich and poor is likely to widen due to accumulated knowledge and application of new technologies in generating more knowledge. This raises doubts about the hypothesis of long-run income convergence among countries, particularly concerning those which do not have enough resources to sustain appropriate institutions and incentives to facilitate learning and technological change (Lynn, 2002: 54-55).

As demonstrated by Williamson (1990), with the so-called Washington Consensus there was a general agreement in the end-1980s about the necessary basic macroeconomic conditions to ensure economic restructuring. However, there were considerable divergences about what was needed on the micro level, which clearly varied from country to country. Based on this general consensus on the macro level, some bilateral development agencies put forward lending programmes including micro level policy requirements. Since the 1960s, USAID's *structural adjustment lending* programme had combined policy packages incorporating both macro and micro ingredients with fast disbursing loans. Anchored in USAID's experience, the International Monetary Fund and the World Bank developed in the 1980s their own conditioned-lending programmes, which were also named structural adjustment lending and have become the subject of lively debate ranging from their cost-effectiveness to infringements of recipient's sovereignty (Ranis, 2004: 11).

For Stiglitz (1998: 7) the development thought by this time did not reach deep down into society, leading to the belief in the idea of uniformity of the development process as an implicit rationale behind several policy initiatives worldwide.

The end-1970s and 1980s also saw the emergence of poverty and income distribution as major issues in the economic development debate, as well as alternative concepts of development beyond the single focus on income growth. The apparent contradiction of how to best satisfy the basic needs of the poorest (i.e. social development) without hindering the economic growth of the rest of the society received considerable attention (Srinivasan, 1977; Streeten, 1977; Ram, 1985).

Newman and Thomson (1989) point out at least four ways of analysing the relationship between economic growth and social development in the literature: a) research that assumes that economic growth is a cause of subsequent social development (the 'trickle-down' approach); b) research that tends to treat the two types of development as separate, unrelated variables; c) research that suggests that neither one of the two types of development is a primary cause of the other, but that they are related (mutually causative hypothesis); and, d) research that suggests that social development is a cause of subsequent economic growth (the basic needs or 'trickle up' hypothesis). Newman and Thompson (1989: 469) find that the trickle-up hypothesis is more consistent empirically, based on panel data of 46 developing countries for the years 1960, 1970 and 1980. They conclude that reliance on economic growth policies with the expectation that social development will follow is not realistic, which requires the incorporation of both economic and social policies in overall societal development plans.

During the 1990s, achieving improvements in various dimensions of social or human development such as infant mortality, life expectancy and literacy has come to the fore as the appropriate fundamental objective of development. Sen (1992), ul Haq (1992), Srinivasan (1994) and Streeten (1994) made important contributions which gave further impulse to the debate on 'basic needs' from the 1970s, putting into question the sole emphasis on income growth within the mainstream development debate (Ranis, 2004: 13-14). All in all, their main argument was that attention should be shifted away from the means that allow liberties to expand such as economic growth, increased personal income, technological progress or social modernisation towards the ends which are the liberties themselves. Although environmental issues had already received broad popular attention in the 1960s and 1970s in developed countries, particularly regarding pollution and the sufficiency of food and other resources, only since the end-1990s the preoccupation concerning the environment has been explicitly embodied in the human development debate, with the incorporation of an intergenerational perspective (Anand and Sen, 2000; Røpke, 2004: 297; Constantini and Monni, 2008: 867).

The idea of conciliating environmental degradation and economic development arose essentially from concerns relating to the over-exploitation of natural resources (Anand and Sen, 2000). Towards the end of the 1960s, considerable concern began to be expressed in the developed countries about the impact that economic growth was having on the environment

(Beckerman, 1992: 481). Protests against nuclear fallout and waste disposal in developed countries since the end-1950s contributed to the increasing public interest in the impact of pollution. Drawing from Malthusian theories, the drastic increase of the world population after World War II and its consequences in terms of sufficiency of food and natural resources (Ehrlich, 1968) were additional factors to bring further public attention to environmental issues. The study by Meadows *et al.* (1972) is often pointed out as a pioneering work putting the resource aspect of the environmental challenge on the agenda.

Motivated by the increasing public regulation of the environment, from the early-1970s the field of environmental and resource economics grew rapidly and the cost of pollution control became the central theme (Ayres, 2008). Also in the 1970s energy became a central issue. Since then, energy economics has received a great deal of attention, and has been closely related to the discussion on resource use. The real breakthrough for this concern was the oil price shock in 1973 and the following energy crisis (Constantini and Monni, 2008).

Simultaneously, attempts to relate the economic theory to the biophysical reality, i.e. to recast economics as a life science (see Boulding, 1966; Georgescu-Roegen, 1966; Daly, 1968; Ayres and Kneese, 1969; Kneese *et al.*, 1970; Georgescu-Roegen, 1971), gave impulse to the rise of ecological economics during the 1980s. In general, ecological economics considers that human economy is embedded in nature and, thus, economic processes can also be conceptualised as natural processes in form of biological, physical and chemical processes based on energy and material flows. This perspective calls for an awareness of the human dependence on well-functioning ecosystems that provide the basic life support for human societies. This awareness implies that economic growth may increase the risk of endangering human life in much more subtle ways than the traditional discussion of limits to growth had considered (Meadows *et al.* 1972; Cole *et al.* 1973; Røpke, 2005: 266).

Taking into account this growing environmental attention, international organisations and donor countries began to support debates and policies relating social and economic development with resource and environmental concerns. The United Nations played a key role in bringing this concern to the international public’s attention through its 1972 UN World Conference on the Environment in Stockholm, though its so-called Brundtland Commission, established in 1983; and with its 1992 UN Conference on Environment and Development in Rio de Janeiro. The result of this context was the gradual incorporation of environmental issues in an intergenerational perspective into social and economic development, leading to the emergence and popularisation of the concept of sustainable development.

2.1.2. Sustainability and sustainable development

The concepts of sustainability and sustainable development have generated diverse reactions and interpretations, while having turned increasingly important around the world. Nevertheless, finding a common definition for these terms is far from straightforward, which seems to have motivated many stakeholders to twist their meaning according to their particular interests (Ayres, 2008: 5).

The broad but operational definition by Pezzey and Toman (2002) can be helpful in briefly reviewing the epistemology of sustainable development as from the mid-1970s, with emphasis on the field of economics. According to Pezzey and Toman, *sustainability* involves some concern in the long-term decision-making for intergenerational equity or fairness, as well as some acknowledgement of the role of finite natural resources. The concern of intergenerational equity, however, does not necessarily involve explicit use of the words "sustainability" or "sustainable development", as is the case with most of the literature before the report by the Brundtland Commission (WCED, 1987).

These concepts emerged from the debate on "limits to growth" of the early 1970s mentioned above, which followed Georgescu-Roegen's book *The Entropy Law and the Economic Process* (Georgescu-Roegen, 1971) and discussed whether or not continuing economic growth would inevitably lead to severe environmental degradation and societal collapse on a global scale. By the end-1970s an apparent resolution of the problem was reached: economic development could be sustained indefinitely, but only if development was modified to take into account the interdependency of the economy and the environment (Pezzey, 1992a: 1; Ayres, 2008: 4).

Responding to the limits of growth, the works of Dasgupta and Heal (1974), Stiglitz (1974) and Solow (1974) became classics in the field, despite the fact that none directly mentions the word "sustainability" or "sustainable development". The three papers discuss the nature of economic growth when a non-renewable natural resource, as well as (human-made) capital, are significant inputs to production. For all of them, natural resources are finite, non-renewable and essential to production, while (human-made) capital is indefinitely substitutable for natural resources via a Cobb-Douglas production function. One of Dasgupta and Heal's main conclusions was that present-value optimality, understood as the maximisation of the instantaneous present-value utility, applying a constant discount rate and with absent technological progress, is gloomy for far-distant generations. After an initial peak, these generations are expected to face extremely low utility and consumption levels in the very long run. Stiglitz suggests that one way of avoiding this stalemate requires that the rate of exogenous technological progress remains large enough to offset the effects of resource depletion. From a rather different approach, Solow focuses on maintaining constant consumption levels indefinitely, which under a constant population level and despite declining resource flows would be possible, if resources accounted for less than half of the production value (Pezzey and Toman, 2002: 5-7).

Solow's work motivated other analyses on optimal capital accumulation paths, which supposedly could make possible *indefinite constant consumption*. Hartwick (1977) coined what came to be known as Hartwick's rule, which says that the rent derived from resource depletion in any closed economy is exactly the level of capital investment that is needed to achieve constant consumption over time[8]. Therefore, for constant consumption to be sustained when the resource is non-renewable, some type of substitution between capital and resources would be necessary. These ideas provided the foundations of the so-called weak sustainability approach, which is further explained below.

Apart from few authors (Boulding, 1966; Georgescu-Roegen, 1966; Daly, 1968; Ayres and Kneese, 1969; Kneese *et al.*, 1970; Georgescu-Roegen, 1971), the mainstream economics from the end-1960s to the end-1980s was far from fully acknowledging the systemic links between the economic, social and natural spheres. For Pezzey (1992a: 11) most definitions at that time (Brown et al., 1981; Clark and Munn, 1986; Repetto, 1985; WCED, 1987) understood sustainability to mean sustaining an improvement (or at least maintenance) in the quality of life, rather than sustaining the existence of life.

In the mid-1980s, active discussion of sustainability concepts and criteria began in earnest in the economics literature (Pezzey, 2002: 10). A notable earlier contribution was "The Concept of Sustainable Economic Development" (Barbier, 1987).

Meppem and Gill (1998) classify definitions of sustainability in positivist or in normative terms. The normative interpretation pointed out by them as the most widely quoted is the one expressed by the World Commission on Environment and Development in its report entitled "Our Common Future" (WCED, 1987), which describes sustainable development as development that *meets the needs of the present without compromising the ability of future generations to meet their own needs*[9]. The positivist interpretation relies on quantifiable aspects and measurement tools such as the BCA (Benefit-Cost Analysis).

[8] Pezzey and Toman (2002: 8) hold that many governments and multilateral institutions have invoked the Hartwick's rule, consciously or not, when declaring the importance of investing rents from natural resource depletion in building up capital in the rest of the economy. However, these actors do not seem to be aware of the departure from current, broadly free-market policies on growth and investment, which the Hartwick's rule may imply. Considering that market investment behaviour is driven by a conventional present-value objective, the implementation of the Hartwick's rule actually requires massive government intervention in capital markets.

[9] Redclift (1992: 395) expresses the criticism faced by the WCED definition in the sense that it has placed the emphasis in sustainable development on meeting human needs. However, the WCED report does not further elaborate a theory of human need, while making constant reference to the centrality of needs, and the role of the environment in meeting them. According to Redclift, this has generated a great deal of confusion about the interrelationships of social, economic and biological systems.

The BCA is based on an important insight of environmental economists in the 1960s and 1970s that, if environmental damage can be quantified in monetary terms, the benefits of pollution control can be expressed as an increasing function of the degree of control, and marginal benefits should decline toward zero. Thus, the cost and the marginal cost of control tend to increase as the degree of control approaches its maximum level. As a result, an optimum point can be found where the marginal cost of control is equal to the marginal benefit. This rationale has, however, received a wide array of criticism[10]. On the one hand, critics argue that environmental harm, services, natural and human life cannot be evaluated in monetary terms, implying that the benefits of pollution are beyond price. On the other hand, measures to abate or compensate for environmental damages do have monetary costs and choices must be made, since available funds are always limited (Ayres, 2008).

After the seminal role of the WCED's *Our Common Future* (WCED, 1987), publications by Pearce (1988), Collard *et al.* ed. (1988), Daly and Cobb (1989), Pearce *et al.* (1989), as well as Daly (1990) and Constanza ed. (1991) pulled the debate forward. Daly (1990), particularly, played a crucial role in the foundation of the so-called strong sustainability approach (Pezzey, 2002: 12) by suggesting that a) sustainability requires the total capital (human-made plus natural capital) to be maintained at an optimal level over time; and b) that natural resources and capital are complements rather than substitutes. Based on these assumptions, Daly (1990: 2-4) suggests three "obvious" principles for sustainable development: 1) harvests should equal regeneration rates (sustained yields); 2) waste emission rates should equal natural assimilative capacity of the ecosystems into which wastes are emitted; and 3) non-renewable resources should be used according to the rate of creation of renewable substitutes, which requires re-investment of the earnings obtained into the development of adequate alternatives. Daly's three principles, however, do not consider environmental services (ex.: leisure, pollination, biodiversity, macro- and micro-climate regulation) other than the absorption of waste products and the provision of raw materials and energy. Neither do they address the specific spatial, social and temporal contexts which determine the subjective attribution given by individuals to nature's utility.

For Horwarth and Norgaard (1990), sustainability is a matter of intergenerational equity, i.e. the distribution of rights and assets across generations determines whether the efficient allocation of resources sustains human welfare across generations. Applying the so-called overlapping generations analytical framework to a three-period general equilibrium model, they argue that different endowments of resource rights across two overlapping

[10] According to Meppem and Gill (1998), tools such as the BCA have appealed to the prevailing cultural need for apparent objectivity, quantitative precision and theoretical rigour. Despite the criticism, the BCA has become a standard tool worldwide (Ayres, 2008).

generations result in different but equally efficient (not optimal) distributions of wealth, with considerable consequences in terms of equity. Later, using a model that includes many generations, Howarth and Norgaard (1992) conclude that the path of consumption across time and the marginal valuation of environmental externalities (measured by efficient emission taxes) depend on the distribution of wealth across generations. Considering that values vary with societies' context and views of the future, they argue that no fixed notion of "correct" valuation of environmental costs is possible.

According to Victor (1991), although no agreement about the precise meaning of sustainable development exists, the idea that sustainable development requires the enhancement or maintenance of the stock of capital that one generation passes on to the next was broadly accepted in the early-1990s. This stock of capital comprised two elements: human-made capital and "natural capital". However, the extent to which these are believed to be substitutes or complements remained one factor which separated the neoclassical school from some of its critics.

The so-called *weak* and *strong* sustainability are often indicated as the two main concurrent paradigms providing the grounds for attempts to define sustainable development (Turner *et al.*, 1994; Hediger, 1999; Hediger, 2000; RSU, 2002). They differ mainly in their assumption about the possibility and acceptance of substitution between different types of capital, including natural resources (natural capital). The paradigm of weak sustainability allows the utilisation of natural capital and its transformation into physical or knowledge capital, providing that the general capital utility and, thus, human well-being is improved or at least remains constant. Conversely, defenders of strong sustainability regard natural capital as not substitutable. According to this concept, the economic system must work according to the limits of nature's regenerative capacity. Sustainable development means, thus, to comply with natural frontiers, which determine the optimal output level of the economy.

Economic efficiency, ideally measured as the difference between benefits and costs (Arrow *et al.*, 1996: 221), but more often than not simply understood as the achievement of higher rates of income growth, has been broadly suggested as a necessary element for achieving sustainable development (Daly, 1990: 1). Yet, Common and Perrings (1992) argue that economic efficiency, seen as inter-temporal price efficiency, is not necessary for ecological sustainability and may well be inconsistent with it. They define ecological sustainability as the stability of the ecological system parameters (organisational principles) in face of disturbance by socio-economic activities. This notion is based on the idea of resilience suggested by Holling (1973), which refers to the ecological system's capacity to accommodate the stress imposed by its environment, by selecting a different operating point along the same thermodynamic path and without undergoing some 'catastrophic' change in organisational structure. Common and Perrings hold that, if preferences and technologies are not ecologically sustainable, economic efficiency can conflict with sustainability since consumer sovereignty would lead to systemic instability. The authors defend that tackling this situation would require the regulation of activity levels within the existing structure of preferences and/or changes in that structure of preferences through government interventions in the form of price manipulation, education and changes to property rights, among others.

Criticism arose as soon as the attempts to define sustainable development progressed during the 1990s. Beckerman (1994), for example, holds that “sustainable development” has been defined in such a way as to be either morally repugnant or logically redundant. He criticises the idea of “strong” sustainability as morally unacceptable and impractical, as well as of “weak” sustainability (cf. Pearce and Atkinson, 1993), which, he argues, offers nothing beyond traditional economic welfare maximisation. Furthermore, Beckerman considers the requirement that “sustainability” should mean non-declining human well-being (cf. Pezzey, 1992b) as irrational. Alternatively, he suggests that the welfare theory, when suitably defined, can include the subjective effects of changes as well as the levels of well-being. Hence, there would be no reason why welfare maximisation should not remain an overriding policy objective, providing proper consideration is given to intergenerational justice and correction of market imperfections.

Constanza and Patten (1995) echoed the growing awareness at the time about the need to review the ideas on sustainable development, particularly concerning the acceptance of indefinite sustainability. For these authors, the basic idea of sustainability was simple: *A sustainable system is one which survives or persists.* However, three further questions reveal its real complexity: 1) *what* system, subsystem or characteristics of systems should persist?; 2) for *how long?*, considering that no system, not even the universe, lasts forever; 3) *when* should we assess whether the system, subsystem or system’s characteristic has persisted? Constanza and Patten hold that the main issue behind sustainable development, thus, is not definitional but is one of prediction of what will last, and of achieving consensus on what we want to last. Therefore, they defend that many elements of sustainability definitions are actually predictions of system characteristics that one hopes lead to sustainability (understood as maintenance or increases of systemic longevity), not elements of a definition.

Despite the conceptual challenges and consequent lack of consensus about the idea of sustainable development, the 1990s have witnessed an explosive growth in concepts such as eco-efficiency, de-materialisation, industrial ecology and bio-mimicry (Robinson, 2004: 375). In general, these arguments are based on the idea that by learning from highly efficient natural processes, new industrial systems can be designed that will use less matter and energy throughput required to produce the same products in conventional industrial processes, and ultimately will lead to more sustainable resource use. This in part reflects the growing attention given to technology, which was largely pushed forward by the emerging "new growth theory" at that time, as well as by efficiency gains through the adoption of new technologies.

An important insight from studies in that period according to Ayres (2008: 4) was that technological change is likely to accelerate the rate of environmental degradation in the absence of an adequate resource policy (Smulders, 1998; Smulders, 2000). This applies particularly to renewable resources, since most of them are public goods, including air, fresh water, favourable climate and biodiversity. As such, they are not traded in markets and, thus, environmental damage has the character of an externality. Hence, due to a lack of mechanisms to assure that the polluter pays, regulatory means of abatement or compensation are needed. The issue of the most adequate institutional frameworks in support of efficiency and equity from an intra- and intergenerational point of view remains strongly disputed.

While there has been a growing recognition that sustainability involves gains from efficiency as well as intra- and intergenerational equity, integrating efficiency and equity issues has not been common in the field of Economics. Page (1997) criticises the long tradition to separate efficiency and equity analyses in Economics (cf. Arrow *et al.*, 1996), particularly concerning environmental decisions for cases with long-term consequences. Gowdy and O'Hara (1997: 243) hold that this separation does not allow a proper sustainability assessment, since the sustainability of a system should be judged on the whole system, not just part of it.

From the 1990s social concerns such as poverty and income distribution began to receive more attention within the sustainability debate. While wealth gains, understood as gains in terms of quantity and quality of capital assets, may be a source of pressure on the environment, wealth largely determines the conditions faced by a given set of humans to improve their well-being and chances they have to achieve sustainable development (Pearce and Atkinson, 1998).

Despite the relatively vast literature relating distributional issues to economic growth and growth to the environment, there have been very few attempts to analyse the links between poverty, income distribution and the environment. Koop and Tole (2001), for example, investigate the role played by distributional factors in mediating the effects of economic growth and development on forest depletion in tropical developing countries. For them the distributional profile of a country significantly determines whether economic development will have either a positive or a negative effect on the rate of forest loss. According to the authors, in countries where levels of inequality are high, development will tend to exacerbate deforestation rates while in countries where distributional profiles are more egalitarian, the negative effects of growth and development on forest cover will be ameliorated.

Another front which has received a great deal of attention during the 1990s and continues to do so until today refers to the replacement of natural services by human-made capital and labour. A key insight that has emerged is that there is a number of natural services that cannot be replaced. This has given impulse to a growing literature on the search for the so-called critical natural capital, which is defined as any set of environmental resources which, at a prescribed geographical scale, performs important environmental functions and for which no manufactured, human or other natural substitute exists (O'Connor, 2000: 13-14)[11].

As presented above, the issue of non-substitutability between human-made and natural capital is the essence of what is meant by "strong sustainability". However, strong sustainability has been challenged by a number of reputable mainstream economists such as Solow (1993) and Pearce (1997), who continued to argue that human creativity and human-made capital can indeed replace virtually all environmental services.

The German Council on Environmental Issues in its Environmental Report to the German Parliament in 2000 (RSU, 2000: 67) holds that the classical concept of weak sustainability should be abandoned and, thus, the maintenance of natural capital should become the main guideline for national strategies for sustainable development. Hence, three main rules are important for the sustainable management of natural resources: (1) renewable resources should only be used according to their estimated regenerative capacity; (2) non-renewable raw materials and energy sources should be consumed only to the extent that is both physically and functionally compensated by renewable resources; (3) polluting emissions should not overcome the absorption capacity of the environment and ecosystems, and emissions derived from non-renewable resources are to be minimised no matter the extent to which generation capacity is still available.

From an ethical perspective, Ott (2002: 13) argues that the concept of strong sustainability leaves more possibilities open and is therefore preferable taking into consideration the freedom of choice of future generations. However, Ott considers it dogmatic to generally set the substitution elasticity of natural capital down to zero, but agrees that the 'constant natural capital rule' should be taken as guideline for sustainable development policies.

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[11] According to O'Connor (2000: 14), the application of this concept requires detailed appraisal of the roles and significance of different natural capital systems for supporting economic activity as well as the identification of the destructive environmental effects of each economic use/user category. If this information can be obtained, it is possible to specify spatial and temporal scales for which certain environmental functions and, hence, the natural capital systems may be critical, taking note of social and cultural factors that may contribute to making these of 'critical' importance.

Although ‘strong’ sustainability seems indeed more realistic in terms of policy-making, the rule of constant natural capital should not be considered a blueprint for sustainable development policies without proper consideration of important contextual determinants such as living conditions and poverty. For countries with large natural resource pools and huge developmental challenges, capital substitution with rigid efficiency and effectiveness considerations makes quite a lot of sense. Contrary to what most proponents of the weak sustainability suggest, though, substitution can only be possible up to some point when further substitution will affect critical environmental services, including human quality of life. Determining what “critical” should mean, however, is a challenge indeed and should embrace both natural aspects and human preferences, which are continuously changing and may vary considerably among different communities and countries.

Apart from the operational complexity of sustainable development, the conditions towards it can be improved both in developed and developing countries. Due to the significant development imbalances worldwide, there is considerable room for efficiency and effectiveness improvement. Arguably, efficiency and effectiveness are preconditions for any morally acceptable resource use, since inefficiency and ineffectiveness imply waste (Ruth, 2006: 333).

2.1.3. Industrialisation and sustainable industrial policy

As was shown in the previous sub-section, it seems unanimous among the various economic schools that industrial growth is of crucial importance for economic development. Also, it represents a potential source of environmental pressure, whereas contributing to improving the conditions towards sustainable development. This sub-section explores some theories around the concept of industrialisation as well as the debate on the relationship between industrial growth and sustainable development.

According to Perkins *et al.* (2001: 83), every country that has achieved a high per capita income also has experienced an increase in the share of industrial value added in gross national product. As put by them:

> *The concept of development and the process of industrialisation often have been treated as synonymous, ever since the Industrial Revolution enabled Britain to raise its industrial production by 400 percent over the first half of the nineteenth century. From then until the present, the dominant criterion for development has been the rise in per capita income brought about largely by industrialisation* (Perkins *et al.*, 2001: 652).

Industrialisation is a rather heterogeneous phenomenon influenced by many different historic, economic, social and political factors (Borrmann and Wolff *eds.*, 1991: 12).

Although no commonly agreed criteria exist for defining an industrialised economy, it has usually been interpreted as a process whereby the share of industry in general and of manufacturing in particular in the total economic activity is increased both in terms of output and employment (Weiss, 1988: 4-20).

Already in the early-1990s, Hartje (1991: 191-193) pointed out that the debate on the options in energy and forestry policy for reducing greenhouse gas emissions in developing countries as well as the focus on poverty-induced environmental degradation tended to overshadow other sources of environmental pressure, particularly those deriving from industrial processes. For Hartje, the environmental effects of industrialisation tend to be industry-specific, since manufacturing branches have different levels of pollution intensity. Generally, industries transforming natural resources on a mass scale by chemical or physical processes are more pollution-intensive.

Despite the traditional focus of most development economics literature on major shifts in terms of relative employment and output from agriculture to industry and then to services, Montobbio (2002: 389) argues that one of the most striking stylised facts of long-term and medium-term economic development is the continuous process of transformation in the sectoral composition of economic activities at different levels of aggregation. Since environmental effects tend to be sector-specific, changes within industrial sub-sectors or branches may lead to different concerns in terms of natural resource use and sustainable development.

For Kuznets (1989), structural transformations have three main driving forces: 1) different impact of technological innovations, 2) different income elasticities of domestic demand and, 3) a selection mechanism based on the shifts of comparative advantage in international trade. Montobbio (2002) complements Kuznet's list by arguing that the specific position that a sector occupies in the whole economy in terms of product characteristics, substitutability and the performance regarding output size, growth and unit costs of substitute sectors also play a significant role. The question whether states should develop industrial strategies or policies with a significant influence on such driving forces was not explored by these authors and remains a strongly disputed issue worldwide.

The role of the state in supporting conditions towards sustainable development also remains under strong debate. While some have defended that the sectoral composition of industry follows a 'clean' trend as economic development proceeds (Hettige *et al.*, 1997: 5-6), Michaelis (1998: 247-248), for example, argues that during their process of industrialisation most OECD countries have actually seen an increase in the intensity of energy use in their economies. Although the energy intensity required at later stages of development should decline due to the availability of more efficient technologies, Michaelis holds that absolute levels of energy and material use per capita have been increasing in most industrialised countries.

As defended by Constantini and Monni (2008: 300), negative environmental externalities are not exceptional cases, as they are often considered, but pervasive and persistent and, as population and production grow, become progressively more important. Hence, the mounting socio-environmental challenges faced globally as well as the strategic importance of industrial activities for technological improvement and sustainable development have given new impulse to the re-emergence of proposals for state interventions far beyond the postulates of neoclassical competitive price theory (cf. Nill and Petschow, 2003: 224).

Stern (1991) argues that both theory and the experience of developing countries suggest that there should be a substantial role for the state in economic affairs. Its activities, though, should take a direction different from those emphasised by many of the early post-war writers on development who proposed extensive government involvement in the process of production through both public ownership and physical controls. Taking into account the delicate relationship among industrial growth, development and the environment, some type of public governance or strategy may be indeed necessary for improving conditions towards sustainable development.

Shapiro and Taylor (1990: 861) define industrial strategy as directed public interventions at the sectoral or firm level, necessarily involving some microeconomic targeting of policies toward particular sectors. According to these authors, all governments engage in industrial strategy in this sense and no country has entered into modern economic growth without the state's targeted intervention or collaboration with large-scale private sector entities.

Vartiainen (2000: 137-147) defends that interventionist strategies for industrialisation have in cases such as Korea, Taiwan, Austria and Finland been very effective. Particularly concerning the accumulation of human capital and levels of technical knowledge, Vartiainen holds that there is a growing consensus in mainstream economics that investment in education, research and development should in some ways be publicly sponsored and subsidised. Also, the mediation of conflicts related to distributional issues among economic agents and enforcement of international environmental agreements require strong and autonomous state institutions. For Vartiainen, the state must cope with the paradox that rapid structural change requires more social organisation, mediation and political co-ordination of resources, which may simultaneously aggravate problems of inefficient corporatism and unilateral interest group action aimed at redistributive rent-seeking.

Considering the specific case of industrial greenhouse gas emissions, it seems reasonable to assume a stronger role for the state both in industrialised and developing countries in the coming decades. As has been increasingly recognised, this role in industrial policy needs to embed private initiative in a framework of public action that encourages restructuring, diversification, and technological dynamism beyond what market forces alone would generate (Rodrik, 2004: 1). Providing that other sectors are not neglected at the expense of industrial development, such a perspective seems useful in creating more conducive conditions for sustainable development. This is particularly the case, if one considers the argument that manufacturing is a major driver of product and process environmental technologies, i.e. technologies that limit or reduce negative impacts of products or services on the natural environment (Klassen and Whybark, 1999).

2.2. From the EKC to decomposition studies

A large number of emission studies have been based on the so-called “environmental Kuznets curve” (EKC). A significant limitation of the EKC approach is that it does not allow quantifying other driving forces of emissions apart from GDP per capita. Since 2000 the use of decomposition methods has been more popular as an alternative analytical tool to the EKC (Ang, 2004: 1131). This study will be based on the decomposition method. In order to better understand the method adopted here, the EKC is briefly outlined below.

2.2.1. From the EKC to decomposition of emissions

The EKC is named after Kuznets (1955), who hypothesised that income inequality first rises and then falls at a certain income per capita, as development proceeds, forming an inverted U-shaped function. Based on Kuznets’ theory, the EKC assumes that in the early stages of economic growth, degradation and pollution increase, but beyond some level of income per capita (which will vary for different indicators) the trend reverses, so that high-income levels of economic growth lead to environmental improvement (Stern, 2003: 1). Kuznets’ name was apparently attached to the environmental curve by Grossman and Krueger (1995), who noted its resemblance to Kuznets’ inverted-U-relationship between income inequality and development (Dasgupta *et al.*, 2002: 147).

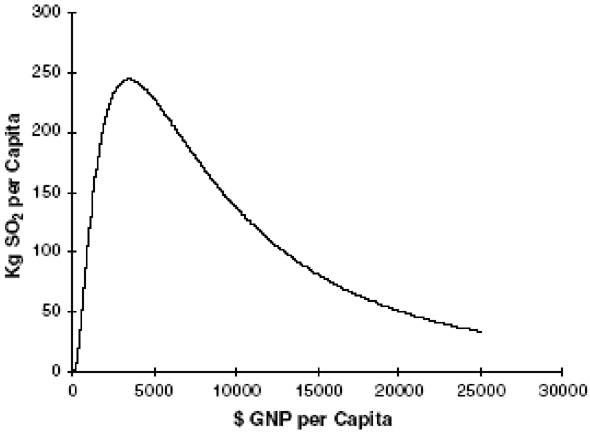

Figure 5. Environmental Kuznets curve for sulphur emissions (Stern, 2004: 1420).

In offering an explanation for the EKC, Grossman (1995) mentioned that emissions E in a given country can be defined by the following identity:

$$E_t = \sum_{j=1}^{n} Y_t I_{j,t} S_{j,t} \tag{1}$$

Here, j = 1,…, n represents the various sectors in the economy, Y_t is the GDP in year t which is equivalent to the sum of the value added of all the n sectors (i.e. $Y_t = \sum Y_{j,t}$), $I_{j,t}$ is the emission intensity of sector j, and $S_{j,t}$ is the share of sector j in GDP, or the 'production share'. Equation (1) is an identity since $I_{j,t} = E_{j,t} / Y_{j,t}$ and $S_{j,t} = Y_{j,t} / Y_t$. Grossman (1995) proposes that (1) can be used to disentangle various factors of influence on emissions. This can be performed by differentiating (1) with respect to time, dividing the derivatives by E_t and rearranging the terms, which results in:

$$\hat{E} = \hat{Y} + \sum_j e_j \hat{S}_j + \sum_j e_j \hat{I}_j \tag{2}$$

where e_j is the share of emissions of sector j in total emissions (=E_j/E) and

$$\hat{X} = \frac{dX/dt}{X_t}, \qquad X \in \{E, I, S, Y\} \tag{3}$$

Changes in Y_t, the first term on the right-hand side (rhs) of (2), reflect the 'scale' effect of economic activity on emissions. Grossman (1995) notes that: "all else equal, an increase in output means an equiproportionate increase in pollution". The 'all else equal' condition, however, is violated by changes in the composition of economic activities and changes in the technology of production which, combined, form the 'intensity of use effect' (De Bruyn, 2000: 164-165).

Changes in $S_{j,t}$ over time represent the influence on emissions of a change in the composition of economic activities. Such compositional changes, given by the second term on the rhs of (2), have been labelled ‘structural’ or ‘intersectoral’ changes and can be positive or negative. If sectors with low emission intensities grow faster than sectors with high emission intensities, structural change results in a downward pressure on emissions and total emissions will grow at a lower rate than the increases in income. Another argument why the ‘all else equal’ condition is violated relates to changes in emission intensities within sectors ($I_{j,t}$). Sectoral emission intensities may decline due to the use of more efficient process technologies, application of end-of-pipe technologies, dematerialisation of products, changes in the range of goods produced within sectors, as well as changes in the material and fuel input mix. Such changes have been labelled ‘technological’ or ‘intrasectoral’ changes and are given by the third term on the rhs of (2) (De Bruyn, 2000: 163-164).

Stern (2005: 101) argues that the statistical analysis on which the environmental Kuznets curve is based is not robust. According to him, the environmental EKC model has been extensively criticised on econometric grounds (Harbaugh, Levinson and Wilson, 2002; Koop and Tole, 1999; Millimet, List and Stengos, 2003; Perman and Stern, 2003; Stern and Common, 2001), and there is little evidence for a common inverted U-shaped pathway that countries follow as their income rises.

According to Stern (2003: 1), the EKC idea rose to prominence because few researchers paid sufficient attention to econometric diagnostic statistics. Stern holds that little or no attention has been paid to the statistical properties of the data used, such as serial dependence or stochastic trends in time series; and few tests of model adequacy have been carried out or presented. Stern defends that time-related effects reduce environmental impacts in countries at all levels of income. However, in rapidly growing middle-income countries, the scale effect, which increases pollution and other degradation, overwhelms the time effect and the contribution of technological change in reducing emissions. In wealthy countries, growth is slower, and pollution reduction efforts can overcome the scale effect, which would be the origin of the apparent EKC effect.

In addition, De Bruyn (2000: 163) argues that the mechanisms through which emissions change are unclear in the empirical literature that has estimated environmental Kuznets curves. De Bruyn claims that the decomposition analysis is an alternative empirical method to examine the importance of structural and technological changes as driving forces underlying changes in pollutants.

Similarly, Stern (2004: 1435) defends that:

[…] the research challenge now is to revisit some of the issues addressed earlier in the EKC literature using the new decomposition and frontier models and rigorous panel[12] *data and time-series statistics.*

2.2.2. Decomposition of emissions

Decomposition is the disentanglement of changes into economically interpretable factors (De Bruyn, 2000: 171). Since energy researchers proposed and adopted what is now often referred to as the index decomposition analysis to study the impacts of structural change (i.e. changes in industry product mix) and sectoral energy intensity change (i.e. changes in the energy intensities of industrial sectors) on trends in energy use in industry in the late 1970s, its application has increased substantially in scope over the years. Based on the number of studies reported, decomposition analysis is now a widely accepted analytical tool for policymaking on national energy and environmental issues (Ang, 2004: 1131; Ebohon and Ikeme, 2006: 3599).

Decomposition analysis begins with defining a governing function relating the aggregate to be decomposed to a number of pre-defined factors of interest. With the governing function defined, various decomposition methods can be formulated to quantify the impacts of changes of these factors on the aggregate. Decomposition can be performed multiplicatively or additively. In multiplicative decomposition, the “ratio” change of an aggregate, and in the additive case its “difference” change, is decomposed (Ang, 2004: 1133-1134).

Another important methodological aspect of decomposition refers to the so-called periodwise and time series decomposition. The periodwise decomposition is a single decomposition based on data for two benchmark years without considering the data for the intervening years, whereas time series decomposition involves yearly decomposition using time series data. Thus, in time series analysis, decomposition is carried out between years t and t+1, where t varies from the first year (year 1) to the year preceding the last year (year N) of a time series. There are altogether (N-1) sets of decomposition results from which the overall or cumulative decomposed effects from year 1 to any year in the series can be constructed. According to Ang and Lee (1994), when time series are available, time series decomposition should be adopted because the decomposed results given by this approach can better explain the underlying mechanisms of change (Ang, 1994: 163-168).

The popular decomposition methods among analysts can be divided into two groups: methods linked to the Laspeyres index and methods linked to the Divisia index. The methods

[12] A panel data set consists of time series observed for a number of individuals, firms, countries, and so forth. Panel regression methods allow for heterogeneity of some of the regression coefficients. (Stern, 2005: 2)

used in the late 1970s and early 1980s are similar to the Laspeyres index in concept, which measures the percentage change in some aspect of a group of items over time, using weights based on values in a specific base year. The Divisia index is a weighted sum of logarithmic growth rates, where the weights are the components' shares in total value, given in the form of a line integral (Ang, 2004: 1132-1133).

In the 1980s, most researchers and analysts used methods linked to the Laspeyres index[13]. Methods linked to the Divisia index started to gain ground only in the 1990s, mainly regarding energy-related emissions. Subsequently, extensions and refinement of methods linked to the Laspeyres index were made. Related studies include Reitler *et al.* (1987), Howarth *et al.* (1991), Park (1992), Sun (1998) and Ang *et al.* (2002). Boyd *et al.* (1987) proposed the Divisia index approach as an alternative to the Laspeyres index approach. In the last decade, reported studies using the two approaches are almost equal in number. Since 2000, an increasing number of studies using the Divisia index decomposition method has been reported (Ang, 2004: 1131). However, few studies seem to have decomposed branch-level industrial CO_2 emissions from fuel combustion in the selected countries. This gap may have considerable consequences for the understanding of the dynamics of manufacturing production-related CO_2 emissions in emerging economies and, hence, for the devising of more effective sustainable development policies.

[13] Generally, methods linked to the Laspeyres index compute the impact of a factor by letting that factor change while holding all the other factors at their respective base year values (Ang, 2004: 1133). De Bruyn (2000: 169) argues that base year weighting considerably underestimates technological and structural effects.

3. Research methodology: the parametric divisia decomposition method

The divisia decomposition method was selected because of its novelty, theoretical foundation, adaptability, ease of application and result interpretation (Ang, 2004). Since the large majority of the existing emission decomposition studies have focused on industrialised countries, the application of the divisia decomposition to Brazil, China, India and Mexico represents an extra contribution of this research. The following chapter describes the mathematical model used, as well as the most important issues of the empirical implementation.

3.1. The mathematical model

Based on Ang (1994: 164), and using manufacturing output (Y_t) and emissions (E_t) in year t as main references, one can first define the emission intensity of a country by dividing (1) by Y_t, which results in:

$$U_t = \sum_j I_{j,t} S_{j,t} \tag{4}$$

Here, $U_t = E_t / Y_t$, which can be labelled the emission-output ratio. U_t is essentially the manufacturing emission intensity of a country (i.e. the emission intensity of all branches in the manufacturing sector combined), but the term 'emission-output ratio' is used here in order to avoid semantic confusion with branch-level 'emission intensities' (De Bruyn, 2000: 166).

Decomposition now aims at separating the influence of changes in the emission intensity (I_j) from changes in the production share (S_j) of each manufacturing branch, which can be done in multiplicative or additive ways[14]. Here the additive way was adopted, and decomposition starts by differentiating expression (4) with respect to time and then integrating over a respective time interval [0,T]. This results in:

$$U_t - U_0 = \sum_j \int_0^T \dot{I}_{j,t} S_{j,t} dt + \sum_j \int_0^T \dot{S}_{j,t} I_{j,t} dt \tag{5}$$

where variables with a dot indicate derivatives with respect to time. The first term on the rhs of (5) defines the 'technology effect' as sum of changes in each branch's emission intensity holding the production share constant. When explaining the decrease in emissions, the technology effect may reflect lowering emission intensities within branches due to improvements in process technology (including changes in material and fuel inputs) and product design. The second term defines the 'structural effect' as the sum of changes in each

[14] According to Ang (2007: 1427), the results given by multiplicative decomposition and additive decomposition in the Divisia decomposition are related by a simple formula and interchangeable.

branch's production share holding the emission intensity constant. When explaining the decrease in emissions, the structural effect may reflect the growing importance of cleaner branches relative to dirty branches of the manufacturing sector.

In order to apply this decomposition in empirical analysis it is necessary to find discrete approximations of the two continuous integrals on the right hand side of (5). For this, the following framework can be set up:

$$\Delta U = \sum_j \Delta U_{tec,j} + \sum_j \Delta U_{str,j} + \sum_j R_j \qquad (6)$$

where Δ gives the change of the variables between year 0 and T. Equation (6) decomposes the change in the emission-output ratio (ΔU) into $\sum \Delta U_{tec,j}$, the technology effect, and $\sum \Delta U_{str,j}$, the structural effect. R_j is the residual term that results from the discrete approximation of the continuous integrals on the right hand side of (5). This study is based on the approximation proposed by Ang (1994) and refined by De Bruyn (2000), called Parametric Divisia Method (PDM), derived from (5) that fit into (6), as follows:

$$\Delta U_{tec,j} = [\alpha_j \,.\, S_{j,T} + (1-\alpha_j)S_{j,0})](I_{j,T} - I_{j,0}) \qquad (7)$$

$$\Delta U_{str,j} = [\beta_j \,.\, I_{j,T} + (1-\beta_j)I_{j,0}](S_{j,T} - S_{j,0}) \qquad (8)$$

These equations define the technology and structural effects as the weighted absolute change in emission intensities and production shares, respectively. The parameters α_j and β_j can be regarded as determining the weights attached to the change in emission intensity and production share, respectively. They are commonly selected *ex ante* by the researcher under the following condition:

$$0 \leq \alpha_j, \beta_j \leq 1 \qquad (9)$$

According to De Bruyn (2000: 167), choosing $\alpha_j = \beta_j = 0$ assures that the changes are weighted against the values of the variable taken in the base year 0. By choosing $\alpha_j = \beta_j = 1$, the changes are weighted against the values of the variables taken in the end year T. Therefore, the values chosen affect the results of decomposition analysis, since the magnitude of the technological and structural effects hinges critically on the chosen parameters. Base year decomposition may result in a large residual term and only provides the *minimum* values of the technological and structural effects. A large residual term would eventually defeat the purpose of decomposition, which is disentanglement of changes into economically interpretable factors. For these reasons, Liu *et al.* (1992) and Ang and Lee (1994) have suggested that minimisation of the residual term is an appropriate selection criterion for choosing decomposition methods (De Bruyn, 2000: 171).

Ang (1994) reviews the results of different methods, one of which proposes a decomposition with $\alpha_j = \beta_j = 0.5$ based on the fact that this gives the arithmetic mean between the base year and the end year. De Bruyn (2000) explains that such a uniform allocation of the residual term has the disadvantage that the relationship between the relative size of the minimum values of the technological and structural effects may be significantly altered, especially when the residual term is relatively large. Hence the results from decomposition with $\alpha_j = \beta_j = 0.5$ lead to a larger increase of the smaller effect.

Following De Bruyn (2000), a more adequate method without residual term is based on the additional condition that the relative increase due to the allocation of the residual remains the same for both effects. This decomposition method is referred to as a 'proportional' method and will be adopted by this study, in which the parameter values for α_j and β_j are defined according to the following two conditions in PDM:

$$\left|\frac{\alpha_j(S_{j,T}-S_{j,0})(I_{j,T}-I_{j,0})}{S_{j,0}(I_{j,T}-I_{j,0})}\right| = \left|\frac{\beta_j(S_{j,T}-S_{j,0})(I_{j,T}-I_{j,0})}{I_{j,0}(S_{j,T}-S_{j,0})}\right| \tag{10}$$

and

$$\alpha_j + \beta_j = 1 \tag{11}$$

The numerators in (10) can now be read as the added part of the residual to the technological and structural effects, respectively. Therefore, the added part of the residual, due to non-zero α_js and β_js, is proportional to the size of the minimum values of these effects when decomposing with $\alpha_j = \beta_j = 0$. The following values for α_j and β_j are the solution to the set of conditions (10) and (11):

$$\alpha_j = \frac{|\hat{I}_j|}{|\hat{S}_j| + |\hat{I}_j|} \tag{12}$$

$$\beta_j = \frac{|\hat{S}_j|}{|\hat{S}_j| + |\hat{I}_j|} \tag{13}$$

where:

$$\hat{X}_j = \frac{X_{j,T} - X_{j,0}}{X_{j,0}}, \qquad X_j \in \{I_j, S_j\} \tag{14}$$

Values calculated for α_j and β_j in this manner are based on the relative growth rates of the variables I_j and S_j. The logic behind these estimated values for α_j and β_j can be discussed by looking at the origins of the residual term, as shown by solving the residual term R_j from (6) using (7) and (8):

$$R_j = (1-\alpha_j-\beta_j)(S_{j,T}-S_{j,0})(I_{j,T}-I_{j,0}) \tag{15}$$

This shows that the residual term is an interaction term between changes in emission intensities and production shares, which depends on the choice of parameter values for α_j and β_j. Any combination of α_j and β_j that satisfies $\alpha_j + \beta_j = 1$ for all j results in a decomposition without residual in PDM. The proportional decomposition method presented above allocates the residual according to the magnitudes of the underlying pure effects. If the change in emission intensities (technology effect) is relatively large compared with the change in production shares (structure effect), α_j will exceed β_j and a larger part of the residual will be added to the technology effect[15].

According to De Bruyn (2000: 172-173), the values estimated for α_j and β_j using (12) and (13) by definition are consistent with condition (9). Applying these values using PDM will result in a decomposition where the residual is completely and proportionally decomposed over the various effects. This 'proportional' decomposition method has the advantage over arbitrarily choosing values for α_j and β_j in allowing the data to determine their values. Moreover, since α_j and β_j are sector-specific, the decomposition will be more sensitive to branch-level differences in changes in technological and structural effects. In summary, the variation of the emission-output ratio is explained by the following equation:

$$\Delta U = \sum_j \left[\alpha_j . S_{j,T} + \left(1-\alpha_j\right) S_{j,0}\right] \Delta I_j + \sum_j \left[\beta_j . I_{j,T} + \left(1-\beta_j\right) I_{j,0}\right] \Delta S_j \qquad (16)$$

It is worth noting that decomposition assumes that each manufacturing production process adheres to constant economies of scale. Hence, if a branch doubles its output using the same technology, this should have an impact only in terms of structural effect. However, with increasing or decreasing returns to scale, part of the increase in production scale will be reflected in the technological effect (De Bruyn, 2000: 179).

3.2. Measurements and data sources

The core data set used in this research is composed of data according to the United Nation's *International Standard of Industrial Classification*[16] (ISIC) concerning: a) carbon dioxide emissions from fuel combustion (IEA, 2007a); and, b) value added (OECD, 2005;

[15] De Bruyn (2000: 173) explains that in the absence of any change in both I_j and S_j, this decomposition method cannot be carried out. In that case, however, there is no change to be decomposed.

[16] The ISIC code groups together enterprises, if they produce the same type of goods or services, or if they use similar processes (i.e. the same raw materials, process of production, skills or technology). The ISIC system has been used widely as a way of classifying data according to economic activity internationally (ESDS, 2004: 2). The code is organised hierarchically into divisions, groups and classes with each level containing an increasing level of detail. Manufacturing is subdivided into 29 categories at the 3 digit level and 81 categories at the 4 digit level. Complete definitions for all classes in the ISIC can be found on the United Nations Statistics Division's website: http://unstats.un.org/ (last accessed: 25/08/2008).

UNIDO, 2006; UNIDO, 2007; IBGE, 1996 - 2006) of eight major branches of the manufacturing industry, namely:

1. Iron and steel (ISIC Group 271 and Class 2731): Includes a) operation of blast furnaces, steel converters, rolling and finishing mills; b) casting finished or semi-finished products of cast iron or cast steel; and c) manufacture of primary iron and steel products.

2. Chemical and petrochemical (ISIC Division 24): Includes the groups a) 241 – *basic chemicals* (basic chemicals, plastic in primary forms, synthetic rubber, fertilizers and nitrogen compounds); b) 242 – *other chemical products* (pesticides and agrochemical products; paints, varnishes and similar coatings, printing ink and mastics; pharmaceuticals, medicinal chemicals and botanical products; soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations; as well as other chemical products n.e.c.[17]); and c) 243 – *man-made fibres* (artificial or synthetic filament tow and staple fibres, not carded or combed; synthetic or artificial filament yarn, whether or not textured, high tenacity, multiple or cabled; and synthetic or artificial non-filament or strip).

3. Non-ferrous metals (ISIC Group 272 and Class 2732): Includes a) casting finished or semi-finished products of non-ferrous metals; and, b) manufacture of the precious metals: gold, silver, and metals of the platinum group as follows:
   - refining of the above mentioned precious metals;
   - production of unwrought or wrought precious metals;
   - production of clad precious metals;
   - production of non-ferrous base metals from ore, mattes, other raw materials intermediate between ore and the metal (e.g. alumina) or from scrap;
   - operations carried on by smelters, by electrolytic refiners, or by other means to produce unwrought non-ferrous base metals;
   - smelters and refiners of copper, lead, chrome, manganese, zinc, aluminium, nickel, tin or other non-ferrous base metals and alloys of such metals;
   - production of alumina and mattes of nickel or of copper;
   - manufacture of non-ferrous base metal products by rolling, drawing or extruding;
   - manufacture of powders or flakes; foil; plates, sheets or strips; bars, rods or profiles; wire; tubes, pipes and tube or pipe fittings;
   - production of monetary gold.

[17] n.e.c. : not elsewhere classified

4. Non-metallic minerals (ISIC Division 26): Includes the groups a) 261 – *glass and glass products*; and , b) 269 – *non-metallic mineral products n.e.c.* (non-structural non-refractory ceramic ware; refractory ceramic products; structural non-refractory clay and ceramic products; cement, lime and plaster; articles of concrete, cement and plaster; cutting, shaping and finishing of stone; and manufacture of other non-metallic mineral products n.e.c.).

5. Machinery (ISIC Divisions 28, 29, 30, 31 and 32): Includes the divisions a) 28 – *fabricated metal products, except machinery and equipment*; b) 29 – *machinery and equipment n.e.c.*; c) 30 – *office, accounting and computing machinery*; d) *electrical machinery and apparatus n.e.c.*; e) 32 – *radio, television and communication equipment and apparatus*.

6. Food and Tobacco (ISIC Divisions 15 and 16): Includes the divisions a) 15 – *food products* (production, processing and preservation of meat, fish, fruit, vegetables, oils and fats; dairy products; grain mill products, starches and starch products; prepared animal feeds; and other food products) and *beverages*; and b) 16 – *tobacco products* (cigarettes or cigars, pipe tobacco, chewing tobacco or snuff).

7. Paper, pulp and printing (Divisions 21 and 22): Includes the divisions a) 21 – *paper and paper products* (wood pulp; cotton linter pulp; pulps of other cellulosic materials including waste paper; newsprint, other printing or writing paper; stock paper for conversion into towels, napkins, facial tissues, etc; papers used for packaging; hand-made paper; composite paper and paperboard, among others); b) 22 – *publishing, printing and reproduction of recorded media*.

8. Textiles and leather (ISIC Divisions 17, 18 and 19): Includes the divisions a) 17 – *textiles* (spinning, weaving and finishing textiles; other textiles; knitted and crocheted fabrics and articles); b) 18 – *wearing apparel, dressing and dyeing of fur*; c) 19 – *tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear*.

The aggregation level presented above is the same used by the International Energy Agency (IEA) in its *2007 CO_2 Emissions from Fuel Combustion* (IEA, 2007a), taking as reference the Revision 3 of the ISIC. The IEA divides the manufacturing sector in twelve branches, comprising the eight branches mentioned above plus ‘mining and quarrying’, ‘wood and wood products’, ‘transport equipment’ and ‘non-specified industry’, which could not be covered due to data availability of emission and value-added data.

IEA’s CO_2-emission estimates are based on official submissions by national statistics offices about the amounts of fuels supplied to the economy, as well as on their respective carbon content according to the *IPCC Guidelines for National Greenhouse Gas*

Inventories[18]. In the calculation of fuels supplied, the IEA distinguishes between *primary fuels*[19] (i.e. fuels which are found in nature such as coal, crude oil, natural gas), and *secondary fuels* or fuel products, such as gasoline and lubricants, which are derived from primary fuels. Since emission estimates are based on fuel combustion, carbon contents and oxidation, this study does not comprise changes in emissions related to the adoption of 'end-of-pipe' technologies[20]. It is worth noting that between 1985 and 2005, no 'end-of-pipe' technology existed neither for treatment, nor handling or disposal of carbon dioxide emissions. A detailed list with the types of fuels covered by the IEA's database is presented in Annex I.

For calculating the supply of fuels of a country, the IEA uses data on: a) produced primary fuels (production of secondary fuels is excluded), b) imported primary and secondary fuels, c) exported primary and secondary fuels, d) fuels used for international marine bunkers and international aviation, and e) net increases or decreases in fuel stocks. For each fuel, production and imports are added together, whereas exports, bunkers/aviation, and stock changes are subtracted to calculate the apparent fuel consumption. The manufacturing of secondary fuels is ignored in the main calculation, since their carbon content has already been accounted for in the supply of primary fuels from which they are derived. Information on production of some secondary fuel products is used, though, to adjust for stored carbon. Hence, carbon of fuels used as raw material (or feedstock) for the manufacturing of products such as plastic or in a non-energy use (e.g. bitumen for road construction) without oxidation (emission) is deducted in the calculation of CO_2 emissions (IEA, 2007b: 37-38).

Since data concerning emissions for the branches of transportation equipment (Divisions 34 and 35) were not available for Brazil and India, as well as wood and wood products (Division 20) for Brazil, India and Mexico, those branches were not covered by this study. Similarly, no data on emissions for 'machinery' was available for Brazil, whereas no data on emissions for 'textile and leather' was available for Mexico.

[18] Both the *1996 IPCC Guidelines* and the *2006 IPCC Guidelines* are available from the IPCC Greenhouse Gas Inventories Programme through the website: http://www.ipcc-nggip.iges.or.jp/ (accessed: 25/08/2008).

[19] It is worth noting that, in line with the IPCC methodology, biomass fuels are not included in the IEA's estimates of CO_2 emissions from fuel combustion. This is because biomass consumption for fuel is assumed to equal its re-growth, and any departure from this hypothesis should be counted within the "Land Use, Land Use Change and Forestry"-module of the 1996 IPCC Guidelines (IEA, 2007b: 38).

[20] End-of-pipe technologies refer to added technical installations for environmental control of emissions, used to treat, handle or dispose of emissions and wastes from production. They operate independently from the production process or are an identifiable part added on to production facilities. Source: United Nations, European Commission, International Monetary Fund, OECD, World Bank (2005), *Handbook of National Accounting: Integrated Environmental and Economic Accounting 2003*, Studies in Methods, Series F, No.61, Rev.1, Glossary, New York: United Nations. / United Nations (1997) *Glossary of Environment Statistics*, Studies in Methods, Series F, No. 67, New York: United Nations. Available at: http://stats.oecd.org/glossary/ (accessed: 03/07/2009).

Bearing in mind that IEA's report on energy balances is the main source for its database on CO_2 emissions from fuel combustion, it is worth mentioning some issues of data quality concerning both publications. According to the IEA (2007d: 43; 2008a: 43), data on energy balances are generally based on official submissions, but some estimations have been made to complement major aggregates after consultation with national statistical offices, oil companies, electricity utilities and national energy experts. Although definitions used in IEA's energy balances comply with those used internationally, energy statistics at the national level are often collected using criteria and definitions which differ from international definitions. In this case, the IEA has identified these differences and adjusted the data where possible. Specific country notes from the IEA (2007b; 2007d; 2007f) concerning Brazil, China, India and Mexico are presented in Annex II.

Data regarding manufacturing value added for Brazil compatible with the ISIC were obtained from *Annual Industrial Surveys*, published by the Brazilian national statistical agency in line with the ISIC Revision 3 (IBGE, 1996-2006). For Mexico, data on value added were obtained from the OECD's STAN Database for Structural Analysis (OECD, 2005a), based on official submissions according to the ISIC Revision 3. Data on manufacturing value added for China and India were obtained from the *Industrial Statistics Database* (INDSTAT) at the 3-digit level of ISIC Revision 2 (UNIDO, 2006) published by the United Nations Industrial Development Organisation. These latter databases provide ISIC-based data supplied by national statistical offices and supplemented with estimates generated by UNIDO. For China and India, data according to Revision 2 were converted to Revision 3 based on the applicable correspondence table published by the United Nations Statistics Division[21]. Further details on the branch equivalence used and on the ISIC list of branches are given in Annex III.

It is worth noting some issues of data quality and sources of cross-country incomparability for the value-added databases. As presented by Yamada (2005: 4), often reported data are known to exclude a significant portion of industrial activity, either because the coverage of small-scale establishments may be incomplete (e.g. exclusion from surveys of establishments below a certain cut-off-point in terms of size), data may refer only to a certain area of the county (e.g. urban area, major provinces), or they may refer to only part of the manufacturing sector (e.g. formal sector, registered establishments, selected industries, among others). Meta-information provided and additional methodological notes for the INDSTAT are presented in Annex IV.

[21] Correspondence tables for conversion of data from ISIC Rev. 3 to Rev 2 are available in English and Spanish at the United Nations Statistics Division's website: http://unstats.un.org/unsd/cr/registry/regot.asp?Lg=1 (accessed: 03/07/2009).

Among the variations in concept that may apply to data on value added, the most important are: a) the difference between the national accounting concept and the industrial census concept, which is the one most used by reporting countries; and b) the difference between valuation at basic prices, producers' prices, factor values and 'other valuations'[22].

The main difference between the industrial census concept and the national accounting concept is in the treatment of non-industrial services[23]. The industrial census concept of value added differs from the national accounting concept (which is identical to the Systems of National Accounts definition[24]) in that it deducts only industrial inputs (intermediate goods and industrial services[25]) instead of all inputs (non-industrial services) from output to calculate value added. Surveys that use the industrial census concept tend to overestimate value added. This upward bias will be greater in countries with larger intensity in the use of non-industrial inputs (Ortega and Rodríguez, 2006: 10).

Concerning different valuations, the main distinction is the treatment given to indirect taxes and subsidies. Value added measured at factor values excludes all indirect taxes falling on production and includes all current subsidies received in support of production. Value added measured at producers' prices, though, includes all indirect taxes and excludes all subsidies. For some industries there may be considerable government subsidies, which results in significant differences between value added measured at factor values and that at producers' prices, for example. Hence, different national practices in industrial statistics limit the extent of comparability of value-added data across countries (Yamada, 2005: 4-9).

In order to avoid distortions caused by conversion factors or exchange rates, the production data used are in national currency values. After the conversion of value-added data in national currency to real terms using manufacturing producer price indices[26] (OECD,

[22] There are several other types of valuation in use by some countries. However, the three types mentioned are the most common in industrial statistics. The fourth category, labelled 'other valuations' is used for all data that cannot be assigned to either category, or for which there is insufficient information on the valuation (UNIDO, 2003: 17).

[23] Payments for non-industrial services comprise legal and accountancy fees, patents and license fees, insurance premiums, costs of meetings of shareholders and governing bodies, contributions to business and professional associations, postal, telephone, electronic communication, telegraph and fax charges, transport services for goods and personnel, advertising costs, commissions (where they are not included in wages and salaries), rents, bank charges (excluding interest payments) and all other business services provided by third parties. Source: OECD (2005) *Structural Statistics for Industry and Services: Standard Definitions*. Available at: http://www.oecd.org/dataoecd/22/56/1934824.htm (accessed: 21/09/2008).

[24] The SNA (*System of National Accounts*) defines value added, or gross value added, as the value of output less the value of intermediate consumption. Source: United Nations (1993) *System of National Accounts*. Paragraphs 1.6 [2.172, 6.4, 6.222]. Available at: http://esa.un.org/unsd/sna1993/introduction.asp (accessed: 09/09/2008).

[25] Services sold to other firms as intermediate inputs to further production activities. They comprise: a) business and professional services; b) financial services; c) insurance services; and d) real estate services. Source: OECD (2003) *Glossary of Statistical Terms*. Available at: http://stats.oecd.org/glossary/detail.asp?ID=2440 (accessed: 21/09/2008).

[26] Since no data on manufacturing producer price indices were available for China in the OECD's Main Economic Indicators Database (OECD, 2008), data on ex-factory price indices of industrial products for the reference period were obtained from various issues of the "China Statistical Yearbook", published by the

2008), all data were grouped according to the aggregation used by the IEA. This choice is rather important, since the level of aggregation can affect the results of decomposition, and its results are only valid for the level of branch disaggregation that is chosen (De Bruyn, 2000: 179). This is due to the fact that when the sample is disaggregated into only few sectors, many technological effects can, in fact, be the result of changes in production structures of a defined sector. While the consequences of using a certain aggregation are uncertain beforehand, choosing a larger number of sectors does not necessarily contribute to an increase in the importance of structural change (De Bruyn, 2000: 178-179).

Considering that a) emissions and value-added data have to be matched at the branch level before the conduction of decomposition analysis, and b) different valuation methods may lead to inter-temporal breaks in value-added data, this study covers the following periods:

Table 2. Time coverage and main characteristics of value-added data

Country	Period	Measurement of value added	Source
Brazil	1996 to 2005	Factor values[27]	IBGE (1996-2006): Official data
China	1985 to 1993	Not defined[28]	INDSTAT, Rev. 2 of the ISIC: Data added/adjusted by UNIDO based on national publications
	1994 to 2005	Not defined	INDSTAT, Rev. 2 of the ISIC: Official submissions
India	1985 to 1997	Factor values	INDSTAT, Rev. 2 of the ISIC: Official submissions
	1998 to 2004	Producers' prices	INDSTAT, Rev. 3 of the ISIC: Official submissions
Mexico	1987 to 2003	Basic prices[29]	STAN Database: Official submissions

Chinese National Bureau of Statistics. Available at: http://www.stats.gov.cn/english/statisticaldata/yearlydata/ (accessed: 29/09/2008).

[27] Value added at *factor values* plus production taxes minus subsidies on production is equivalent to value added at *basic prices*, explained below. Taxes and subsidies on production apply to labour or capital employed, such as payroll taxes or current taxes on vehicles and buildings. Source: OECD (2005) *Structural Statistics for Industry and Services: Standard Definitions*. Available at: http://www.oecd.org/dataoecd/22/56/1934824.htm (accessed: 24/11/2008).

[28] Data on value added for China is in line with the national accounting concept and is obtained by subtracting industrial intermediate input from gross industrial output plus value-added taxes. No additional information is provided on treatment of subsidies and other taxes and duties on production. Therefore, it is not possible to classify the valuation used in neither factor values nor producers' prices. Source: http://www.stats.gov.cn/ (accessed: 30/08/2008).

[29] Value added at *basic prices* plus product taxes minus subsidies on products results in value added at *producer's prices*. Taxes and subsidies on products are payable per unit of some good or service produced, such as turnover taxes and excise duties. Source: OECD (2005) *Structural Statistics for Industry and Services: Standard Definitions*. Available at: http://www.oecd.org/dataoecd/22/56/1934824.htm (accessed: 24/11/2008).

4. Decomposition results

This section presents the results obtained through the application of the parametric divisia decomposition method. The decomposition of the emission-output ratio variation was undertaken based on annual αs and βs as presented before in equations 7 and 8. As discussed in section 3.1, the emission-output ratio combines the emission intensity of all covered manufacturing branches in a country. It simply represents the emission intensity of the entire manufacturing sector. The term emission-output ratio is used in order to avoid confusion with branch-level emission intensities.

4.1. Brazil

The Brazilian manufacturing sector in this study comprises seven branches for which data on emissions were available, namely: 1. chemical and petrochemical, 2. iron and steel, 3. food and tobacco, 4. non-metallic minerals, 5. non-ferrous metals, 6. paper, pulp and printing, and 7. textile and leather. The manufacturing branches covered accounted on average for 55% of total manufacturing value added over the period. Together, these branches had a contraction in real value added of -0.94%/year for the period between 1996 and 2005, while their emission-output ratio increased by 31% at a rate of 3.5% per year, having reached in 2005 around 0.56 million tons (MT) of CO_2 / billion national currency, as shown in Figure 6.

The structure of the Brazilian manufacturing industry in terms of value-added shares saw considerable changes, as shown in Figure 7. The branches ‘iron and steel’, ‘non-ferrous metals’ and ‘food and tobacco’ increased their shares in total value added in 81.2%, 42.3% and 3.3%, respectively. All other covered branches reduced their shares in total value added relative to 1996, with emphasis on ‘textile and leather’ (-26.8%) and ‘paper, pulp and printing’ (-16.7%). The branch ‘machinery’, which also saw a contraction in value added of -1.8%/year, and alone accounted for 15.8% of the total manufacturing value added during the period, could not be covered in this study due to lack of data on emissions.

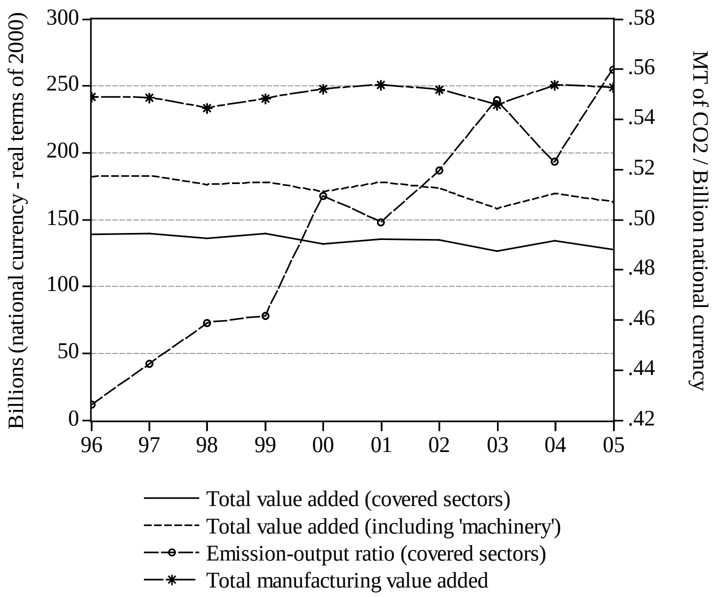

Figure 6. Brazil / Manufacturing value added and emission-output ratio

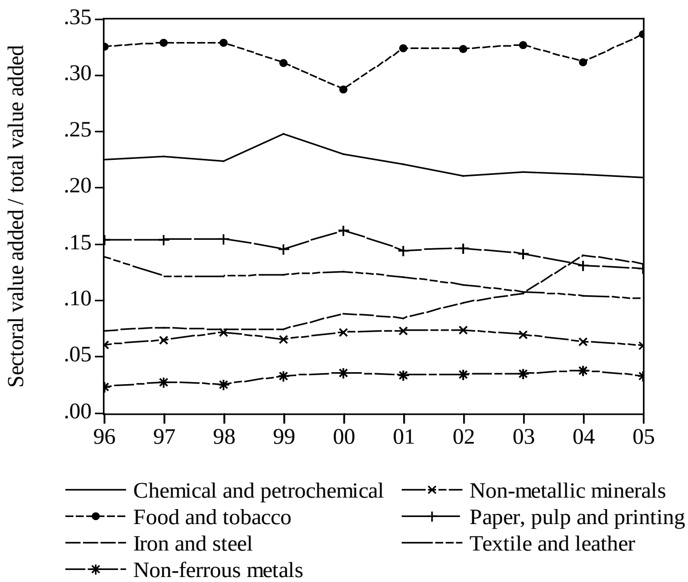

Figure 7. Brazil / Shares in total value added covered

Apart from the branches ‘iron and steel’ and ‘non-ferrous metals’, all other branches (including machinery) had negative annual growth rates in real value added (Table 3). This aspect deserves attention for these two branches are generally the most emission-intensive ones. In addition, the branch ‘non-ferrous metals’ was the only one growing in real value added, while becoming more emission-intensive. Emission intensity only fell in the branches ‘food and tobacco’ and ‘iron and steel’. The latter, though, had the second highest growth rate in emissions (3.3%/year), after the branch ‘non-ferrous metals’ (4.7%/year). Branch-level emissions in million tons (MT) of CO_2 are presented in Figure 8.

Table 3. Brazil / Annual growth rates by branch and shares (1996-2005)

Branches	Annual growth rates (1996 – 2005)			Shares in total value added	
	Emissions	Value added	Emission intensity	1996	2005
Chemical and petrochemical	2.4%	-1.7%	4.8%	22.5%	21%
Food and tobacco	-2.6%	-0.6%	-2.1%	32.6%	33.6%
Iron and steel	3.3%	7.3%	-2.4%	7.3%	13.2%
Machinery	-	-1.8%	-	-	-
Non-ferrous metals	4.7%	3.4%	1%	2.3%	3.3%
Non-metallic minerals	2.3%	-1.1%	3.8%	6.0%	5.96%
Paper, pulp and printing	-0.6%	-2.6%	2.6%	15.4%	12.8%
Textile and Leather	-2.4%	-3.7%	1.9%	13.9%	10.1%
Total	*2.3%*	*-0.94%*	*3.5%*	*100%*	*100%*

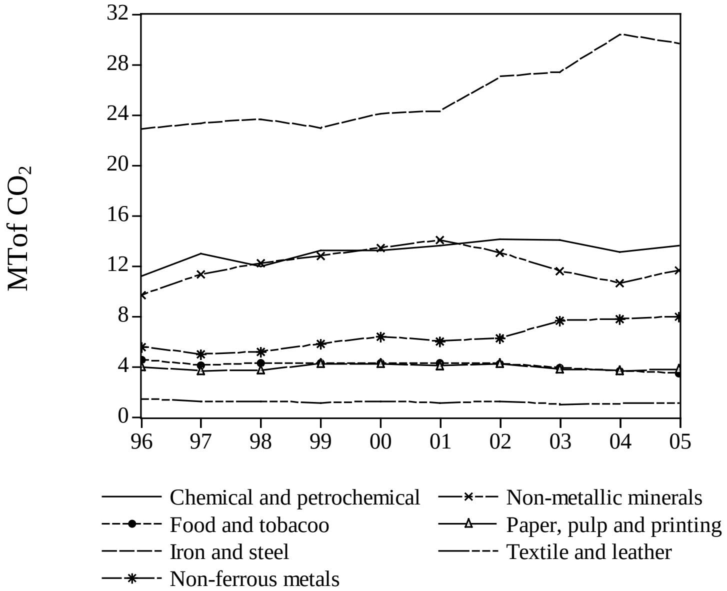

Figure 8. Brazil / Branch-level CO_2 emissions

While real value added of the branches ‘chemical and petrochemical’ and ‘non-metallic minerals’ declined at a rate of -1.7% and -1.1% per year, their carbon dioxide emissions from fuel combustion have increased at 4.8% and 3.8% per year, respectively. Conversely, the branch ‘non-ferrous metals’, the most emission-intensive sector in 2005 (Figure 9), had the highest growth rate in emissions (4.7%/year), followed by ‘iron and steel’ (3.3%/year), ‘chemical and petrochemical’ and ‘non-metallic minerals’ (2.3%/year).

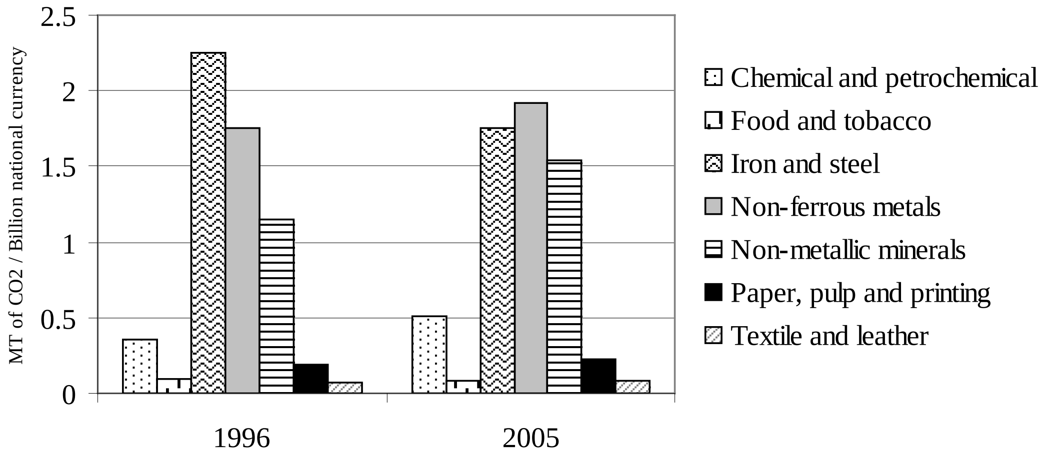

Figure 9. Brazil / Branch-level emission intensity (1996 and 2005)

Considering real GDP growth in Brazil during the reference period (2.65%/year)[30], the relatively high growth rates in value added of particular emission-intensive branches such as 'iron and steel' (7.3%/year) and 'non-ferrous metals' (3.4%/year), as well as the sharp increase in their respective value-added shares, seems inconsistent with the hypothesis of a 'clean' development trend. This conclusion is emphasised by the increasing emission-output ratio during the reference period (3.5%/year). Regarding the most emission-intensive branches in the Brazilian context, despite a reduction of the emission intensity of 'iron and steel' at a rate of -2.1%/year, other branches such as 'non-ferrous metals' increased its emission intensity at 1%/year, while 'chemical and petrochemical' and 'non-metallic minerals' saw substantial increases of emission intensity at 4.8%/year and 3.8%/year, respectively.

From 1996 to 2005 the emission-output ratio (i.e. the emission intensity of the covered manufacturing sector) increased by 31.3%, or 0.1334 MT of CO_2 / billion value added in national currency values. The decomposition of this variation is presented in Table 4. The format used for this table is similar for all covered countries. It presents the results at the branch level in order to make possible the assessment of the contribution of each branch to the emission-output ratio variation. The first column lists the covered branches, while the second and third ones present structural (ΔStructural) and technological (ΔTechnological) effects, respectively. The fourth column shows the variation at the branch-level emission intensity, which is simply the result of the sum of the branch-level structural and technological effects. The vertical sum of the last three columns gives the values for the covered manufacturing sector as a whole, which is represented in the last line of the table.

[30] Gross Domestic Product (GDP) in national currency values at *market prices*, as well as GDP deflators estimates are World Bank estimates from the *United Nations Common Database*. Available at: http://data.un.org/ (accessed: 02/10/08). Valuation at *market prices* equals the valuation at *producer's prices* plus import taxes minus subsidies on imports plus separately invoiced transport costs plus non-deductible VAT.

Percentages in brackets are relative values of emissions attributed either to technological or structural effects in relation to the emission-output ratio variation (0.1344), represented as ΔTotal for the category 'total manufacturing'.

Technological effects leading to branch-level emission-intensity reduction are only found in the branches 'iron and steel' (-36%) and 'food and tobacco' (-4.6%). For the first branch, however, structural effects (87.3%) compensate the reduction by far, leading 'iron and steel' to become the largest contributor to the increase in the emission-output ratio during the period, with a 51.2% share.

Table 4. Brazil / Decomposition of emission-output ratio variation (1996-2005)

Branches	**ΔStructural**	**ΔTechnological**	**ΔTotal**
Chemical and petrochemical	-0.0081 (-6.1%)[31]	0.0345 (25.9%)	0.0264 (19.8%)
Food and tobacco	0.0010 (0.7%)	-0.0062 (-4.6%)	-0.0053 (-3.9 %)
Iron and steel	0.1164 (87.3%)	-0.0480 (-36%)	0.0683 (51.2%)
Non-ferrous metals	0.0132 (9.9%)	0.0091 (6.8%)	0.0223 (16.7%)
Non-metallic minerals	-0.0011 (-0.8%)	0.0233 (17.5%)	0.0222 (16.7%)
Paper, pulp and printing	-0.0052 (-3.9%)	0.0061 (4.6%)	0.0009 (0.7%)
Textile and leather	-0.0028 (-2.1%)	0.0013 (1%)	-0.0015 (-1%)
Total manufacturing	0.1133 (84.9%)	0.0201 (15.1%)	0.1334 (100%)

Technological effects apparently made a modest contribution to a supposed 'clean' development trend hypothesis in the Brazilian manufacturing sector despite the GDP growth from 1996 to 2005. In fact, technological effects accounted for 15.1% of the increase in the emission-output ratio with emphasis on the branches 'chemical and petrochemical' (25.9%) and 'non-metallic minerals' (17.5%). One should bear in mind, though, that due to the assumption of fixed economies of scale, changes related to increasing or decreasing returns to scale are reflected in the technological, instead of structural effects.

Regarding the impact of structural effects, the two most emission-intensive branches ('iron and steel' and 'non-ferrous metals') were the only ones apart from 'food and tobacco' leading to an increase in the emission-output ratio. The third most emission-intensive sector, 'non-metallic minerals', had a small reduction allocated to structural effects (-0.8%), which was largely overwhelmed by an increase of its emission intensity. Again, seems inconsistent with the 'clean' development trend hypothesis.

[31] Percentages in brackets represent relative values of sectoral or branch-level emissions attributed either to technological or structural effects in relation to the emission-output ratio variation (0.1344).

Figure 10 presents the year-to-year variation of the Brazilian manufacturing emission-output ratio $\Delta(U)$ as well as the technological and structural effects underlying the decomposition results. In general, structural effects determined most of the increase in the emission-output ratio. Between 1996 and 2003, technological effects also led to an increase in the emission-output ratio. However, between 2003 and 2004, a sharp emission reduction occurred through technological effects, which largely compensated a simultaneous and environmentally negative pressure from structural effects. Such improvement could not be sustained and the emission-output ratio increased again in 2005 due to environmentally negative technological effects, while structural effects had a positive impact. Despite the increase of the Brazilian manufacturing emission-output during the whole period, there was a considerable variation around the trend. As from 2002, this variation became more and more determined by technological effects rather than structural effects.

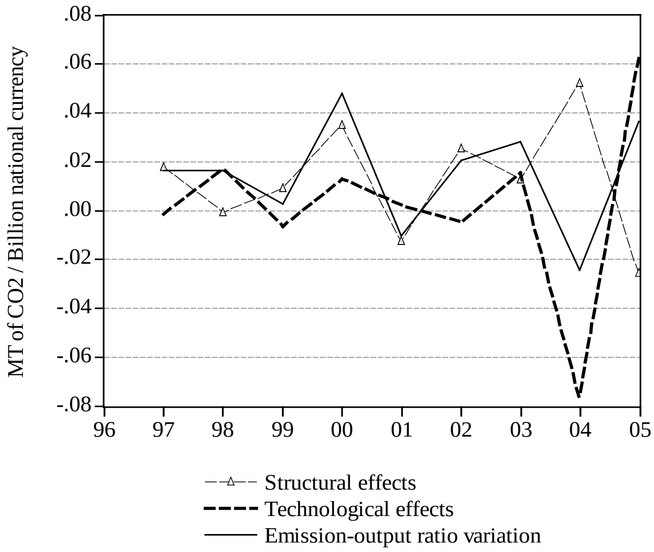

Figure 10. Brazil / Emission-output ratio variation and effects (1996-2005)

From the decomposition analysis, 'iron and steel' is the only branch with results which might be consistent with the 'pollution haven' hypothesis. Considering its strong growth in value added relative to the GDP growth rate during the period, as well as its predominant structural effects, industrial relocation could in theory be valid.

4.2. China

The covered Chinese[32] manufacturing sector comprised all eight branches defined before, namely: 1. chemical and petrochemical, 2. food and tobacco, 3. iron and steel, 4. machinery, 5. non-ferrous metals, 6. non-metallic minerals, 7. paper, pulp and printing, and

[32] Due to data incompatibility issues, China in this study refers only to the People's Republic of China and does not include Hong Kong and Macao.

8. textile and leather. Data on value added for China was obtained from the *Industrial Statistics Database* - INDSTAT (UNIDO, 2006). As shown on Table 2, from 1985 to 1993 value-added data are UNIDO's estimates based on national publications, whereas from 1994 to 2005 data are official submissions[33]. In order to account for these differences, this study decomposes the Chinese manufacturing emission-output ratio variation in two periods: a) from 1985 to 1993 and b) from 1994 to 2005. Value-added data at national currency values were converted to real terms of 1990 for the first reference period, and to real terms of 2000 for the second one using ex-factory price indices specific for the manufacturing industry in China[34].

Between 1985 and 1993, on average the covered manufacturing branches accounted for 83% of total manufacturing value added. Together, these branches had a positive annual growth in real value added of 14.6% for this first period, while GDP grew at 13.5%/year (real terms of 1990)[35]. The emission-output ratio decreased by -36%, at a rate of -4.6% per year, having reached in 1993 around 1.26 MT of CO_2 / billion value added, as presented in Figure 11.

For the second reference period, between 1994 and 2005, the covered branches accounted on average for roughly 81% of total manufacturing value added. As show in Figure 12, these branches saw a sharp growth in real value added at a rate of about 30%/year during this second period, while GDP grew at 14.9%/year (real terms of 2000). Their emission-output ratio decreased by -65%, at a rate of -5.9%/year, having reached in 2005 approximately 0.29 MT of CO_2 / billion value added.

[33] Data for 1994 and 1996 were adjusted by UNIDO based on official publications. Data on value added for the year 2004 were missing in the INDSTAT (UNIDO, 2006) for all Chinese manufacturing branches. Since sectoral emissions data were available in the IEA's report (IEA, 2007a), value-added data for 2004 were estimated after having defined sectoral emission intensities for 2004 as the arithmetic average between the corresponding values for 2003 and 2005. Available sectoral emissions for 2004 were then divided by the estimated sectoral emission intensities, resulting in sectoral value added. The procedure was also adopted for the estimation of total manufacturing value added for 2004, considering the sum of emissions of all sectors in the manufacturing industry, including the categories 'wood and wood products', 'transport equipment', 'mining and quarrying' and 'non-specified industry', as classified by the IEA (IEA, 2007a).

[34] Data on ex-factory price indices for manufacturing were obtained from various issues of the "China Statistical Yearbook", published on a yearly basis by the Chinese National Bureau of Statistics. These price indices are available as from 1988, while price indices for the overall industry are available as from 1983. Manufacturing ex-factory price indices for the years 1985, 1986 and 1987 were estimated based on price indices for the overall industry for those same years (1988 = 100). This was done under the assumption that the ratio between the manufacturing price indices and those for the overall industry remained the same as the average ratio in the period from 1989 to 1993. Available at: http://www.stats.gov.cn/english/statisticaldata/yearlydata/ (accessed: 11/10/2008).

[35] Gross Domestic Product (GDP) in national currency values at market prices, as well as GDP deflators are World Bank estimates obtained from the *United Nations Common Database*. Available at: http://data.un.org/ (accessed: 02/10/08).

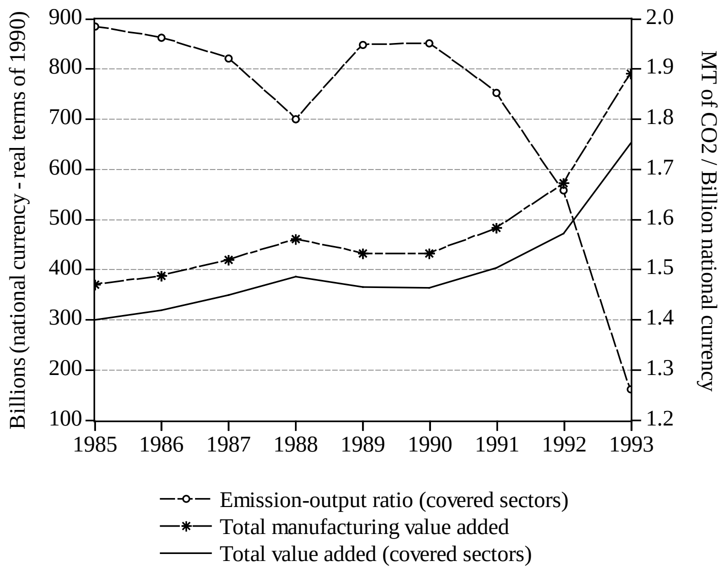

Figure 11. China / Manufacturing value added and emission-output ratio (1985-1993)

Figure 13 shows the changes in terms of value-added shares within the Chinese manufacturing between 1985 and 1993. Compared to 1985, value-added shares increased for the branches ‘iron and steel’ (57.9%), ‘non-metallic minerals’ (14.6%), ‘food and tobacco’ (8.1%) and ‘non-ferrous metals’ (7.6%). All other branches reduced their shares in total value added relative to 1985, with emphasis on ‘paper, pulp and printing’ (-21.3%) and ‘machinery’ (-16.7%).

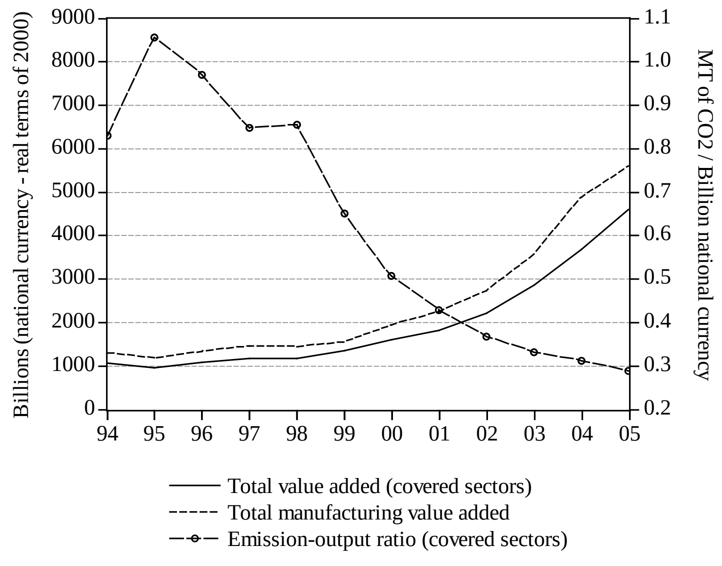

Figure 12. China / Manufacturing value added and emission-output ratio (1994-2005)

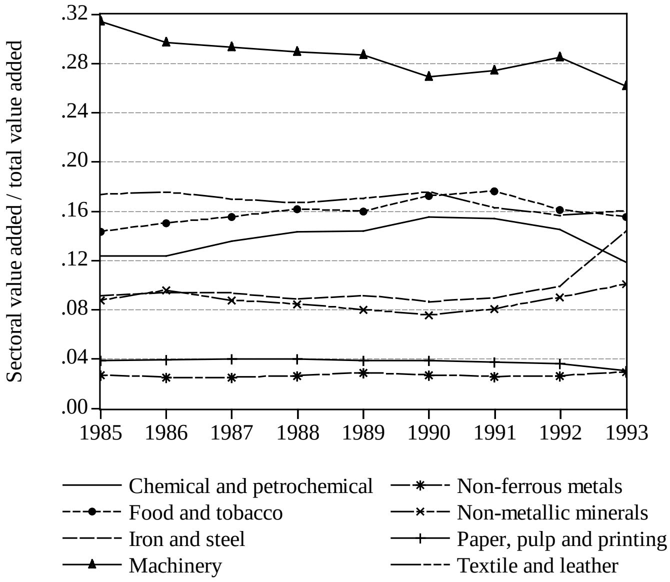

Figure 13. China / Shares in total value added covered (1985-1993)

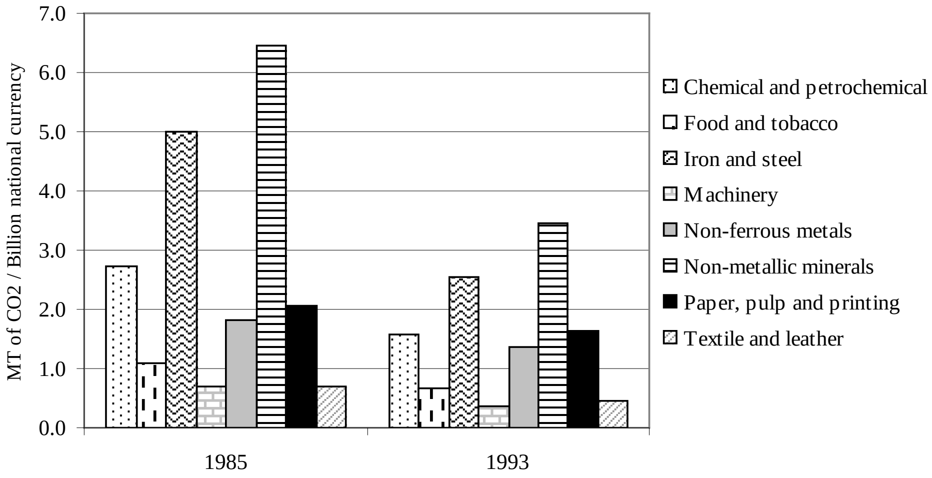

Figure 14. China / Branch-level emission intensity (1985 and 1993)

The strong increase in the importance of emission-intensive branches such as ‘iron and steel’ and ‘non-metallic minerals’ respecting value added seems inconsistent with the ‘clean’ development trend during the first reference period. However, it is worth noting that these two branches had the strongest reduction in emission intensity, as shown in Figure 14.

As presented in Table 5, all branches had positive annual growth rates in real value added for the period between 1985 and 1993, led by ‘iron and steel’ (30.3%/year),

Table 5. China / Annual growth rates by branch and shares (1985-1993)

Branches	Annual growth rates (1985 – 1993)			Shares in total value added	
	Emissions	Value added	Emission intensity	1985	1993
Chemical and petrochemical	2.4%	13.5%	-5.3%	12.4%	11.9%
Food and tobacco	5.1%	16.8%	-5.0%	14.3%	15.5%
Iron and steel	9.3%	30.3%	-6.1%	9.1%	14.4%
Machinery	-0.2%	10.1%	-5.7%	31.4%	26.2%
Non-ferrous metals	9.4%	16.7%	-3.1%	2.7%	2.9%
Non-metallic minerals	4.2%	18.6%	-5.8%	8.8%	10.1%
Paper, pulp and printing	4.5%	8.9%	-2.6%	3.9%	3.1%
Textile and leather	3.2%	12.5%	-4.7%	17.4%	16%
Total	**4.7%**	**14.6%**	**-4.6%**	**100%**	**100%**

All branches with above-the-average growth rates in value added also saw reductions in emission intensity at a faster pace than the overall average values, except for 'non-ferrous metals'. The branch 'non-ferrous metals' was the second slowest in terms of emission intensity reduction (-3.1%), whereas having the fastest growth in emissions (9.4%), closely followed by 'iron and steel' (9.3%). Although 'machinery' and 'chemical and petrochemical' had a slower growth in value added than the average, their emission intensity reduced considerably. As a result, emissions of 'chemical and petrochemical' grew much slower than the average, while there was a slight reduction in emissions for 'machinery' (-0.2%/year) during the first period.

Changes in total sectoral emissions in million tons (MT) of CO_2 for the period from 1985 to 1993 are presented in Figure 15. The branches 'non-metallic minerals' and 'iron and steel' were the main contributors to the emissions from fuel combustion in the Chinese manufacturing, representing 53.1% of total emissions from 1985 to 1993.

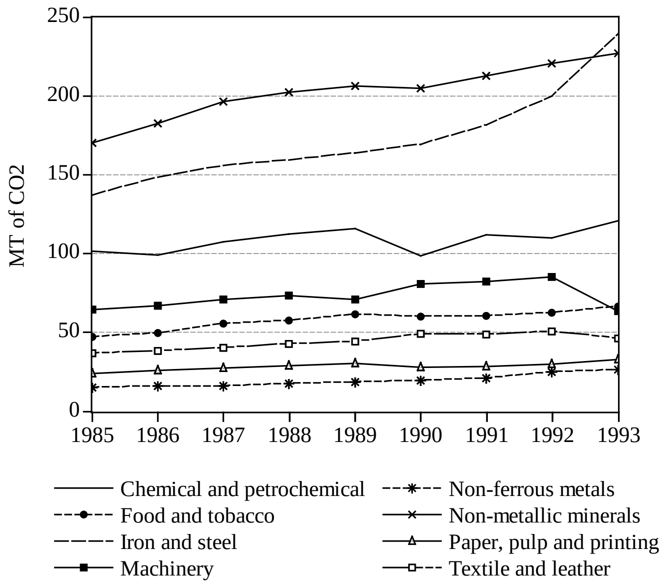

Figure 15. China / Branch-level CO_2 emissions (1985-1993)

For the second period, between 1994 and 2005, there were substantial changes in value-added shares (Figure 16). Apart from the branch 'non-ferrous metals', the growing branches differed markedly from those described for the period between 1985 and 1993. Compared to 1994, value-added shares in 2005 increased for 'non-ferrous metals' (57.7%), 'machinery' (25.6%), 'chemical and petrochemical' (13.4%) and 'paper, pulp and printing' (9.6%). All other branches reduced their participation in total value added, particularly 'non-metallic minerals' (-35.8%), 'textile and leather' (-28%) and 'food and tobacco' (-10.5%).

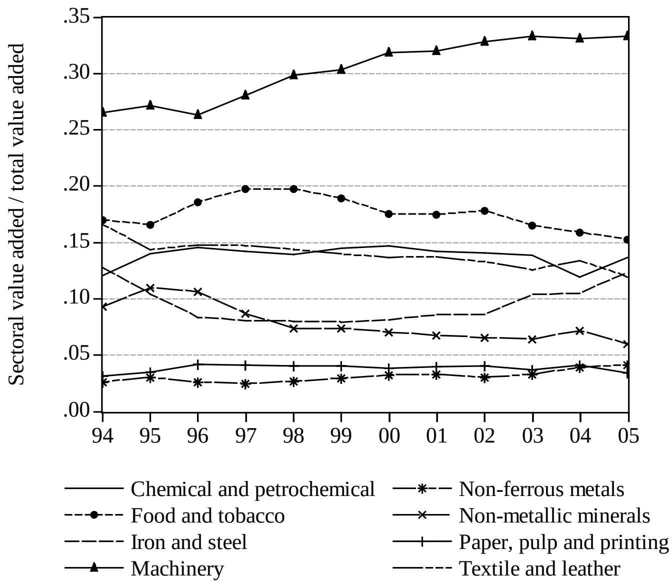

Figure 16. China / Shares in total value added covered (1994-2005)

In the period between 1994 and 2005, the covered branches saw a decrease in emission intensity at an annual rate of -5.9%, while emissions and real value added increased at a rate of 4.5%/year and 30%/year, respectively. Considering that the Chinese GDP grew at a rate of about 15%/year during this second period, the covered manufacturing branches have substantially increased its importance to the Chinese economy.

Table 6. China / Annual growth rates by branch and shares (1994-2005)

Branches	Annual growth rates (1994 – 2005)			Shares in total value added	
	Emissions	Value added	Emission intensity	1994	2005
Chemical and petrochemical	-0.2%	35.2%	-7.3%	12.0%	13.7%
Food and tobacco	-2.0%	25.9%	-7.2%	17.0%	15.2%
Iron and steel	12.2%	28.5%	-3.9%	12.8%	12.3%
Machinery	-2.0%	40.0%	-7.8%	26.5%	33.3%
Non-ferrous metals	4.3%	52.5%	-7.1%	2.6%	4.1%
Non-metallic minerals	4.3%	16.0%	-4.2%	9.3%	6.0%
Paper, pulp and printing	0.9%	33.7%	-7.0%	3.1%	3.4%
Textile and leather	-1.6%	19.0%	-6.7%	16.6%	11.9%
Total	*4.5%*	*30.0%*	*-5.9%*	*100%*	*100%*

All branches had positive annual growth rates in real value added between 1994 and 2005, with emphasis on ‘non-ferrous metals’ (52.5%/year), ‘machinery’ (40%/year) and ‘chemical and petrochemical’ (35.2%/year), as shown in Table 6. In general, the fastest growing branches in value added had the strongest reduction in emission intensity, except for ‘food and tobacco’ and ‘textile and leather’. These two branches had considerable reductions in emission intensity, despite having grown below the average in terms of value added between 1994 and 2005.

The fastest increase in total emissions was seen in the branches ‘iron and steel’ (12.2%/year), ‘non-metallic minerals’ (4.3%/year), and ‘non-ferrous metals’ (4.3%/year), as presented in Figure 17. The first two branches also had the slowest reductions in emission intensity, at an annual rate of -3.9% for ‘iron and steel’ and -4.2% for ‘non-metallic minerals’. This may reflect a stronger rigidity of these branches in decoupling[36] growth in value added from increasing carbon dioxide emissions. Various branches had considerable reductions in total emissions, particularly ‘machinery’ (-2.0%/year), ‘food and tobacco’ (-2.0%/year) and ‘textile and leather’ (-1.6%/year).

[36] Decoupling usually means the lessening of correlation or dependency between variables. For the purpose of this analysis, decoupling occurs when the growth rate of the environmentally relevant variable is less than that of its economic driving force, such as GDP and sectoral value added, over a given period. When, for example, GDP grows positively, ‘absolute’ or ‘strong’ decoupling is said to occur, if the growth rate of the environmentally relevant variable is zero or negative. ‘Relative’ or ‘weak’ decoupling occurs when the growth rate of the environmentally relevant variable is positive, but less than the GDP growth rate (OECD, 2002: 11).

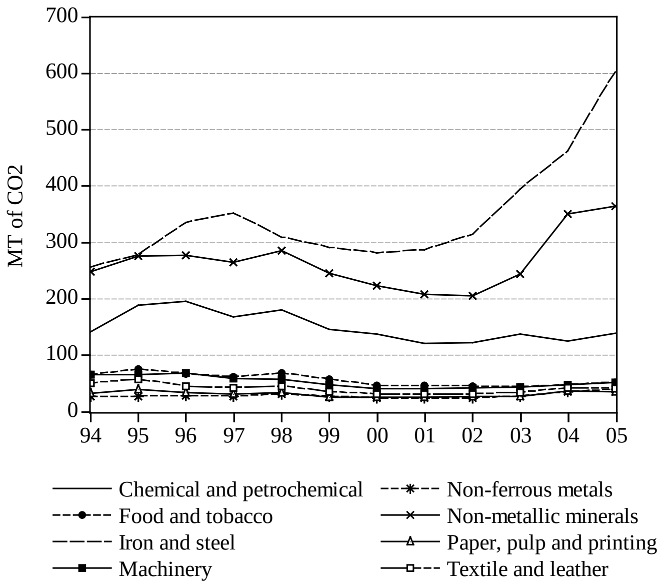

Figure 17. China / Branch-level CO_2 emissions (1994-2005)

In general, the ranking of the most emission-intensive branches did not change from 1994 to 2005 (Figure 18). Considering changes in value-added shares and emission intensities, the Chinese manufacturing seems to have followed a 'clean' development trend as GDP grew in the second period. The most polluting and emission-intensive branches such as 'non-metallic minerals' and 'iron and steel' saw a decline in their shares in total value added, particularly the former, while the least emission-intensive branch 'machinery' had a strong increase in its value added share. Other less emission-intensive branches such as 'textile and leather' and 'food and tobacco' saw considerable declines in value-added shares, at the expense of 'non-ferrous metals', 'chemical and petrochemical' and 'paper, pulp and printing', which in the Chinese context can be considered as having intermediate emission intensities. All these three branches, though, had a considerable reduction in their emission intensity during the period, whereby the latter two maintained relatively stable levels of emission.

Table 7 presents the results of the decomposition for the period between 1985 and 1993. Technological effects played a key role in this first reference period and accounted for all the reduction in the emission-output ratio variation. In contrast, structural effects led to a considerable increase in the emission-output ratio. The branches with the strongest increase allocated to structural effects, namely 'iron and steel' (0.1886) and 'non-metallic minerals' (0.0611), were also the ones with the strongest reduction due to technological effects. These results are consistent with the 'pollution haven' hypothesis, which may have been true for these two branches. For all other branches covered, however, the 'pollution haven' hypothesis does not seem likely, since structural effects either played a small role or contributed to a reduction in the emission-output ratio.

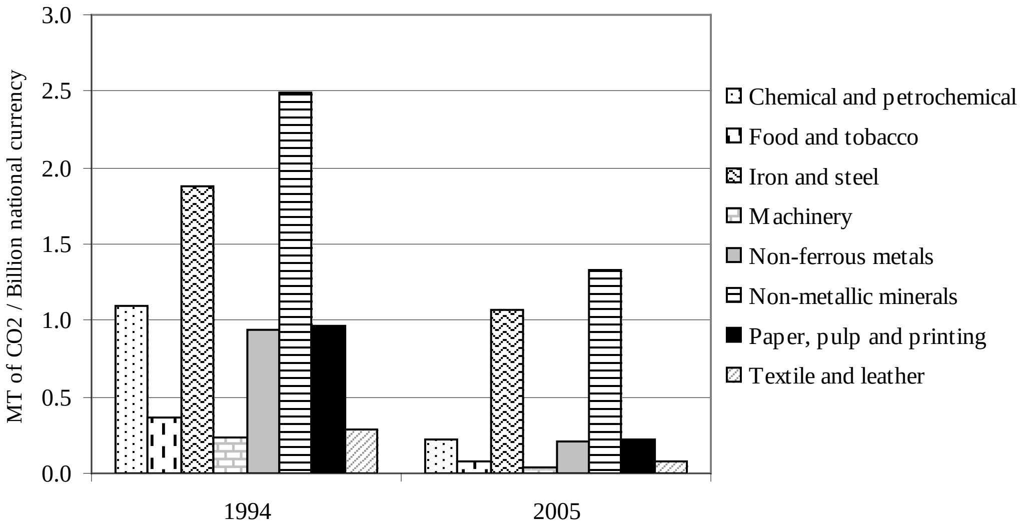

Figure 18. China / Branch-level emission intensity (1994 and 2005)

Concerning the question of a 'clean' development trend between 1985 and 1993, although emission-intensive branches did not lose share in terms of value added to cleaner branches, technological development played a major role, leading to a considerable reduction in the emission-output ratio. Therefore, the decomposition results for this first period seem consistent with the clean development trend hypothesis.

Table 7. China / Decomposition of emission-output ratio variation (1985-1993)[37]

Branches	ΔStructural	ΔTechnological	ΔTotal
Chemical and petrochemical	0.0108 (-1.5%)[38]	-0.1629 (22.5%)	-0.1521 (21%)
Food and tobacco	0.0160 (-2.2%)	-0.0710 (9.8%)	-0.0550 (7.6%)
Iron and steel	0.1886 (-26.1%)	-0.2779 (38.4%)	-0.0893 (12.3%)
Machinery	-0.0333 (4.6 %)	-0.0840 (11.6%)	-0.1172 (16.2%)
Non-ferrous metals	0.0033 (-0.5%)	-0.0128 (1.8%)	-0.0095 (1.3%)
Non-metallic minerals	0.0611 (-8.4%)	-0.2798 (38.7%)	-0.2187 (30.2%)
Paper, pulp and printing	-0. 0143 (2%)	-0.0157 (2.2%)	-0.0300 (4.1%)
Textile and leather	-0.0102 (1.4%)	-0.0412 (5.7%)	-0.0514 (7.1%)
Total manufacturing	0.2220 (-30.7%)	-0.9453 (130.7%)	-0.7233 (100%)

[37] The format used for this table is similar for all covered countries. It presents the results at the branch level in order to make possible the assessment of the role of each specific manufacturing branch in the emission-output ratio variation. The first column lists the covered branches, while the second and third ones present structural (ΔStructural) and technological (ΔTechnological) effects, respectively. The fourth column shows the variation at the branch-level emission intensity, which is simply the result of the sum of the branch-level structural and technological effects. The vertical sum of the last three columns gives the values for the covered manufacturing sector as a whole, which is represented in the last line of the table.

[38] Percentages in brackets represent relative values of sectoral or branch-level emissions attributed either to technological or structural effects in relation to the emission-output ratio variation (-0.7233).

The decomposition results for the period between 1994 and 2005 are shown in Table 7. In contrast to the first period, structural effects contributed to a reduction in the emission-output ratio as whole, mainly structural effects from the branches 'iron and steel' and 'non-metallic minerals'. In all other branches technological effects largely predominated over structural effects which contributed to a relatively small increase in the emission-output ratio led by 'chemical and petrochemical'.

The branch 'chemical and petrochemical' was the only one with some significant contribution to an increase in the emission-output ratio allocated to structural effects (4.8% of the total variation). Nevertheless, its technological effects were highly predominant, and as a whole the branch delivered the largest contribution to the reduction in the emission-output ratio during the period. Apart from 'chemical and petrochemical', none of the branches had results consistent with the 'pollution haven' hypothesis in the second reference period.

From 1994 to 2005, the value-added shares of emission-intensive branches remained stable or contracted, whereas cleaner branches experienced faster growth rates, with emphasis on 'machinery'. This differed greatly from the first period, which saw a predominant growth of primary industries and, thus, seems to have provided the seedbed for the sharp growth rates of cleaner branches from 1994 to 2005. Similarly to the first period, technological effects were largely predominant, playing a major role in the reduction of the emission-output ratio. Therefore, these results seem consistent with the 'clean' development trend hypothesis for the case of the Chinese manufacturing sector.

Table 8. China / Decomposition of emission-output ratio variation (1994-2005)

Branches	∆Structural	∆Technological	∆Total
Chemical and petrochemical	0.0260 (-4.8%)	-0.1283 (23.7%)	-0.1023 (18.9%)
Food and tobacco	0.0035 (-0.6%)	-0.0534 (9.9%)	-0.0499 (9.2%)
Iron and steel	-0.0676 (12.5%)	-0.0416 (7.7%)	-0.1092 (20.2%)
Machinery	0.0098 (-1.8%)	-0.0604 (11.2%)	-0.0506 (9.3%)
Non-ferrous metals	0.0069 (-1.3%)	-0.0231 (4.3%)	-0.0162 (3%)
Non-metallic minerals	-0.0770 (14.2%)	-0.0755 (14%)	-0.1525 (28.2%)
Paper, pulp and printing	0.0083 (-1.5%)	-0.0308 (5.7%)	-0.0226 (4.2%)
Textile and leather	-0.0094 (1.7%)	-0.0283 (5.2%)	-0.0377 (7%)
Total manufacturing	-0.0995 (18.4%)	-0.4414 (81.6%)	-0.5410 (100%)

Figure 19 and Figure 20 show the year-to-year variation of the Chinese emission-output ratio as well as of technological and structural effects from 1985 to 1993 and from 1994 to 2005, respectively. In both periods, technological effects determined most of the emission-output ratio variation. From 1985 to 1991 structural effects remained relatively stable and contributed to a slight reduction in the Chinese manufacturing emission-output ratio. This trend changed considerably from 1991 to 1993, when structural effects led to an increase in the emission-output ratio, but were compensated by much stronger environmentally positive technological effects. From 1994 to 2001 the emission-output ratio saw a significant variation, which was marked by a reduction mainly driven by technological effects. Although structural effects also contributed to a slight reduction in the emission-output ratio from 1995 to 1998, their influence remained practically neutral from 1994 to 2005. The pace of reduction of the Chinese emission-output ratio became slower as from 2001 and appears to have stabilised as from 2004 (Figure 20).

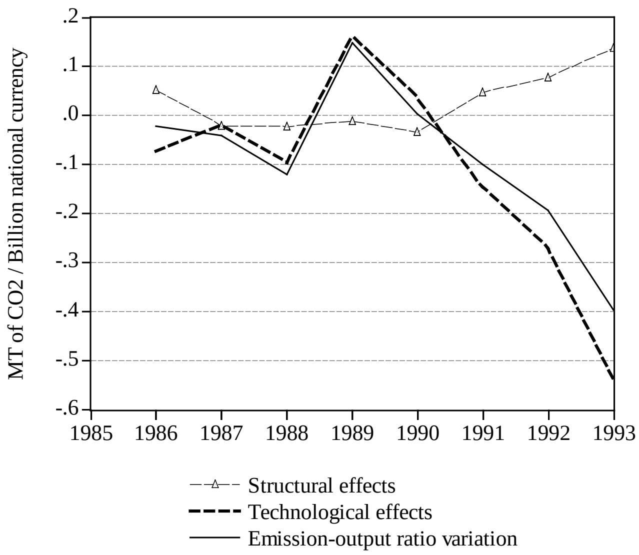

Figure 19. China / Emission-output ratio variation and effects (1985-1993)

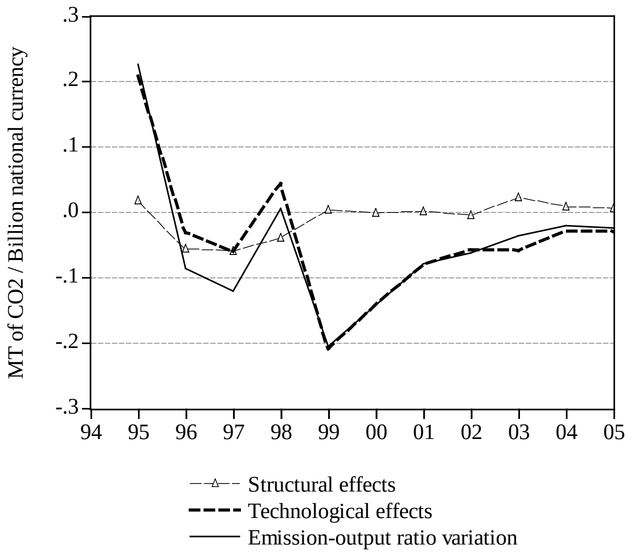

Figure 20. China / Emission-output ratio variation and effects (1994-2005)

4.3. India

The analysis of the Indian manufacturing sector comprises seven branches, namely: 1. chemical and petrochemical, 2. iron and steel, 3. machinery, 4. non-ferrous metals, 5. non-metallic minerals, 6. paper, pulp and printing, and 7. textile and leather. Due to missing data on emissions, the branch 'food and tobacco' could not be included in the study. The analysis for India was divided into two periods, so as to account for the incomparability of its value-added data throughout time as shown in Table 2. The first period, between 1985 and 1997, is based on value added obtained from the INDSTAT in Revision 2 of the ISIC (UNIDO, 2006), measured at factor costs (real terms of 1990). The second period, between 1998 and 2004, is based on data from the INDSTAT in Revision 3 of the ISIC (UNIDO, 2007) at producers' prices (real terms of 2000). Both series were used in national currency values and converted to real terms using manufacturing wholesale price indexes for India (OECD, 2008).

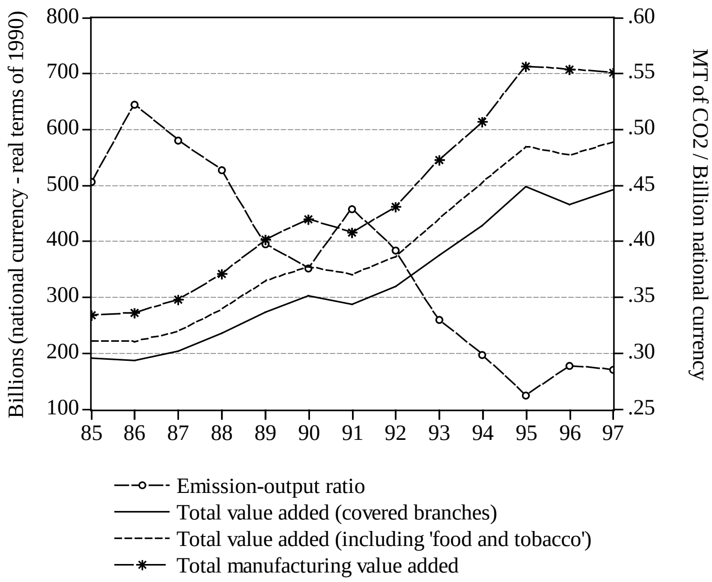

Figure 21. India / Manufacturing value added and emission-output ratio (1985-1997)

During the period between 1985 and 1997, on average the covered branches represented 69% of the Indian total manufacturing value added. In the first period, they experienced an annual growth rate of 13.6%/year, while the Indian real GDP grew at 7.95%/year[39]. In contrast, the manufacturing emission-output ratio declined by -37%, at -3.1% per year, having reached 0.29 MT of CO_2 / billion value added in 1997, as shown in Figure 21.

[39] Gross Domestic Product (GDP) in national currency values at market prices, as well as GDP deflators are World Bank estimates obtained from the *United Nations Common Database*. Available at: http://data.un.org/ (accessed: 18/11/08).

In the second period, between 1998 and 2004, the covered branches accounted, on average, for 66% of the Indian total manufacturing value added. From 1998 to 2004 real value added in these branches grew at an annual rate of 4.5%, while GDP grew at 7.1% per year (real terms of 2000). The emission-output ratio decreased by -12%, at a rate of -2%/year from 1998 to 2004, reaching 0.09 MT of CO_2 / billion value added in 2004 (Figure 22).

Changes in terms of real value-added shares in the Indian manufacturing between 1985 and 1997 are presented in Figure 23. Value-added shares relative to 1985 increased for the branches 'non-ferrous metals' (259%), 'chemical and petrochemical' (23.3%) and 'iron and steel' (15.8%). All other branches saw a reduction in their value-added shares compared to 1985, particularly 'non-metallic minerals' (-22.9%), 'textile and leather' (-16.6%) and 'machinery' (-14.7%). The contraction in value-added shares of the least emission-intensive branches, simultaneously to the increase of 'iron and steel', the second most emission-intensive branch as shown in Figure 24, is inconsistent with the 'clean' development trend in India between 1985 and 1997. Nevertheless, it is worth noting that the contraction in value added share of the emission-intensive branch 'non-metallic minerals' contributed to a 'cleaner' trend relative to 1985.

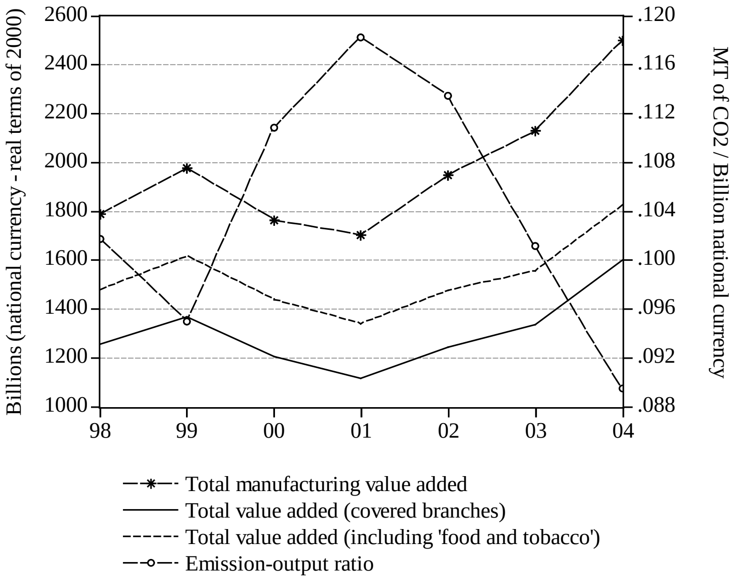

Figure 22. India / Manufacturing value added and emission-output ratio (1998-2004)

As shown in Table 8, all branches had positive growth rates in real value added between 1985 and 1997, particularly 'non-ferrous metals' (68.5%/year), 'chemical and petrochemical' (18.1%/year) and 'iron and steel' (16.5%). The branch 'machinery', which had the third slowest growth rate in value added (9.9%/year), was the only one with an increase in emission intensity (0.3%/year) among the covered branches. As a result, ‘machinery’ had the highest growth rate in terms of emissions (10.7%/year), followed by ‘chemical and petrochemical’ (6.9%/year).

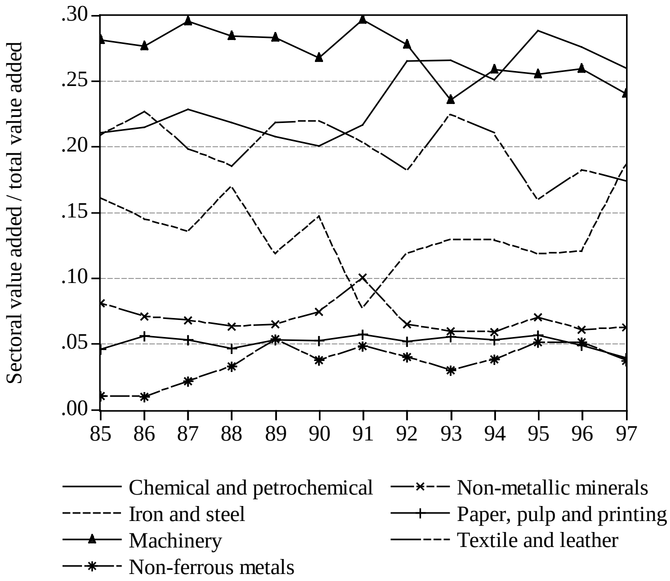

Figure 23. India / Shares in total value added covered (1985-1997)

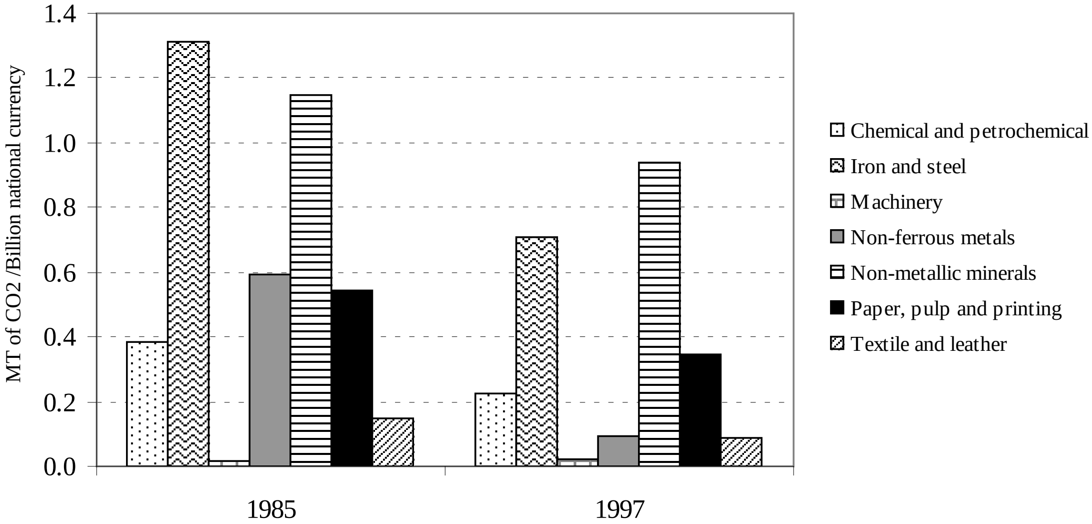

Figure 24. India / Branch-level emission intensity (1985 and 1997)

The branch ‘non-metallic minerals’ had the slowest reduction in emission intensity (-1.5%) between 1985 and 1997, remaining the second largest source of emissions during the period (Figure 25). On average, ‘iron and steel’, ‘non-metallic minerals’ and ‘chemical and petrochemical’, the three largest branches in terms of emissions in India, together accounted for roughly 86% of the CO_2 emissions from fuel combustion during the first period.

Table 9. India / Annual growth rates by branch and shares (1985-1997)

Branches	Annual growth rates (1985 – 1997)			Shares in total value added	
	Emissions	Value added	Emission intensity	1985	1997
Chemical and petrochemical	6.9%	18.1%	-3.5%	21.1%	26.0%
Food and tobacco	-	14.6%	-	-	-
Iron and steel	5.0%	16.5%	-3.8%	16.1%	18.6%
Machinery	10.7%	9.9%	0.3%	28.2%	24.0%
Non-ferrous metals	3.8%	68.5%	-7.0%	1.0%	3.7%
Non-metallic minerals	5.1%	8.2%	-1.5%	8.1%	6.3%
Paper, pulp and printing	3.5%	10.0%	-3.0%	4.6%	3.9%
Textile and leather	2.2%	9.5%	-3.4%	20.9%	17.4%
Total	*5.14%*	*13.8%*	*-3.09%*	*100%*	*100%*

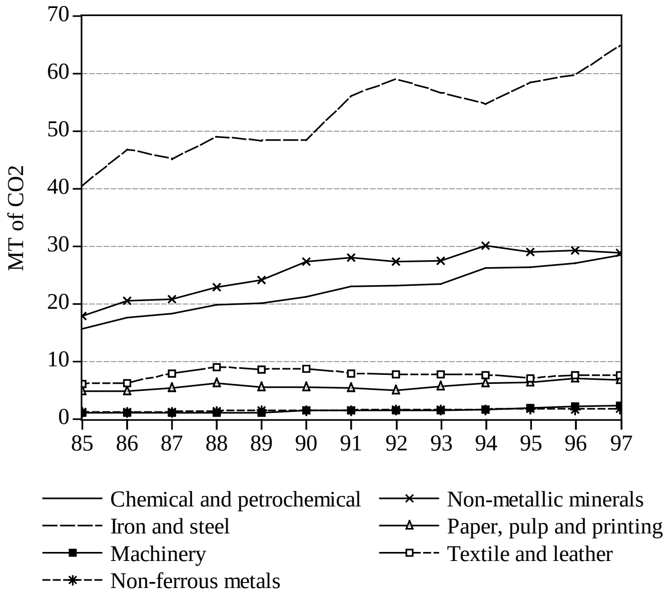

Figure 25. India / Branch-level CO_2 emissions (1985-1997)

Despite the slow growth rate in manufacturing value added (4.6%/year) compared to the GDP growth (7.1%/year) from 1998 to 2004, the reduction in the Indian emission-output ratio continued in the second period, but at a slower pace (-2.0%/year). A substantial increase in the emission-output ration occurred between 2000 and 2002, which seems to have been determined by a temporary contraction in output by 'iron and steel' relative to the other branches in that same period. As presented in Table 10, growth in value added between 1998 and 2004 occurred mostly in the branches 'non-ferrous metals' (18.2%/year), 'iron and steel' (17.4%/year) and 'non-metallic minerals' (12.9%/year). In contrast, 'machinery' grew at a much slower rate (1.5%/year), while some branches went through a period of stagnation, such as ‘chemical and petrochemical’ (0.1%/year), ‘food and tobacco’ (0.2%/year) and ‘textile and leather’ (0.2%/year).

Even though value added growth was slow or stagnated for some of the covered branches all of them saw a decline in emission intensity. The case of ‘textile and leather’ is particularly striking in this sense. The fast-growing ‘iron and steel’, conversely, had a relatively modest reduction in emission intensity (-4.8%/year), becoming one of the main contributors to the increase in emissions from 1998 to 2004.

Value-added shares remained stable or declined for most branches apart from ‘non-ferrous metals’, ‘iron and steel’ and ‘non-metallic minerals’, as shown in Figure 26. Even though the latter had the strongest reduction in emission intensity (Figure 27), the increase in importance of emission-intensive branches from 1998 to 2004 seems inconsistent with the ‘clean’ development trend hypothesis.

Table 10. India / Annual growth rates by branch and shares (1998-2004)

Branches	**Annual growth rates (1998 – 2004)**			**Shares in total value added**	
	Emissions	**Value added**	**Emission intensity**	**1998**	**2004**
Chemical and petrochemical	-3.7%	0.1%	-3.7%	32.9%	26.0%
Food and tobacco	-	0.2%	-	-	-
Iron and steel	7.5%	17.4%	-4.8%	15.2%	24.5%
Machinery	-1.5%	1.5%	-2.7%	22.7%	19.4%
Non-ferrous metals	8.2%	18.2%	-4.8%	3.1%	5.1%
Non-metallic minerals	1.0%	12.9%	-6.7%	5.6%	7.8%
Paper, pulp and printing	-3.5%	5.1%	-6.6%	4.0%	4.1%
Textile and leather	-6.3%	0.2%	-6.4%	16.5%	13.1%
Total	*2.0%*	*4.6%*	*-2.0%*	*100%*	*100%*

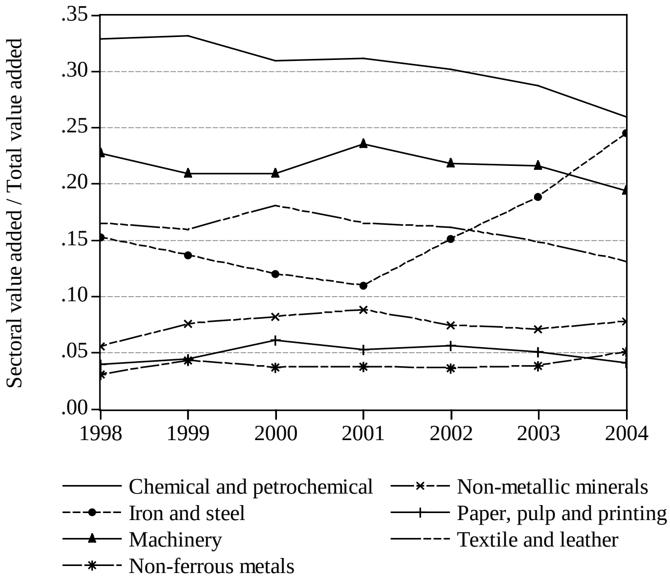

Figure 26. India / Shares in total value added covered (1998-2004)

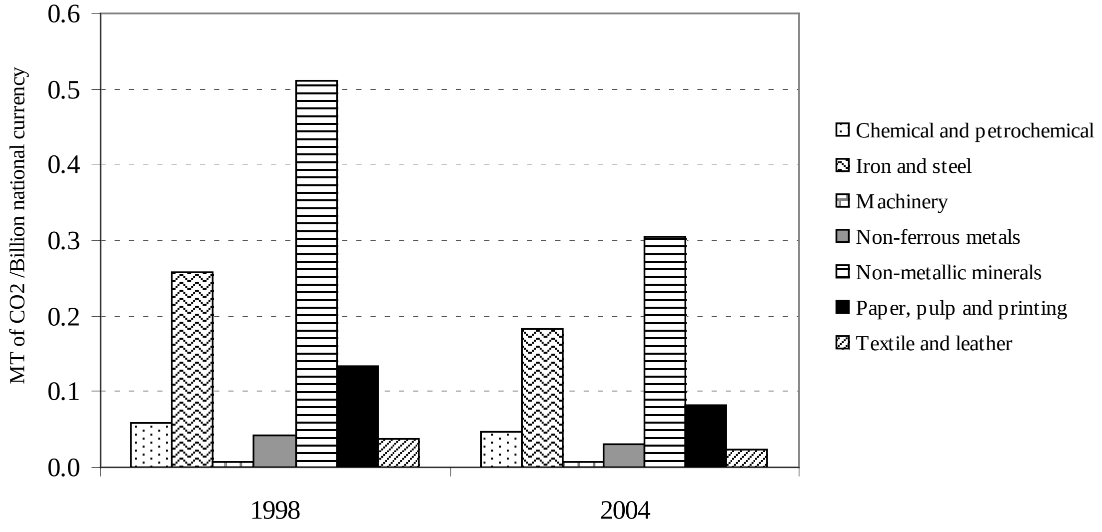

Figure 27. India / Branch-level emission intensity (1998 and 2004)

As shown in Figure 28, 'iron and steel' considerably increased its share in the Indian manufacturing emissions from 1998 to 2004. During this second period, the three major branches concerning CO_2 emissions, 'iron and steel', 'non-metallic minerals' and 'chemical and petrochemical', increased their average share in total emissions compared to the first period, and represented alone 88.5% of the total Indian manufacturing CO_2 emissions from fuel combustion between 1998 and 2004.

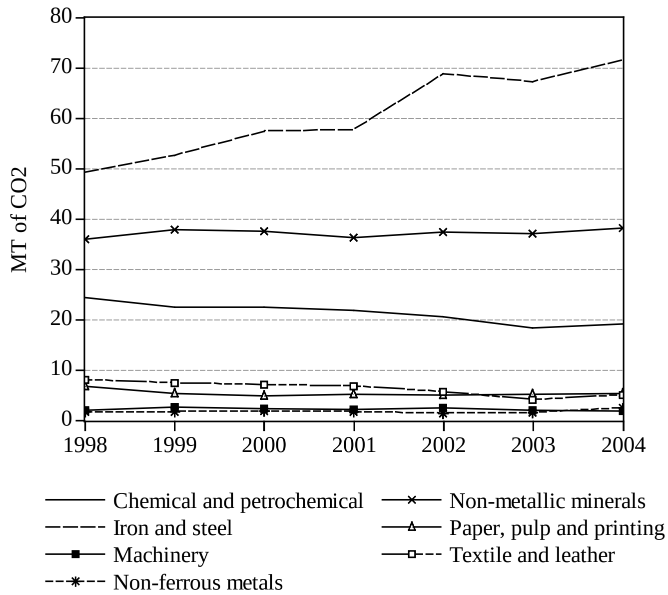

Figure 28. India / Branch-level CO_2 emissions (1998-2004)

The decomposition results of the emission-output ratio variation in India from 1985 to 1997 are presented in Table 10. During this first reference period, the emission-output ratio was reduced by -0.1682 MT of CO_2 / billion real value added. Technological effects were largely predominant over structural effects, accounting for most of the reduction in the emission-output ratio. Apart from 'machinery', all branches had technological effects leading to a reduction in the emission-output ratio.

Although the branch 'iron and steel' was the largest contributor to an increase in the emission-output ratio through structural effects (0.0186), its technological effects predominated and led it to become the main contributor to the reduction in the emission-output ratio, followed by 'non-metallic minerals' and 'chemical and petrochemical'. The branches 'iron and steel', 'chemical and petrochemical' and 'non-ferrous metals' were the only ones with structural effects contributing to an increase to the emission-output ratio, which could be consistent with 'pollution haven' hypothesis. For most of the other ones, the results do not seem consistent with the 'pollution haven' hypothesis, since structural effects contributed to a reduction in the emission-output ratio.

Table 11. India / Decomposition of emission-output ratio variation (1985-1997)[40]

Branches	ΔStructural	ΔTechnological	ΔTotal
Chemical and petrochemical	0.0175 (-10.42%)[41]	-0.0410 (24.37%)	-0.0235 (13.95%)
Iron and steel	0.0186 (-11.06%)	-0.0981 (58.37%)	-0.0796 (47.31%)
Machinery	-0.0006 (0.38%)	0.00005 (-0.03%)	-0.0006 (0.35%)
Non-ferrous metals	0.0077 (-4.55%)	-0.0103 (6.14%)	-0.0027 (1.59%)
Non-metallic minerals	-0.0256 (15.2%)	-0.0091 (5.44%)	-0.0347 (20.64%)
Paper, pulp and printing	-0.0007 (0.4%)	-0.0105 (6.27%)	-0.0112 (6.67%)
Textile and leather	-0.0029 (1.7%)	-0.0131 (7.79%)	-0.0160 (9.49%)
Total manufacturing	0.0140 (-8.34%)	-0.1822 (108.34%)	-0.1682 (100%)

Although some emission-intensive branches such as 'non-metallic minerals' did lose share in terms of value added to cleaner branches, less emission-intensive branches such as 'machinery' and 'textile and leather' lost considerable share in real value added from 1985 to 1997. Hence, despite becoming less emission intensive during this period, changes in value-added shares seem inconsistent with a 'clean' development trend in the Indian manufacturing sector. Technological effects, however, were the main drivers in the emission-output ratio reduction from 1985 to 1997.

[40] The format used for this table is similar for all covered countries. It presents the results at the branch level in order to make possible the assessment of the role of each specific manufacturing branch in the emission-output ratio variation. The first column lists the covered branches, while the second and third ones present structural (ΔStructural) and technological (ΔTechnological) effects, respectively. The fourth column shows the variation at the branch-level emission intensity, which is simply the result of the sum of the branch-level structural and technological effects. The vertical sum of the last three columns gives the values for the covered manufacturing sector as a whole, which is represented in the last line of the table.

[41] Percentages in brackets represent relative values of sectoral or branch-level emissions attributed either to technological or structural effects in relation to the emission-output ratio variation (-0.0123).

The decomposition results for the period between 1998 and 2004 are shown in Table 12. During this second period, the emission-output ratio was reduced by -0.0123 MT of CO_2 / billion real value added. In contrast to the first period, structural effects contributed to a considerable increase in the emission-output ratio, mainly driven by the most emission-intensive branches, ‘iron and steel’ and ‘non-metallic minerals’, which also had the strongest reduction allocated to technological effects.

As a whole, technological effects predominated over structural effects, with the exception of the branches ‘iron and steel’ and ‘non-ferrous metals’, whose total effects contributed to an increase in the emission-output ratio. Considering the significant structural effects leading to an increase in the emission-output ratio for the most emission-intensive branches, the Indian manufacturing sector seems to have changed its structure towards more emission-intensive branches compared to 1998. Thus, the results seem inconsistent with a ‘clean’ development trend for India, and the ‘pollution haven’ hypothesis may be applicable for this second period, particularly for ‘iron and steel’ and ‘non-metallic minerals’.

Table 12. India / Decomposition of emission-output ratio variation (1998-2004)

Branches	ΔStructural	ΔTechnological	ΔTotal
Chemical and petrochemical	-0.0035 (28.64%)	-0.0040 (32.75%)	-0.0075 (61.4%)
Iron and steel	0.0278 (-226.54%)	-0.0222 (181.49%)	0.0055 (-45.1%)
Machinery	-0.0002 (1.77%)	-0.0002 (2%)	-0.0005 (3.8%)
Non-ferrous metals	0.0006 (-5.18%)	-0.0004 (3.35%)	0.0002 (-1.8%)
Non-metallic minerals	0.0090 (-73.31%)	-0.0137 (112.14%)	-0.0048 (38.8%)
Paper, pulp and printing	0.0003 (-2.31%)	-0.0023 (18.84%)	-0.0020 (16.5%)
Textile and leather	-0.0009 (7.15%)	-0.0024 (19.2%)	-0.0032 (26.4%)
Total manufacturing	0.0331 (-269.78%)	-0.0453 (369.78%)	-0.0123 (100%)

The branch ‘chemical and petrochemical’ was the main contributor to the reduction in the emission-output ratio from 1998 to 2004, followed by ‘non-metallic minerals’ and ‘textile and leather’. Similarly to the first period, technological effects played an important role, mainly concerning the most emission-intensive branches, which compensated their structural effects and made possible the reduction in the emission-output ratio in this second period.

The year-to-year variation of the Indian emission-output ratio as well as of the decomposed technological and structural effects are presented in Figure 29, from 1985 to 1997, and in Figure 30, from 1998 to 2004. From 1987 to 1990 structural effects determined a great deal of the variation of the emission-output ratio. From 1990 to 2004, however, technological effects became predominant over structural effects in determining the emission-output ratio variation. Although there was a general decline in the emission-output ratio during both periods, there were sharp increases in the years 1991, 1996, 2000 and 2001 (Figure 29 and Figure 30). All of these spikes have been mostly determined by environmentally negative technological effects.

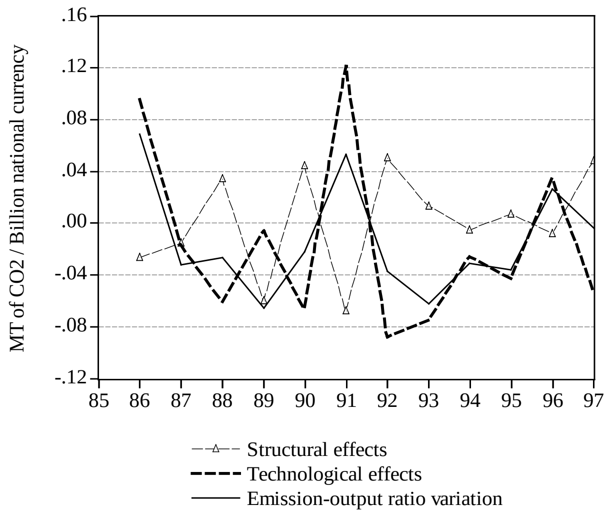

Figure 29. India / Emission-output ratio variation and effects (1985-1997)

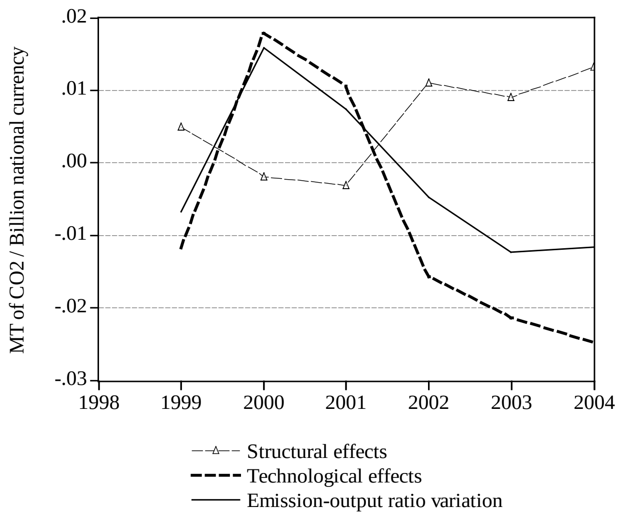

Figure 30. India / Emission-output ratio variation and effects (1998-2004)

4.4. Mexico

Seven manufacturing branches between 1987 and 2003 were covered for Mexico, namely: 1. chemical and petrochemical, 2. food and tobacco, 3. iron and steel, 4. machinery, 5. non-ferrous metals, 6. non-metallic minerals, and 7. paper, pulp and printing. The branch 'textile and leather', which on average accounted for 8.3% of the total manufacturing value added during the period, could not be covered due to lack of data on emissions.

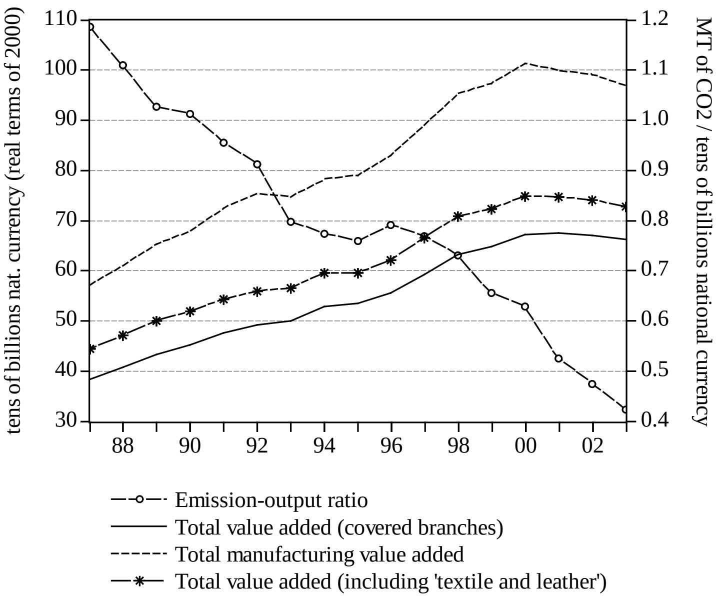

Figure 31. Mexico / Manufacturing value added and emission-output ratio (1987-2003)

The covered manufacturing branches represented, on average, 67% of the Mexican total manufacturing value added between 1987 and 2003. While the Mexican GDP grew at 3.7%/year, the real value added of the covered branches grew at 4.5%/year, and their emission-output ratio decreased by -64.4%, at a rate of -4%/year, having reached in 2003 around 0.42 MT of CO_2 per tens of billions real value added (Figure 31).

Figure 32 shows changes in the value-added shares of the covered manufacturing branches. 'Food and tobacco' and 'machinery', the largest branches in terms of value added, were the only ones with increasing shares in total value added. All other branches saw a reduction in value added share compared to 1987, mainly 'non-ferrous metals' (-2.6%/year), 'iron and steel' (-2.3%/year) and 'paper, pulp and printing' (-2.3%/year).

Real value added grew for all branches covered during the period (Table 13), with particular emphasis to 'food and tobacco' (7.5%/year) and 'machinery' (5.5%/year). Most branches saw a reduction in total emissions from fuel combustion, apart from 'non-ferrous metals' with an annual growth in emissions of 12.5% and 'food and tobacco' with 0.6%. The strong increase in emissions for 'non-ferrous metals' was accompanied by a sharp increase in its emission intensity (12.1%/year), which may be related to its low growth in real value added (0.1%/year) during the period. Although ‘iron and steel’ and ‘paper, pulp and printing’ also had relatively low annual growth rates in real value added, the emission intensity still slightly declined, as presented in Figure 33.

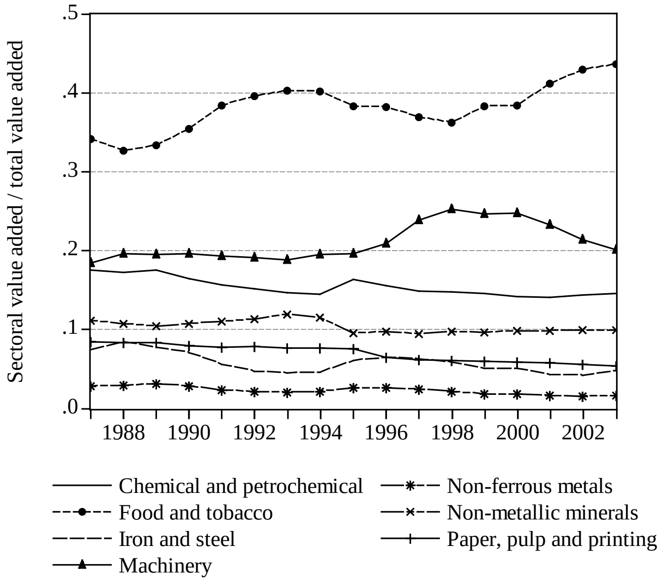

Figure 32. Mexico / Shares in total value added covered (1987-2003)

Considering changes in value-added shares during the period, emission-intensive branches lost share to cleaner ones. There was a substantial reduction in emission intensity in most branches except for ‘non-ferrous metals’, which represented only 0.34% of the emissions during the period, as can be seen in Figure 34. These changes in the Mexican manufacturing sector seem consistent with the ‘clean’ development trend hypothesis. The strong reduction in emissions for most manufacturing branches, mainly as from 2000 (Figure 34), also suggests a ‘cleaner’ trend.

From 1987 to 2003 the emission-output ratio in Mexico declined in -0.7641 MT of CO_2 per tens of billion real value added. Structural effects, mainly those related to the branches ‘iron and steel’ and ‘chemical and petrochemical’, contributed to nearly 27% of this reduction. The only branches with an increase in the emission-output ratio allocated to structural effects were ‘food and tobacco’ (0.0206) and ‘machinery’ (0.0003), the structural effects of which together represented only 3% of the emission-output ratio. Since these two branches were among the least emission-intensive ones, such results are inconsistent with a significant emission-intensive industrial relocation in line with the ‘pollution haven’ hypothesis.

Table 13. Mexico / Annual growth rates by branch and shares (1987-2003)

Branches	Annual growth rates (1987 – 2003)			Shares in total value added	
	Emissions	Value added	Emission intensity	1987	2003
Chemical and petrochemical	-3.6%	2.7%	-4.4%	17.5%	14.6%
Food and tobacco	0.6%	7.5%	-3.1%	34.1%	43.6%
Iron and steel	-1.3%	0.6%	-1.7%	7.5%	4.8%
Machinery	-2.4%	5.5%	-4.2%	18.4%	20.1%
Non-ferrous metals	12.5%	0.1%	12.1%	2.8%	1.7%
Non-metallic minerals	-2.8%	3.4%	-4.0%	11.2%	10.0%
Paper, pulp and printing	-2.4%	0.6%	-2.7%	8.4%	5.3%
Textile and leather	-	0.4%	-	-	-
Total	*-2.4%*	*4.5%*	*-4.0%*	*100%*	*100%*

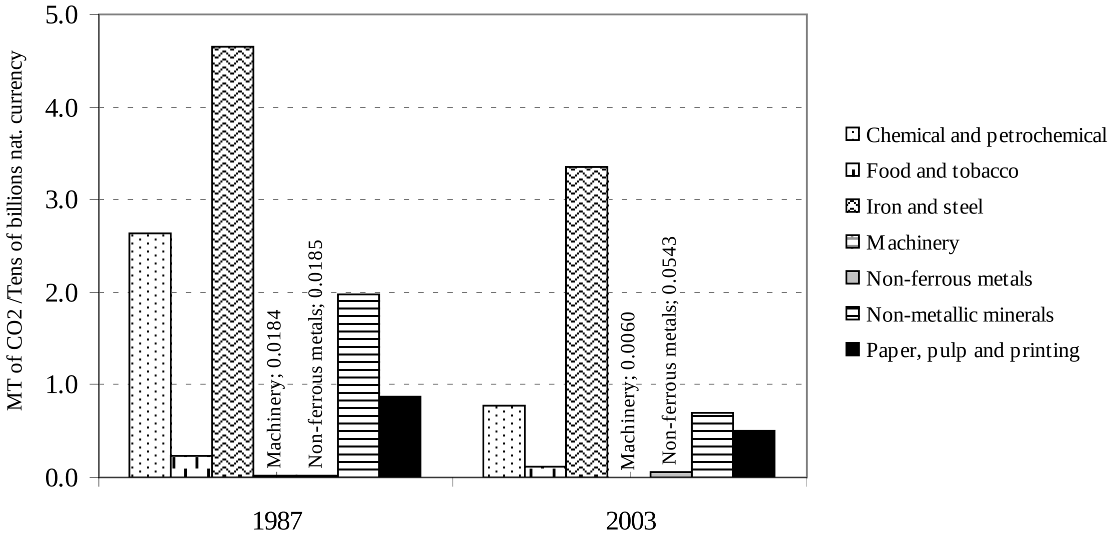

Figure 33. Mexico / Branch-level emission intensity (1987 and 2003)

As shown on Table 14, around 73% of the emission-output ratio variation was allocated to technological effects, which were largely predominant over structural effects with the exception of ‘non-ferrous metals’, the technological effects of which contributed to a small increase in the emission-output ratio. The branch ‘chemical and petrochemical’ had the largest variation allocated to technological effects (-0.2849), followed by ‘non-metallic minerals’ (-0.1299). As a whole, these two branches, together with ‘iron and steel’, accounted for almost 90% of the reduction in the emission-output ratio. Considering that those branches were the most emission-intensive ones in the period, this supports the hypothesis of a ‘clean’ development trend in the Mexican manufacturing sector even further.

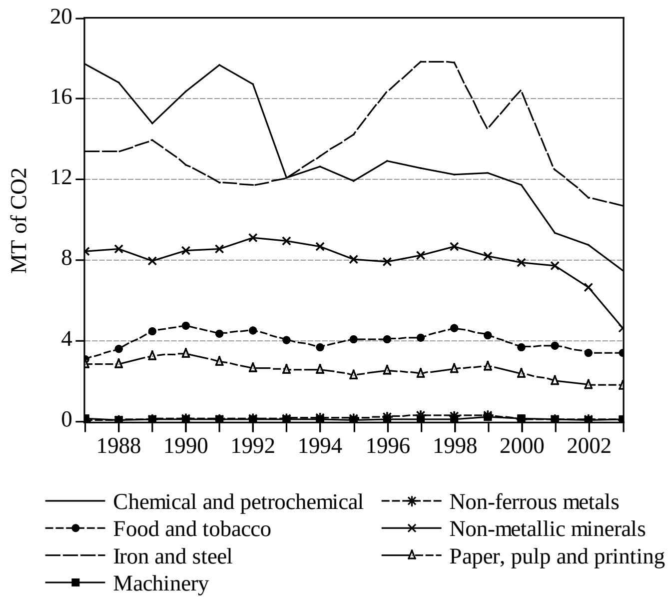

Figure 34. Mexico / Branch-level CO_2 emissions (1987-2003)

Table 14. Mexico / Decomposition of emission-output ratio variation (1987-2003) [42]

Branches	**ΔStructural**	**ΔTechnological**	**ΔTotal**
Chemical and petrochemical	-0.0636 (8.32%)[43]	-0.2849 (37.28%)	-0.3485 (45.6%)
Food and tobacco	0.0206 (-2.7%)	-0.0499 (6.54%)	-0.0293 (3.84%)
Iron and steel	-0.1193 (15.62%)	-0.0682 (8.93%)	-0.1876 (24.54%)
Machinery	0.0003 (-0.04%)	-0.0024 (0.32%)	-0.0022 (0.28%)
Non-ferrous metals	-0.0017 (0.22%)	0.0021 (-0.27%)	0.0004 (-0.05%)
Non-metallic minerals	-0.0200 (2.62%)	-0.1299 (17%)	-0.1499 (19.61%)
Paper, pulp and printing	-0.0207 (2.71%)	-0.0264 (3.46%)	-0.0471 (6.17%)
Total manufacturing	-0.2044 (26.75%)	-0.5597 (73.25%)	-0.7641 (100%)

Figure 35 presents the year-to-year variation of the Mexican manufacturing emission-output ratio as well as of technological and structural effects. The emission-output ratio reduced considerably from 1987 to 2003, apart from an increase in 1995-1996, right after a strong decline in 1992-1993. As shown in Figure 35, in both occasions technological effects

[42] The format used for this table is similar for all covered countries. It presents the results at the branch level in order to make possible the assessment of the role of each specific manufacturing branch in the emission-output ratio variation. The first column lists the covered branches, while the second and third ones present structural (ΔStructural) and technological (ΔTechnological) effects, respectively. The fourth column shows the variation at the branch-level emission intensity, which is simply the result of the sum of the branch-level structural and technological effects. The vertical sum of the last three columns gives the values for the covered manufacturing sector as a whole, which is represented in the last line of the table.

[43] Percentages in brackets represent relative values of sectoral or branch-level emissions attributed either to technological or structural effects in relation to the emission-output ratio variation (-0.7641).

were by far the most important determinant of the emission-output ratio variation. Although structural effects contributed to some increase in the emission-output ratio, their net impact led to a decline.

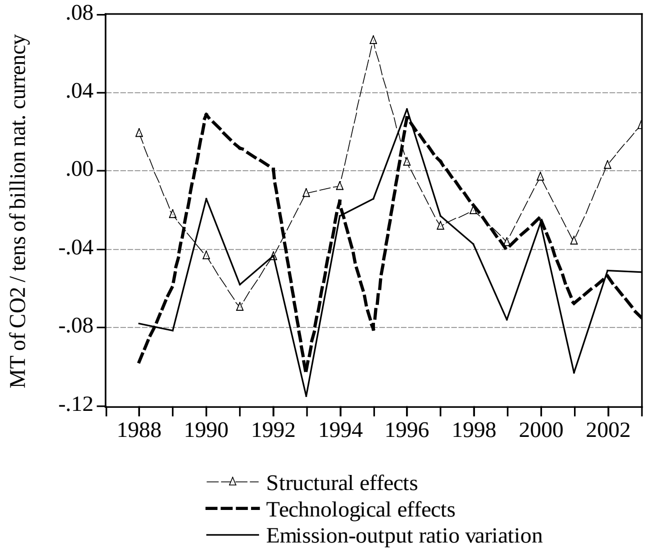

Figure 35. Mexico / Emission-output ratio variation and effects (1987-2003)

5. Discussion of the results

This chapter discusses the results presented above, on the basis of the research questions. The main objectives pursued by this chapter are to: a) discuss trends in terms of fuel use and manufacturing structure, b) explain the development of technological and structural effects *vis-à-vis* broader macroeconomic indicators as well as detailed fuel data on the national and sectoral levels, and c) provide a general cross-country comparison of the covered cases.

5.1. Brazil

As shown in the preceding chapter, the covered manufacturing branches in Brazil experienced a contraction in real value added at -0.94%/year from 1996 to 2005, while its intensity of emissions from fuel combustion grew at a rate of 3.5%/year. In contrast, the Brazilian real GDP[44] grew at 2.6%/year during that same period, whereas the GDP emission intensity increased at 0.3%/year (Figure 36).

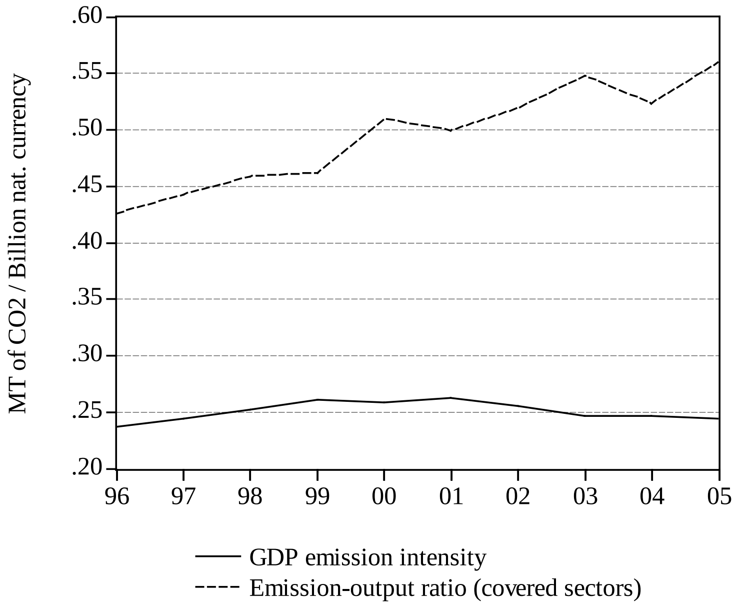

Figure 36. Brazil / GDP emission intensity and emission-output ratio (1996-2005)

Considering the period between 1985 and 2005, the Brazilian real GDP grew at 3%/year, while its total emissions from fuel combustion increased at 5%/year. Therefore, Brazil was unable to decouple[45] its growth in emissions from GDP growth, having increased

[44] Gross Domestic Product (GDP) in national currency values at market prices, as well as GDP deflators are World Bank estimates obtained from the *United Nations Common Database*. Available at: http://data.un.org/ (accessed: 18/11/08).

[45] Decoupling usually means the lessening of correlation or dependency between variables. For the purpose of this analysis, decoupling occurs when the growth rate of the environmentally relevant variable is less than that of its economic driving force, such as GDP and sectoral value added, over a given period. When, for example,

its GDP emission intensity from 1985 to 2005 by 21.3% (1.1%/year). However, it is important to take into account the very small share of fossil-fuel CO_2 relative to total GHG emissions in Brazil compared with most countries (cf. Table 1). Brazilian total CO_2 emissions from fuel combustion increased by 97.2%, from 167 MT of CO_2 in 1985 to 330 MT of CO_2 in 2005 (Figure 37).

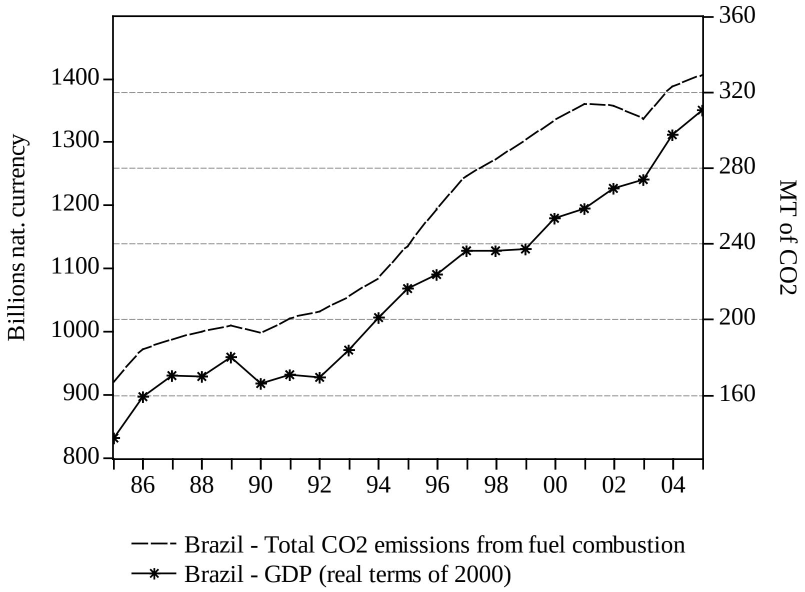

Figure 37. Brazil / Total CO_2 emissions and real GDP (1985-2005)

Figure 38 presents real value added by main industry groups, based on World Bank estimates. From 1985 to 2005, 'services' and 'agriculture, forestry and hunting' increased their shares in total value added from 59.6% and 5.9% in 1985 to 66.7% and 6% in 2005, respectively. The group 'industry' reduced its share from 34.4% to 27.3%. A slower decline was observed for 'manufacturing', which represented 20.5% of total value added in 1985 and 17.2% in 2005.

Since the groups 'services' and 'agriculture, forestry and hunting' are normally less emission intensive than 'industry' and 'manufacturing', such structural changes may partly explain the lower increase in the Brazilian GDP emission intensity compared with the variation in the emission-output ratio during the period. It is important to notice, however, that emissions from fuel-combustion represent only a fraction of the Brazilian total emissions. The panorama concerning emission intensity by economic activities differs considerably, if other sources of emissions are taken into account[46].

GDP grows positively, 'absolute' or 'strong' decoupling is said to occur, if the growth rate of the environmentally relevant variable is zero or negative. 'Relative' or 'weak' decoupling occurs when the growth rate of the environmentally relevant variable is positive, but less than the GDP growth rate (OECD, 2002: 11).

[46] According to the last Brazilian national inventory of GHG emissions, 'land use change and forestry', particularly the conversion of forests for agricultural use, represented 75.4% of the Brazilian total CO_2 emissions in 1994, estimated at 1,030 MT of CO_2-equivalent[46]. In the Brazilian government's estimations,

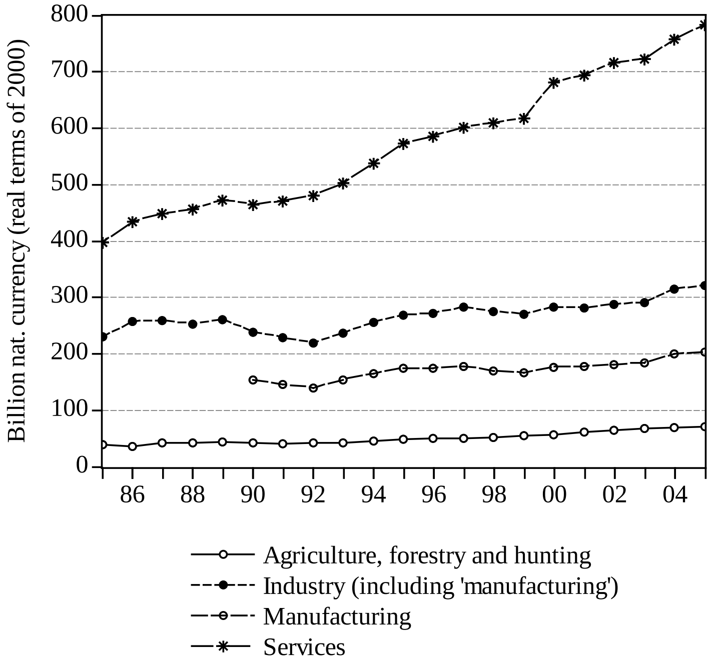

Figure 38. Brazil / Real value added by industry group (1985-2005)[47]

The development of the Brazilian CO_2 emissions by fuel type (Figure 39) indicates a significant change in the national fuel mix from 1985 to 2005. Emissions from fuel combustion increased particularly for 'coking coal' (57.5%/year)[48], 'petroleum coke' (45.5%/year) and 'natural gas' (38.9%/year), whereas emissions from 'heavy fuel oil' and 'sub-bituminous coal' were the only ones to decline, both at -1.1%/year. The most predominant fuel type in terms of emissions was 'gas / oil diesel', which saw a slight increase in its share in total emissions from 31.7% in 1985 to 32.3 in 2005. The largest increase in share in total emissions occurred for 'petroleum coke' (from 0.9% to 4.7%), 'natural gas' (from 2.6% to 11.5%) and 'motor gasoline' (10.4% to 12.2%). Shares declined considerably for 'sub-bituminous coal' (from 4.1% to 1.6%), 'heavy fuel oil' (from 18.1% to 7.1%), 'coke oven gas' (from 1.4% to 0.8%) and 'lignite brown coal' (from 1.6% to 1.0%). Together, the twelve fuel types presented in Figure 39 accounted, on average, for 88.3% of total emissions from fuel combustion from 1985 to 2005.

manufacturing industries' emissions from fuel combustion accounted for 7.2% of Brazilian total CO_2 emissions in 1994 (MCT, 2004: 87).

[47] Value added by main industry groups in national currency values and constant prices (2000) are World Bank estimates obtained from the *United Nations Common Database / Key Global Indicators*. Available at: http://data.un.org/ (accessed: 30/11/08)

[48] A significant level of emissions (i.e. at least 0.01 MT of CO_2) for this fuel type was only detected as from 1993 (IEA, 2007a).

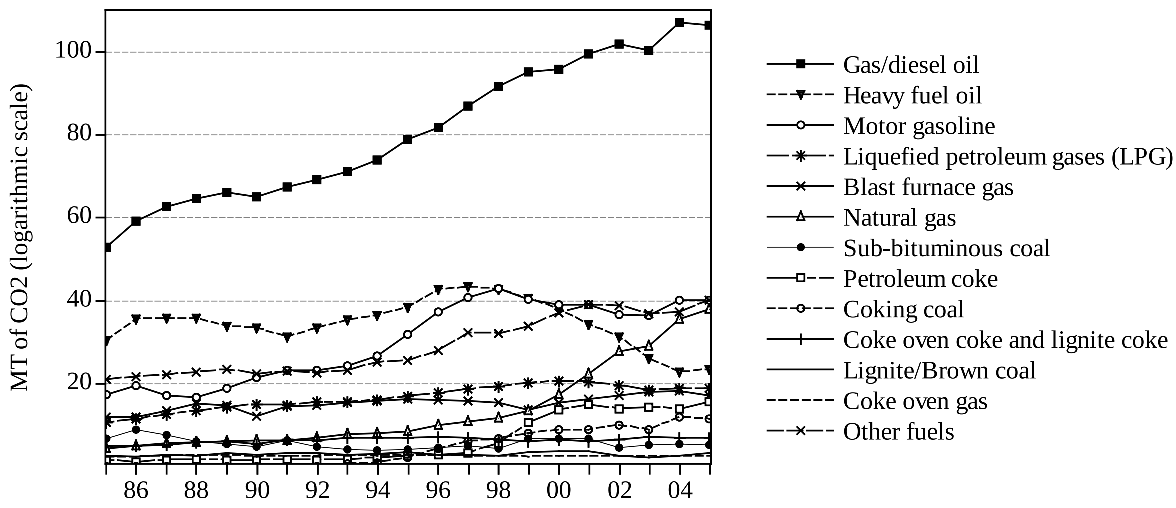

Figure 39. Brazil / CO_2 emissions by fuel type (1985-2005)

As presented in Figure 40, the Brazilian case shows a balanced trend from 1985 to 2005, taking into account its fuel mix and carbon emission factors (CEF). Following the classification presented in Annex I, emissions from high-CEF fuels grew at an annual rate of 6%/year, whereas emissions derived from low-CEF fuels grew at 7.9%/year. In contrast, fuels with medium carbon emission factors grew at 3%/year. During the whole period, emissions from fuels with medium and low emission factors predominated over those from fuels with high emission factors. Despite the increase in its manufacturing emission-output ratio from 1996 to 2005, the overall Brazilian fuel mix shows a trend of improvement towards 'cleaner' fuels in terms of carbon emission factors.

Considering specifically the covered manufacturing sector, emissions from fuels with high emission became largely predominant as from 1999 (Figure 41). Comparing emission shares in 1985 to those in 2005, the participation of fuels with high CEF remained almost stable (from 51% to 52.1%), while fuels with medium CEF had their share reduced by nearly 40% (from 41% to 25.1%). The share of fuels with low CEF, however, increased by more than 180%, from 8% in 1985 to 22.7% in 2005. Between 1997 and 2005 medium-CEF fuels contracted considerably, at a rate of -3.7%/year. The variation in the Brazilian manufacturing emission-output ratio, thus, seems to have been influenced by a substitution of medium-CEF fuels by low-CEF and, mainly, high-CEF fuels.

In the covered manufacturing branches, emissions increased particularly for 'natural gas' (53%/year), 'petroleum coke' (34%/year) and 'liquefied petroleum gases' (22%/year), whereas emissions declined for 'lignite/brown coal' (-4.8%/year) and 'sub-bituminous coal' (-4.1%/year). Apart from 'petroleum coke', the shares of all high-CEF fuels listed in Figure 42 declined from 1985 to 2005, especially for 'sub-bituminous coal' (from 11% to 1%), ‘lignite brown coal’ (from 3.1% to 0.1%) and ‘blast furnace gas’ (from 20.4% to 12%). Share in total emissions also declined considerably for ‘heavy-fuel oil’ (from 35.5% to 15.6%), which in 1985 was the most predominant source of emissions from fuel combustion. In 2005, though, the most predominant source of emissions was ‘natural gas’ (18.5%), closely followed by ‘petroleum coke’ (16.8%).

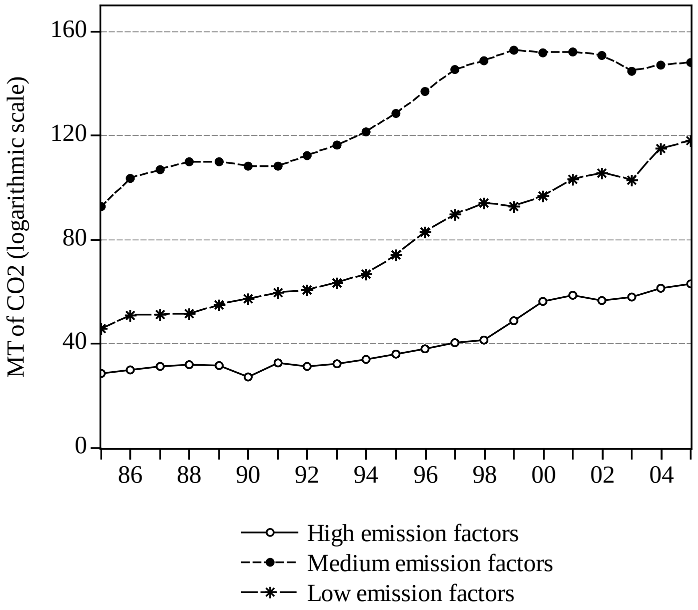

Figure 40. Brazil / CO_2 emissions by carbon emission factor (1985-2005)[49]

Fuel-mix changes towards fuels with higher carbon-emission factors explain some of the environmentally negative technological effects found in the Brazilian case, which predominated between 1996 and 2005. Also, the structural effects leading to an increase in the emission-output ratio indicates that emission-intensive branches became more important than ‘cleaner’ branches during the period. At first sight, these results seem inconsistent with the ‘clean’ development trend hypothesis. However, real manufacturing value added declined although GDP was growing at 2.6%/year. This contraction of the Brazilian manufacturing production may have contributed to a lack of financial opportunities to invest in the reduction of fuel combustion and emissions. The results are in line with the assumption that positive production growth rates are needed for ‘cleaner’ production, as a stagnating production went along with a ‘dirtier’ industrial structure and a widespread increase in the intensity of emissions per value-added unit. Hence, although no ‘clean’ development trend was identified for Brazil, the results seem consistent with the ‘clean’ development trend hypothesis

[49] For additional information on the carbon emission factor classification used, please see Annex I.

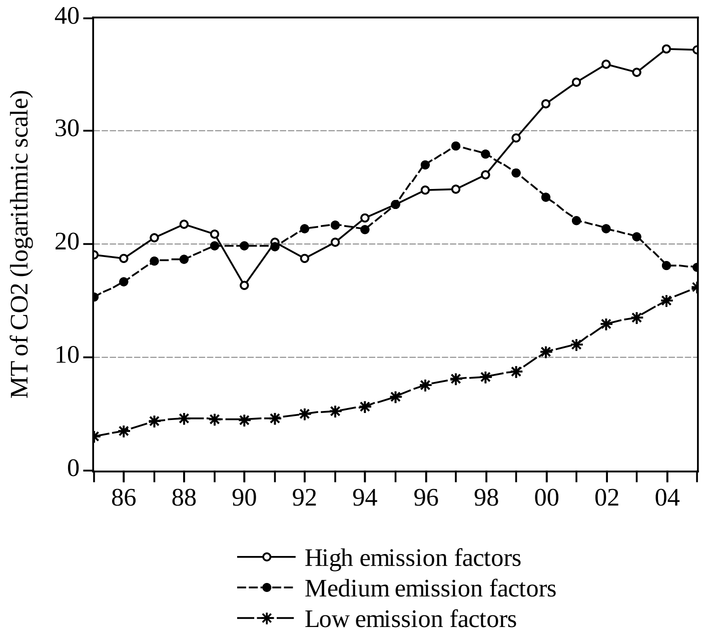

Figure 41. Brazil / Manufacturing CO_2 emissions by carbon emission factors (1985-2005)

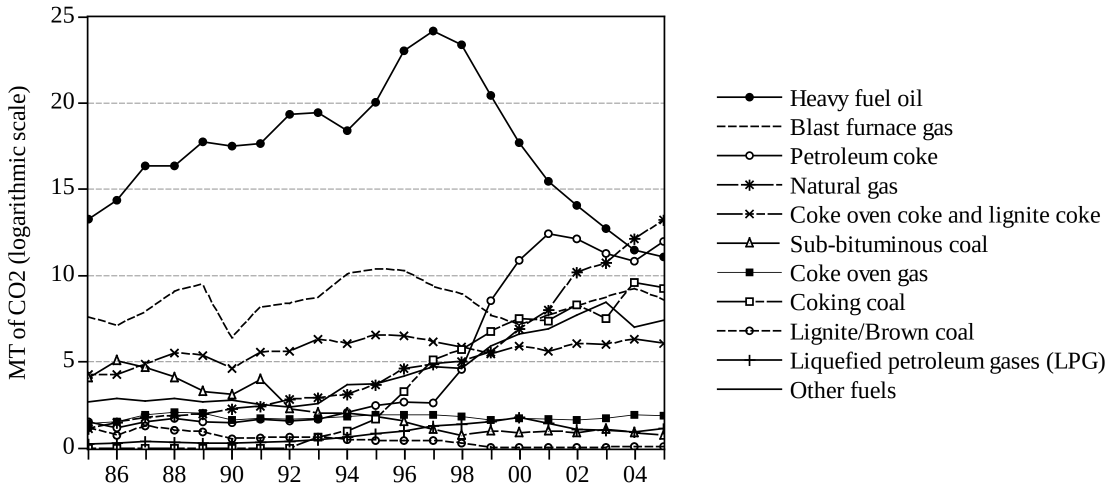

Figure 42. Brazil / Manufacturing CO_2 emissions by fuel type (1985-2005)

The ‘pollution haven’ hypothesis does not seem likely for almost all branches apart from ‘iron and steel’, which alone accounted for 51.2% of the increase in the emission-output ratio. Therefore, considering its strong growth in value added relative to the GDP growth rate during the period, as well as the allocation of its emission intensity increase to structural effects, industrial relocation could in theory be valid. However, this is a sector where natural resource endowment may play a strong role, since Brazil is a major producer of iron ore.

5.2. China

From 1985 to 2005, the Chinese GDP[50] grew at 26%/year (real terms of 2000), while its total emissions from fuel combustion increased at 9.8%/year. The slower growth of emissions compared with the GDP growth indicates a 'weak' decoupling (OECD, 2002: 11) for China. In absolute terms, total emissions in China increased by 196% from 1725 MT of CO_2 in 1985 to about 5100 MT of CO_2 in 2005 (Figure 43).

The Chinese manufacturing sector experienced a decline in its emission-output ratio at a rate of -4.6%/year from 1985 to 1993 (Figure 44), and of -5.9%/year from 1994 to 2005 (Figure 45). In contrast, the Chinese GDP emission intensity[51] declined at a rate of -3.2%/year from 1985 to 1993, but slowed down to -2.8%/year between 1994 and 2005. This gradually slower reduction of the emission-intensity for the whole Chinese economy may have derived from fewer incentives for and increasing marginal costs of investments in fuel-saving technologies. Furthermore, the increasingly concrete perspective of a Chinese participation in future international climate agreements might have driven attention to the temporary advantages of carbon-intensive, though more cost-effective, fuels, while no emission commitment has yet been set.

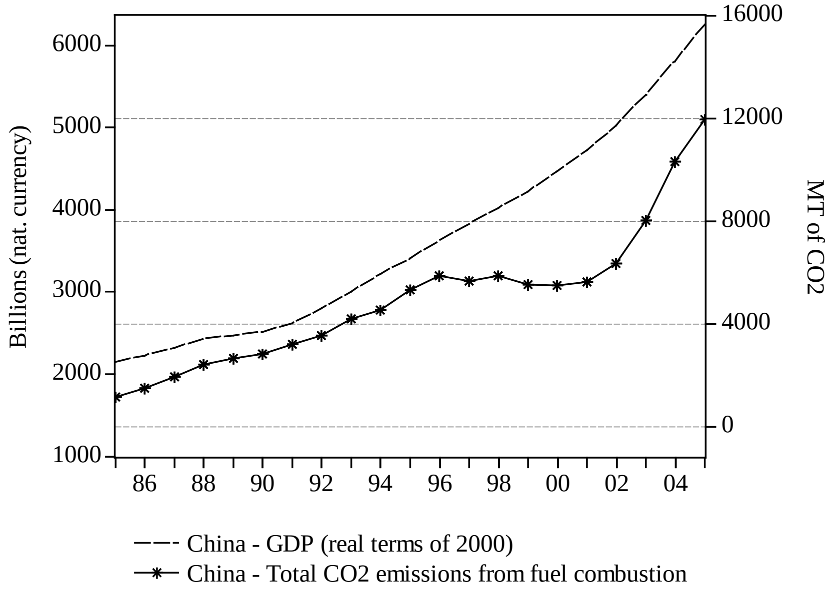

Figure 43. China / Total CO_2 emissions and real GDP (1985-2005)

[50] Gross Domestic Product (GDP) in national currency values at market prices, as well as GDP deflators are World Bank estimates obtained from the *United Nations Common Database*. Available at: http://data.un.org/ (accessed: 18/11/08).

[51] GDP emission intensity simply refers to the ratio between a country's overall emissions from fuel combustion and its real GDP at market prices.

Carbon-dioxide emissions from fuel combustion in China increased by 54.8% from 1985 to 1993, at a rate of 6.8%/year. Growth in emissions accelerated from 1994 to 2005 at a rate of 7.6%/year, leading to an increase of 83.4% relative to 1994. Although there was a positive growth in emissions, the Chinese GDP growth rates have been considerably faster.

Figure 46 shows real value added by main industry groups in China from 1985 to 2005. During this period ‘industry’ (including ‘manufacturing’) increased its share in total value added by 47.5% relative to 1985, while “services” increased its share by 7.4%. In 2005, ‘industry’ and ‘services’ represented 58% and 31% of the Chinese value added, respectively. In contrast, ‘agriculture’ lost share in value added by 65%, declining from 32% of the total Chinese value added in 1985 to nearly 11% in 2005.

Although the structural changes shown in Figure 46 indicate that the industrial sector, which is generally more emission intensive, increased its role in the GDP composition, the Chinese GDP emission intensity declined at -2.6%/year (Figure 47). Such a result may be explained by increasing returns to scale, adoption of a less carbon-intensive fuel mix, as well as improvements in terms of fuel-saving technologies and production processes.

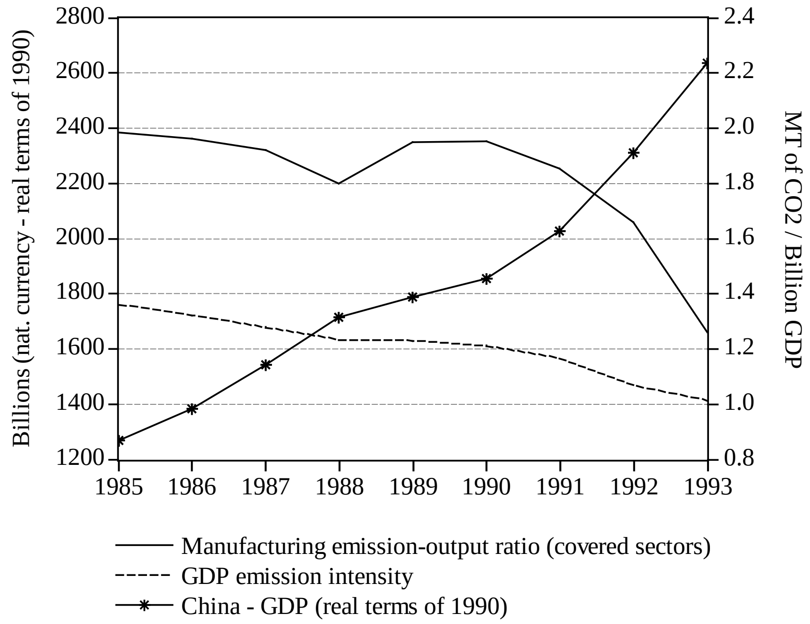

Figure 44. China / GDP, GDP emission intensity and emission-output ratio (1985-1993)

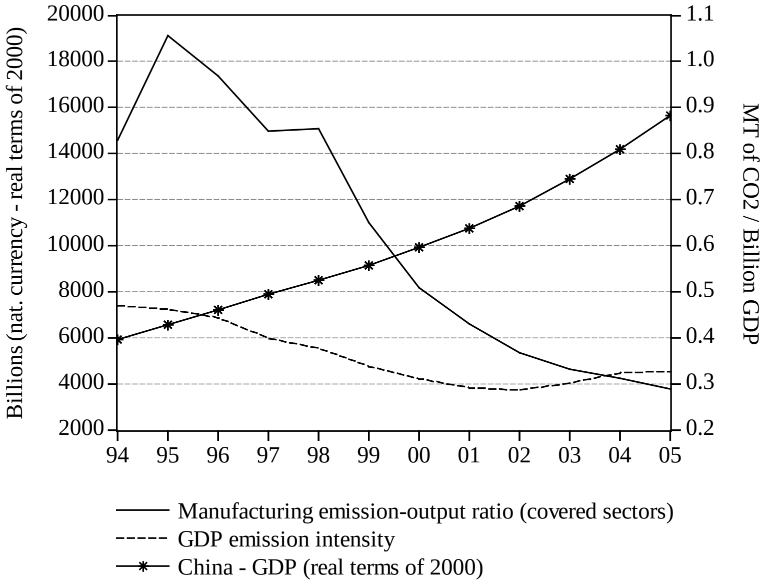

Figure 45. China / GDP, GDP emission intensity and emission-output ratio (1994-2005)

From 1985 to 2005 there were significant changes in terms of fuel mix in China as a whole (Figure 48). Although 'other bituminous coal' remained by far the most predominant fuel in emissions, its share in total emissions declined by -9.7%, from 76% in 1985 to 68% in 2005. The strongest decline in share occurred for 'heavy-fuel oil' (-57.1%). In fact, 'heavy-fuel oil' and 'other bituminous coal' were the only fuels which had their shares reduced among those listed in Figure 48.

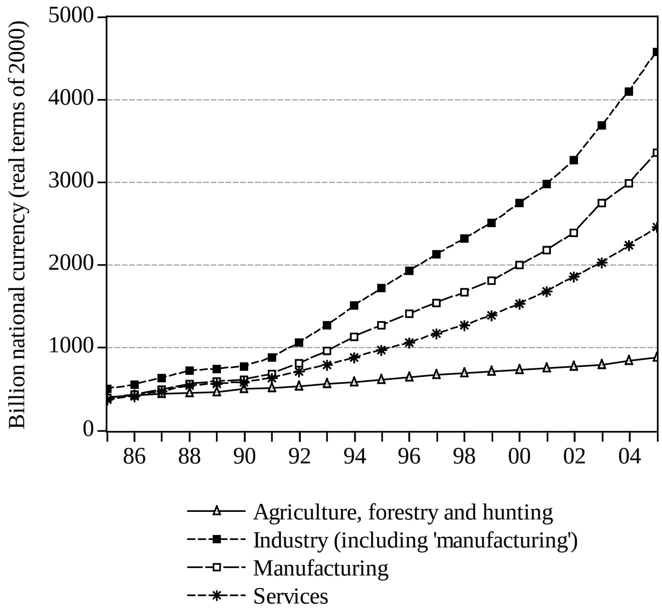

Figure 46. China / Real value added by industry group (1985-2005)[52]

[52] Value added by main industry groups in national currency values and constant prices (2000) are World Bank estimates obtained from the *United Nations Common Database / Key Global Indicators*. Available at: http://data.un.org/ (accessed: 23/02/09).

The fastest growing source of emissions from fuel combustion was 'liquefied petroleum gases' (60%/year), followed by 'blast furnace gas' (36.4%/year) and 'gas/diesel oil' (22%/year). This indicates a trend towards fuels with low carbon emission factors (CEF). On the one hand, 'liquefied petroleum gases', one of the fuels with the lowest carbon emission factor, represented only 1.3% of total emissions from fuel combustion in 2005. On the other hand, 'blast furnace gas', the most emission-intensive fuel, represented around 7.4%. The fuel with the lowest carbon emission factor, 'natural gas', was the fourth fastest growing (16%/year), but also represented only 1.8% of the Chinese emissions from fuel combustion in 2005.

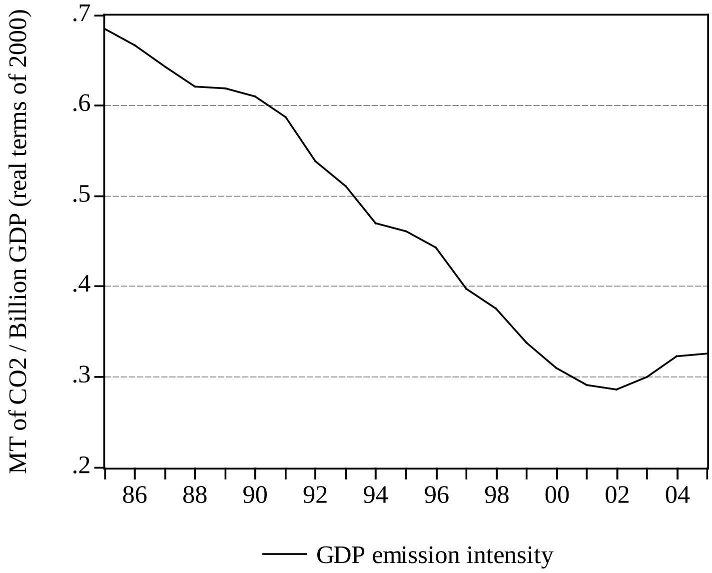

Figure 47. China / GDP intensity of emissions from fuel combustion (1985-2005)

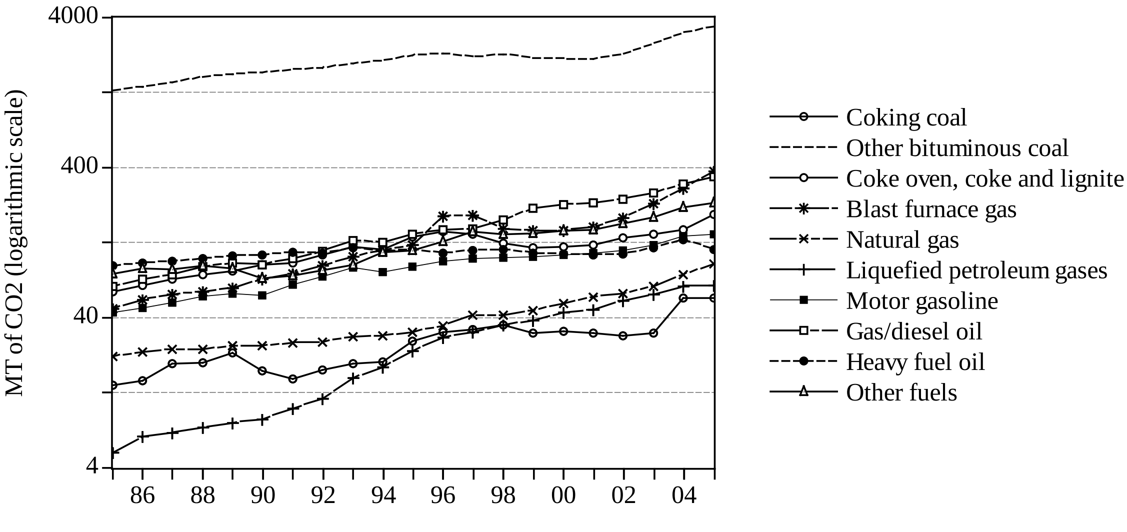

Figure 48. China / CO_2 emissions by fuel type (1985-2005)

Figure 49 presents emissions considering all fuel types covered by IEA (2007a), according to their carbon emission factors, as shown in Annex I. Emissions from fuels with a high CEF remained predominant for China, particularly between 2001 and 2005 when they began to grow faster than in previous years, at 17.3%/year. High-CEF fuels grew at 9.5%/year from 1985 to 2005, and accounted for 81.1% of the Chinese emissions from fuel combustion in 2005. Compared with their share in 1985 (82.7%), this change represented a reduction of almost 2%.

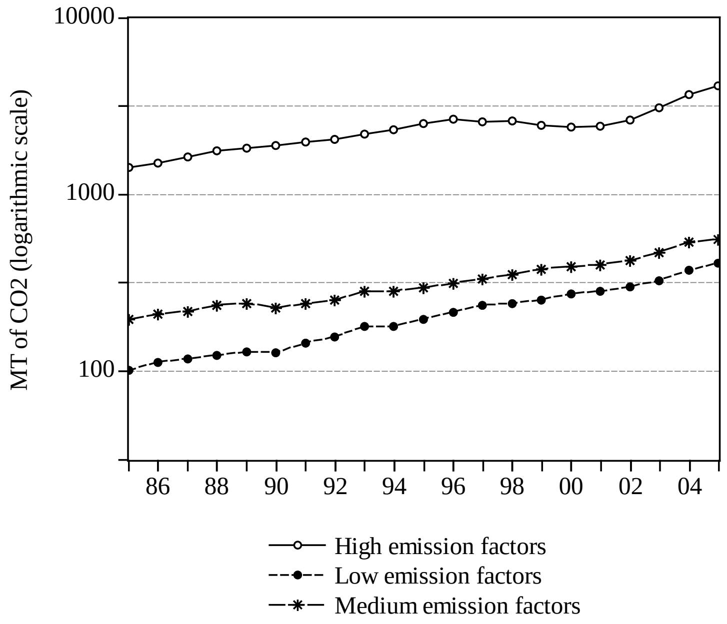

Figure 49. China / CO_2 emissions by carbon emission factor

While fuels with low CEF represented only 8% of Chinese emissions from fuel combustion in 2005, their participation increased considerably from 1985 to 2005, and their emissions grew at 15.2%/year. Fuels with a medium CEF grew slower (9.1%/year) than those with a high CEF, and accounted for 10.9% of total emissions in 2005. Despite the growth in emissions from low-CEF fuels, the fast growth of those from high-CEF fuels as from 2001 indicates a trend towards carbon-intensive fuels, mainly coal-based ones.

Specifically concerning the Chinese manufacturing sector (Figure 50), change towards low-CEF fuels for the whole reference period was stronger than what was seen for the entire Chinese economy. Emissions from low-CEF fuels increased at 84.3%/year, while those from high and medium-CEF increased at 5.7%/year and 4.9%/year, respectively. Fuels with a high CEF reduced their participation in total emissions from 1985 to 2005 by -3.9%, but still accounted for the large majority of manufacturing emissions from fuel combustion in 2005, with a share of 89.1%. Similarly, fuels with medium CEF reduced their participation by -11.4%, accounting for 6% of total emissions in 2005, while low CEF fuels increased their share in total manufacturing emissions from 0.6% in 1985 to 5% in 2005.

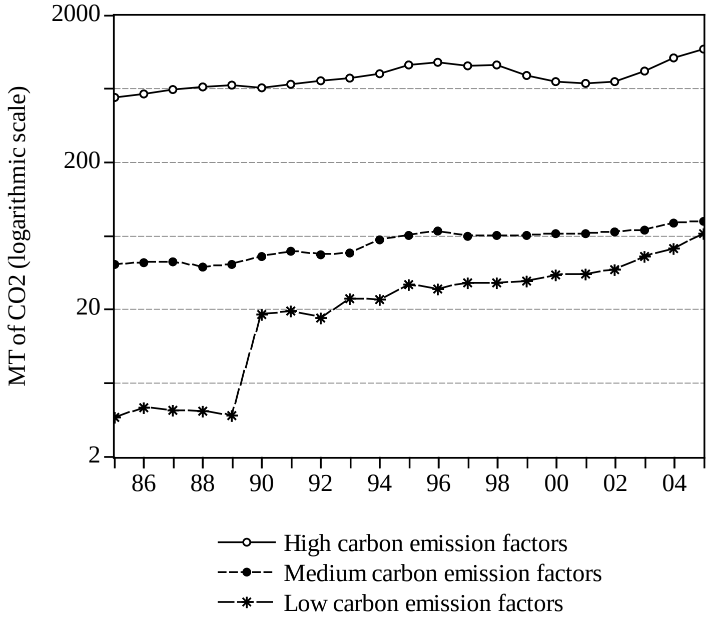

Figure 50. China / Manufacturing CO_2 emissions by carbon emission factor

As shown in Figure 51, ‘other bituminous coal’ remained the most important fuel type for the Chinese manufacturing emissions. Nevertheless, similarly to the figures for the whole Chinese economy, ‘other bituminous coal’ and ‘heavy-fuel oil’ were the only fuel types which lost share in emissions from 1985 to 2005. Substantial increases in emission shares occurred for ‘blast furnace gas’ and ‘coke oven, coke and lignite coke’, which increased their shares in total emissions from 7.7% and 8.8% in 1985 to 25.4% and 11.5% in 2005, respectively. The fuel types ‘other bituminous coal’, ‘blast furnace gas’ and ‘coke oven, coke and lignite coke’ seem to have accounted for most of the increase in manufacturing emissions as from 2002. This is worth noting, since these three fuel types are among those with the highest carbon emission factors (cf. Annex I).

Fuels with low carbon emission factors such as ‘natural gas’ and ‘liquefied petroleum gases’ had a strong increase in share and seem likely to overtake those with medium carbon emission factors in the years ahead. This conclusion is further supported, if one takes into account the stagnating trend in emissions by medium-CEF fuels from 1985 to 2005. Although such prospects are positive in terms of increased sustainability, low and medium-CEF fuels together represented 11% of the Chinese manufacturing emissions from fuel combustion in 2005. Despite the improvement in the Chinese manufacturing fuel mix from 1985 to 2005, the trend after 2002 has not been one towards cleaner fuels. Actually, ‘heavy-fuel oil’ and ‘gas/diesel oil’, i.e. medium-CEF fuels, were rather than high-CEF fuels the most affected by reductions.

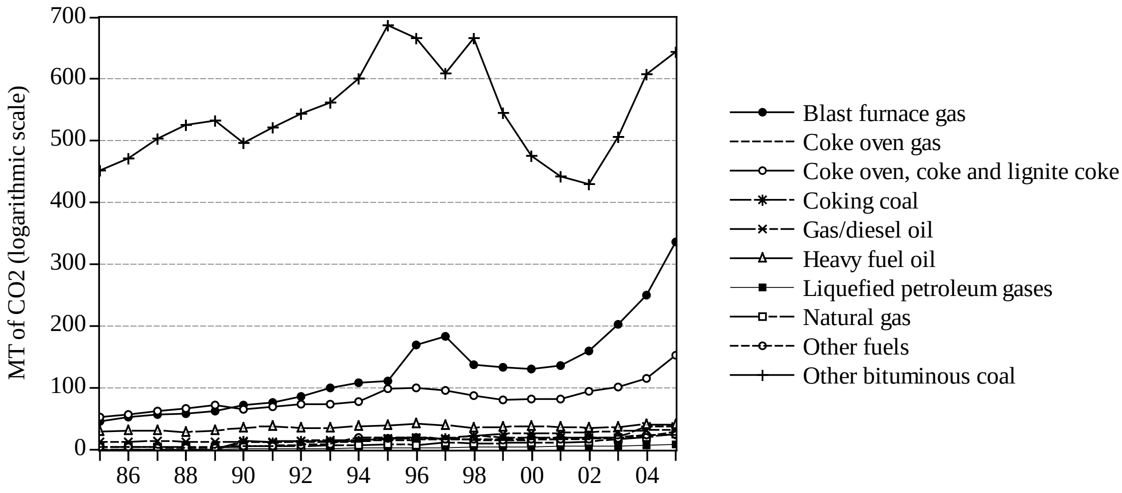

Figure 51. China / Manufacturing CO_2 emissions by fuel type (1985-2005)

In general, the results obtained for the Chinese manufacturing sector from 1985 to 2005 seem to be consistent with the 'clean' development trend hypothesis. Although from 1985 to 1993, a faster growth of emission-intensive branches is inconsistent with such a trend, a considerable reduction in the manufacturing emission-output ratio took place as from 1990. From 1994 to 2005, the most emission-intensive branches saw a decline in their shares in total value added, while branches with low and intermediate emission intensity grew faster. Meanwhile, manufacturing emission-output ratio decreased at -5.9%/year and technological effects accounted for most of its reduction, both in the first and second reference periods. Similarly to the case of the whole Chinese economy, a trend towards coal-based fuels was found for the Chinese manufacturing sector as from 2002. Combustion of the most emission-intensive fuels, mainly 'other bituminous coal' and 'blast furnace gas', have increased substantially since 2002, which seems weakens the case of a continuous 'clean' development trend.

Concerning the 'pollution haven' hypothesis, the results from the analysis of the two periods (1985 to 1993, and 1994 to 2005) seem consistent with it, however restricted to mainly three branches: 'iron and steel', 'non-metallic minerals' and 'chemical and petrochemical'.

Following the assumption that 'dirty' industrial relocation will only take place, if structural effects contribute to an increase in the emission-output ratio, the 'pollution haven' hypothesis may have been true for 'iron and steel' and 'non-metallic minerals' in the first period, and for 'chemical and petrochemical' in the second period. In both periods, branches with significant structural effects leading to an increase in the emission-output ratio also had considerable technological effects leading to its reduction.

Two explanations for this are that a) the increase in production scale within these branches took place along with investments in more fuel-efficient technologies; and b) that these branches have experienced a strong reduction of fuel combustion due to increasing returns to scale.

The first explanation would be consistent with a ‘pollution haven’ hypothesis, considering that ‘iron and steel’, ‘non-metallic minerals’ and ‘chemical and petrochemical’ are in general the most emission-intensive branches in the manufacturing sector worldwide. If the ‘pollution haven’ hypothesis was true for China, however, it would not necessarily imply a negative result in terms of environmental gains, on a global scale. Direct investment may have stimulated the adoption of more efficient technologies and production processes, which may explain the considerable reduction in emission intensity during the period. Transfer of technology during the establishment of new plants, for example, may have had a positive impact in terms of emission intensity.

The second possible explanation is probably true and, in this case, environmentally positive technological effects will be overestimated. However, it seems unlikely that increasing economies of scale alone would explain the level of emission-intensity reduction verified in these three branches. Unfortunately, the assumption of fixed economies of scale in the adopted decomposition method does not allow a further insight into the issue of returns to scale.

5.3. India

Between 1985 and 2005, the Indian GDP[53] grew at 11.1%/year (real terms of 2000), while its total CO_2 emissions from fuel combustion grew at 8.7%/year. Hence, the slower growth of emissions *vis-à-vis* the GDP growth indicates a ‘weak’ decoupling (OECD, 2002: 11) for the Indian case. In absolute terms, emissions grew from 419.3 MT of CO_2 in 1985 to 1,147.5 MT of CO_2 in 2005, representing a shift of nearly 174% (Figure 52).

Some of the discussion for India is presented in two periods, so as to account for the methodological differences in value-added data throughout the whole reference period, as explained in Table 2.

From 1985 to 1997, India experienced a GDP growth of roughly 8%/year (real terms of 1990), while total manufacturing value added grew at 13.6%/year in the same period. Between 1998 and 2004, its GDP grew at 7.1%/year (real terms of 2000), while total manufacturing value added grew at 6.6%/year. These figures indicate a nearly stationary

[53] Gross Domestic Product (GDP) in national currency values at market prices, as well as GDP deflators are World Bank estimates obtained from the *United Nations Common Database*. Available at: http://data.un.org/ (accessed: 18/11/08).

trend in the share of the manufacturing sector in the Indian GDP formation. Such stagnation relative to other sectors might have stimulated consumption of low-cost fuels with higher carbon contents, as well as discouraged investments in cleaner technologies and fuel mix.

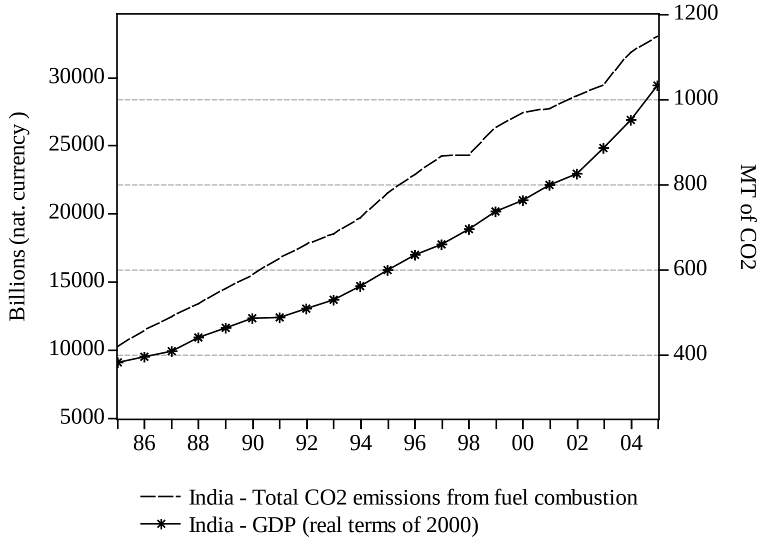

Figure 52. India / Total CO_2 emissions and real GDP (1985-2005)

Nevertheless, in both periods annual growth rates of CO_2 emissions in the covered manufacturing branches were considerably slower than their value added growth rates. From 1985 to 1997, emissions grew at 5.1%/year, while value added grew at 13.1%/year. From 1998 to 2004, emissions grew at 2%/year, whereas the real value added growth rate equalled 4.6%/year. As in the case of the overall economy, the covered branches experienced a 'weak' decoupling between their value added and CO_2 emissions from fuel combustion in both periods.

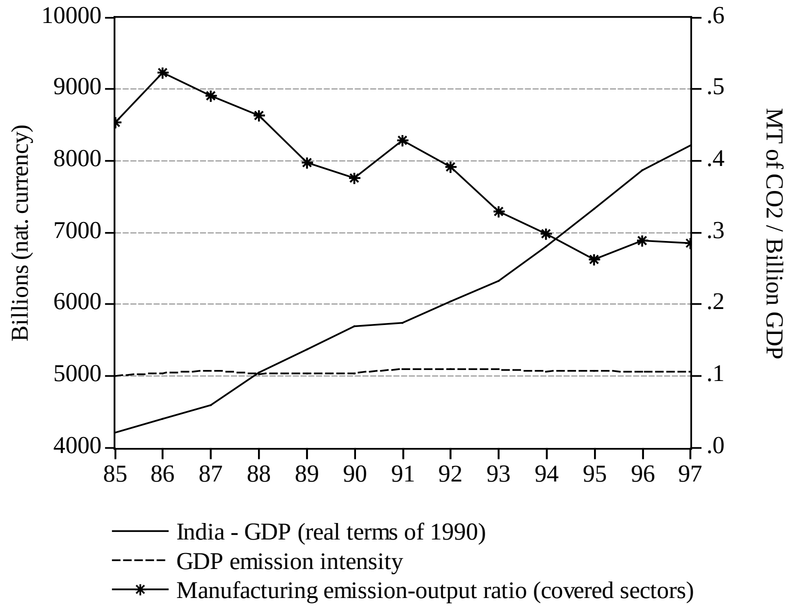

Figure 53. India / GDP, GDP emission intensity and emission-output ratio (1985-1997)

From 1985 to 1997, the emission-output ratio declined at -3.1%/year, whereas from 1998 to 2004, it declined at -2%/year. In contrast, the Indian GDP emission intensity increased at 0.5%/year between 1985 and 1997 (Figure 53), while from 1998 to 2004, it declined at -1.7%/year (Figure 54).

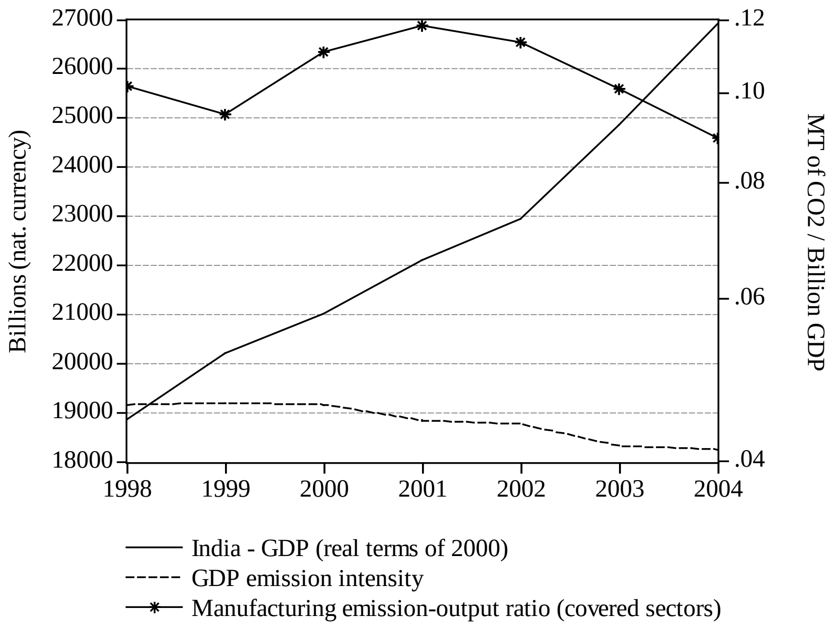

Figure 54. India / GDP, GDP emission intensity and emission-output ratio (1998-2004)

The nearly stagnating trend in the share of the manufacturing sector in the Indian GDP from 1985 to 2005 is confirmed by Figure 55, showing real value added by major economic sectors. The share of ‘agriculture, forestry and hunting’ in total value added declined from 36% in 1985 to 20% in 2005. The industrial sector accounted for nearly 24% of the Indian total value added in 1985, having remained almost stable until 2005, with a 26% share. In contrast, ‘services’ became the most predominant sector, rising from 40% in 1985 to 54% of the Indian total value added in 2005. Considering its relatively low emission intensity compared with the other two sectors, the much faster growth of ‘services’, particularly as from 2000, seems helpful to explain part of the reduction in the emission intensity of the Indian GDP.

In addition, the mix of fuels in India saw considerable changes from 1985 to 2005, as presented in Figure 56. The fuel category ‘other bituminous coal’ remained the largest source of emissions in India, increasing its share in total CO_2 emissions from 54% in 1985 to 59% in 2005. The fuel with the strongest decline in share was ‘coking coal’ (-64%), followed by ‘coke oven, coke and lignite coke’ (-53.2%), ‘blast furnace gas’ (-45.2%) and ‘heavy-fuel oil’ (-45%). Apart from the latter, these fuels are among the most carbon intensive ones. Hence, these changes also contributed to reduce the Indian GDP emission intensity.

The fastest growing fuel from 1985 to 2005 was ‘natural gas’ (38%/year), followed by ‘liquefied petroleum gases’ (36.5%/year). These fuels had by far the largest increases in share (213% and 204%, respectively), together with ‘lignite brown coal’ (79%), ‘other kerosene’ (66.5%) and ‘motor gasoline’ (39%). Apart from ‘lignite brown coal’, these fuels have relatively low carbon emission factors. Thus, such fuel-mix changes also contributed to the reduction in the emission intensity of the Indian GDP from 1985 to 2005 (Figure 57).

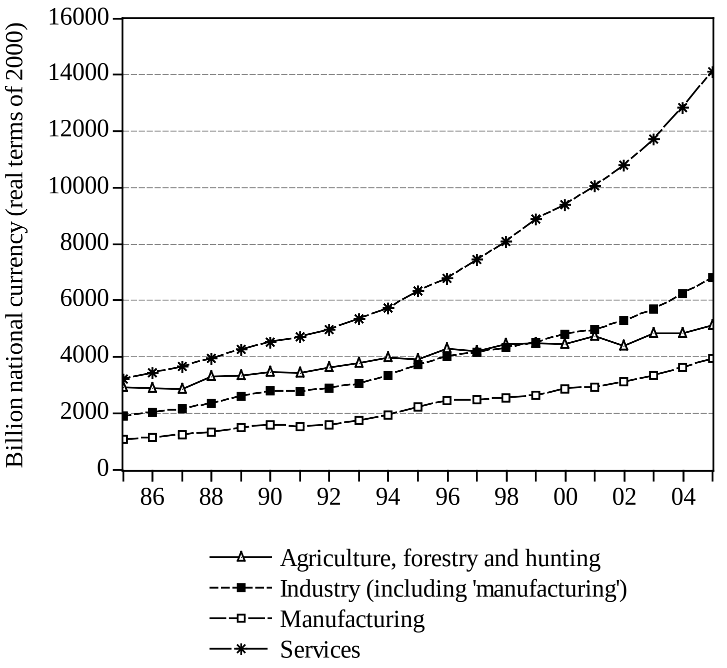

Figure 55. India / Real value added by industry group (1985-2005)[54]

Figure 58 classifies all fuels covered in IEA (2007a) for India by carbon emission factor (cf. Annex I). Emissions from fuels with low CEF grew much faster (28.3%/year) than those from fuels with high (8.2%/year) and medium CEF (5.8%/year). Although the Indian economy followed a positive trend in terms of lower emission intensity, the share of high-CEF fuels in total CO_2 emissions remained almost the same between 1985 (71%) and 2005 (70%). The share of low-CEF fuels in total emissions increased from 4% to 11%, whereas that of medium-CEF fuels declined from 24% to 19%. Thus, changes in the Indian fuel mix from 1985 to 2005 were characterised by the substitution of medium-CEF by low-CEF fuels[55], while the share of high-CEF fuels remained almost constant.

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[54] Value added by main industry groups in national currency values and constant prices (2000) are World Bank estimates obtained from the *United Nations Common Database / Key Global Indicators*. Available at: http://data.un.org/ (accessed: 23/02/09)

[55] Shares were calculated based in the fuels listed on Figure 56, with the exception of the category ‘other fuels’. This category represented 3.6% of the total Indian emissions in 2005 and includes ‘refinery gas’, ‘paraffin waxes’, ‘lubricants’, ‘non-specified fuels’, ‘natural gas liquids’, ‘naphtha’, ‘gas works gas’ and ‘BKB/peat briquettes’.

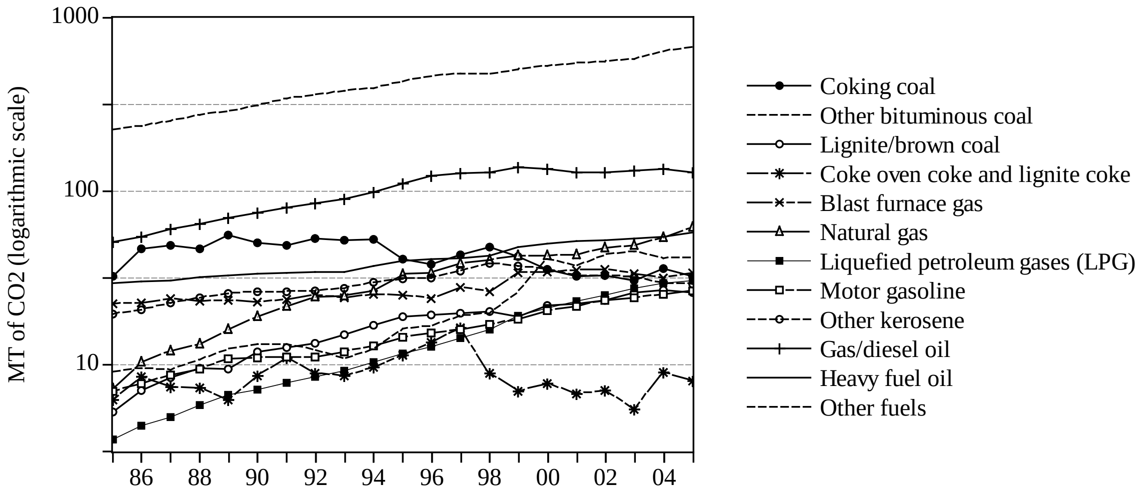

Figure 56. India / CO_2 emissions by fuel type (1985-2005)

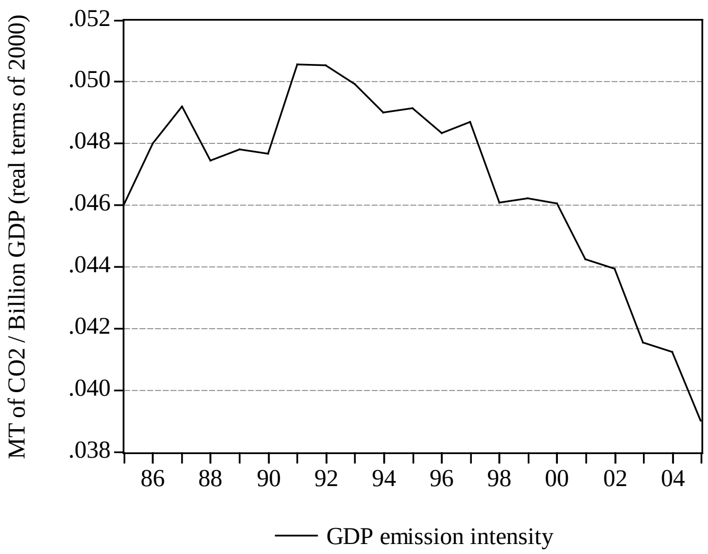

Figure 57. India / GDP intensity of emissions from fuel combustion (1985-2005)

The Indian manufacturing branches saw a scenario quite different from the overall economy regarding fuels classified by emission factor (Figure 59). While a relevant amount of emissions (at least 0.01 MT of CO_2) for low-CEF fuels was only detected as from 1997, it declined at -6.3%/year from then to 2005. In addition, high-CEF fuels experienced the fastest growth (3.6%/year), whereas medium-CEF fuels grew slower (3%/year). Compared with 1985, high-CEF fuels increased their shares in total emissions from 84.1% to 85% in 2005, while low-CEF increased from zero to 0.02%[56]. The share of medium-CEF fuels declined

[56] Shares were calculated based on the fuels listed in Figure 56, with the exception of the category ‘other fuels’. This category represented 0.2% of the Indian manufacturing emissions in 2005 and includes the fuel categories mentioned in the previous footnote.

from 16% to 15%. All in all, these figures indicate a trend towards more emission-intensive fuels in the Indian manufacturing sector.

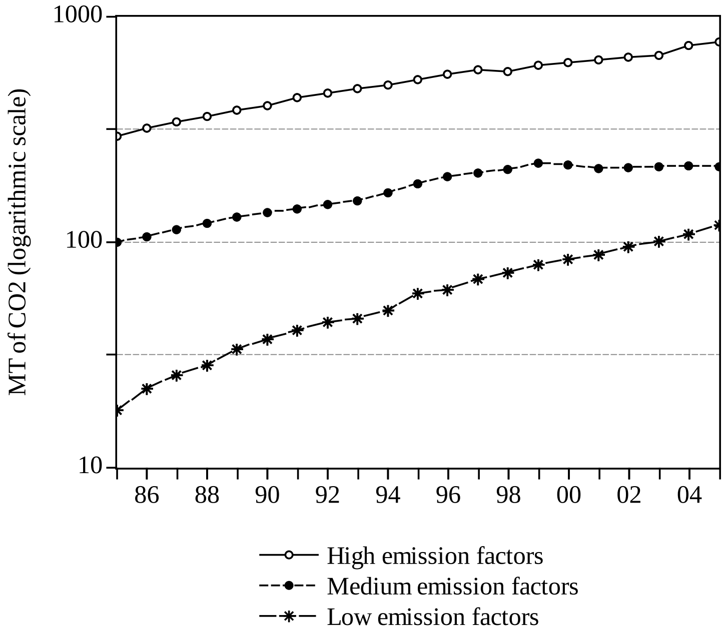

Figure 58. India / CO_2 emissions from fuels by carbon emission factor (1985-2005)

As shown in Figure 60, the high-CEF fuels ‘other bituminous coal’ and ‘blast furnace gas’ remained the major contributors to the increase in manufacturing emissions, particularly as from 1997. The largest contributor to the increase in emissions from high-CEF fuels in India was ‘other bituminous coal’, which from 1985 to 2005 saw its emissions growing at 5.4%/year and represented 52% of the total emissions covered in 2005. The fastest growth rate in emissions occurred for ‘lignite/brown coal’ (15.5%/year), followed by ‘gas/diesel oil’ (2.9%/year), ‘heavy fuel oil’ (2.8%/year) and ‘blast furnace gas’ (2.5%/year).

Although ‘lignite and brown coal’ and ‘other bituminous coal’ are among the fuels with the highest carbon emission factors, they were the only ones to experience an increase in their shares in total emissions[57]. The only fuel to experience a decline in emissions from combustion was ‘coking coal’, which contracted at -2%/year and represented 2.6% of the total Indian manufacturing emissions in 2005. Emissions from the least emission-intensive fuels, such as ‘natural gas’ and ‘liquefied petroleum gases’, remained negligible throughout the period.

[57] Apart from the category ‘other fuels’. See previous footnote.

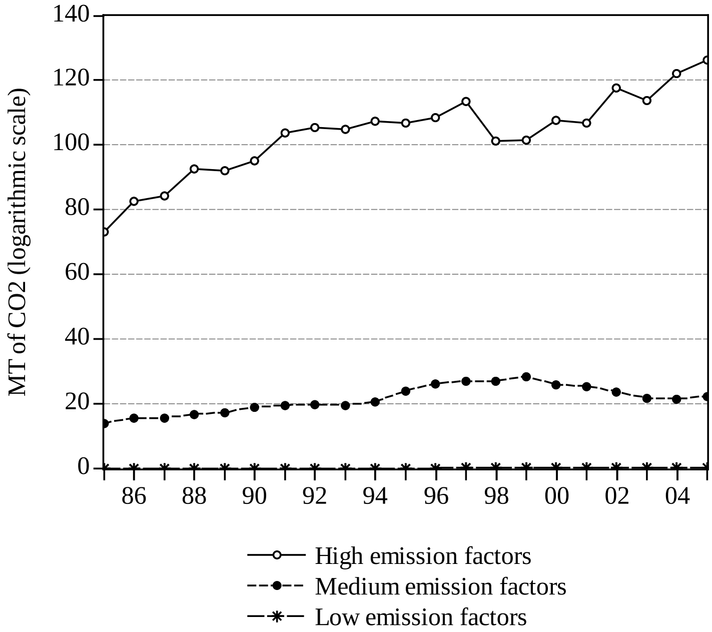

Figure 59. India / Manufacturing CO_2 emissions by carbon emission factor (1985-2005)

The results obtained for the Indian manufacturing from 1985 to 2005 seem inconsistent with the 'clean' development trend hypothesis. Although the Indian manufacturing emission-output ratio declined, changes in value-added shares actually indicate a dirty trend. In addition, the analysis of the fuel-mix changes in the covered manufacturing sector indicates a trend towards fuels with high-carbon emission factors such as 'other bituminous coal'. This indicates that the adoption of fuel-saving technologies and production processes reflected in the technological effects may have influenced the decline in the Indian emission-output ratio, which together with increasing returns to scale may explain the environmentally positive technological effects found in the decomposition results.

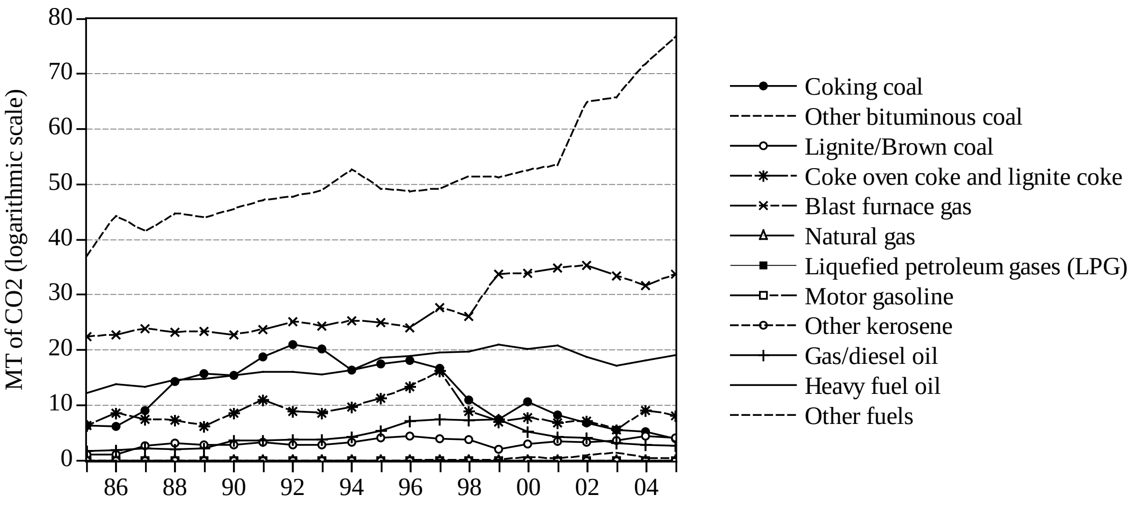

Figure 60. India / Manufacturing CO_2 emissions by fuel type (1985-2005)

The results considering the period between 1985 and 2005 seem consistent with the 'pollution haven' hypothesis for the Indian manufacturing sector, particularly concerning the branch 'iron and steel', which concentrated the bulk of the environmentally negative structural effects. Although not as pronounced as for 'iron and steel', the results obtained for 'chemical and petrochemical' and 'non-ferrous metals' from 1985 to 1997 as well as 'non-metallic minerals' from 1998 to 2004 also seem consistent with the 'pollution haven' hypothesis. The technological effects leading to a decline in emissions were also mainly concentrated on these branches.

5.4. Mexico

The Mexican real GDP[58] grew at 3.3%/year from 1985 to 2005 (real terms of 2000), whereas its total emissions from fuel combustion increased at 2.7%/year. Hence, the Mexican economy went through a 'weak' decoupling between emissions and GDP (OECD, 2002: 11). Total emissions increased by 54.5%, from 252.1 MT of CO_2 in 1985 to 389.4 MT of CO_2 in 2005 (Figure 61).

From 1987 to 2003, the total manufacturing value added grew at 4.3%/year, while the GDP growth rate equalled 3.7%/year (real terms of 2000). The faster growth in manufacturing value added compared with GDP growth indicates an increasing relevante of this sector to the Mexican economy.

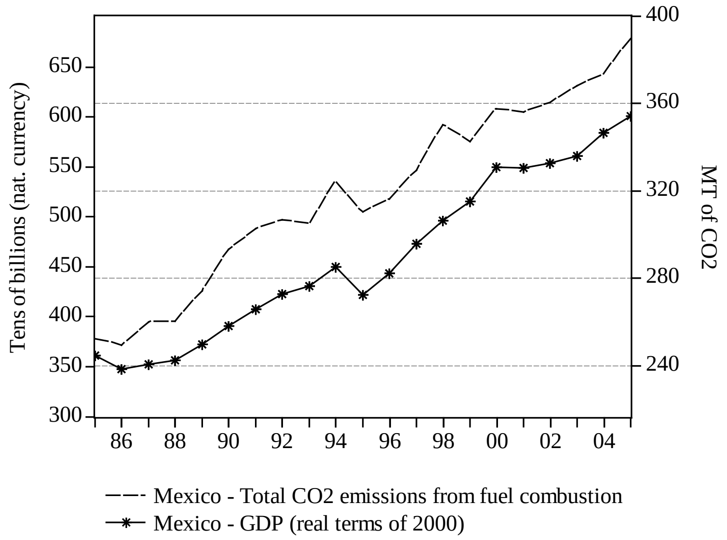

Figure 61. Mexico / Total CO_2 emissions and real GDP (1985-2005)

From 1987 to 2003, total CO_2 emissions in the covered manufacturing branches declined at -2.4%/year, while their total value added increased at 4.5%/year. Therefore, a

[58] Gross Domestic Product (GDP) in national currency values at market prices, as well as GDP deflators are World Bank estimates obtained from the *United Nations Common Database*. Available at: http://data.un.org/ (accessed: 17/06/09).

‘strong’ decoupling between emissions from fuel combustion and value added occurred for these manufacturing branches. As shown in Figure 62, the covered manufacturing emission-output ratio declined much faster (-4%/year) than the Mexican GDP emission intensity (-0.7%/year).

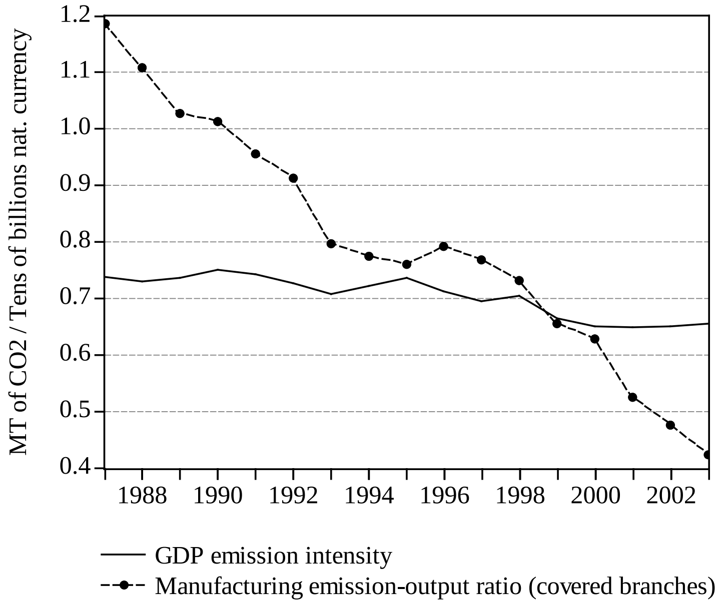

Figure 62. Mexico / GDP emission intensity and emission-output ratio (1987-2003)

Value-added shares by main industry groups remained relatively stable from 1985 to 2005, apart from ‘agriculture, forestry and hunting’, which saw a decline of its share in total value added from 7.2% in 1985 to 5.4% in 2005 (Figure 63). In contrast, ‘services’, which represented 66.4% of the total value added in 1985, increased its share to 67.7% in 2005. The more general category ‘industry’ and its sub-category ‘manufacturing’ increased their shares from 26.4% and 22.6% in 1985 to 26.9% and 24.3% in 2005, respectively.

Changes in the total Mexican fuel mix from 1985 to 2005 are presented in Figure 64. During this period, the fastest-growing fuel in terms of emissions was ‘sub-bituminous coal’ (49.4%/year), followed by ‘refinery gas’ (27%/year), ‘motor gasoline’ (4.4%/year) and ‘natural gas’ (4.2%/year). Negative growth rates were found for ‘other kerosene’ (-4.1%), ‘coke oven, coke and lignite coke’ (-2%/year) and ‘heavy-fuel oil’ (0.5%/year). In 2005, ‘natural gas’ had the largest share in total emissions (25.3%), followed by ‘motor gasoline’ (22%), ‘heavy-fuel oil’ (16.3%), ‘gas/diesel oil’ (13.7%) and ‘liquefied petroleum gases’ (7.7%). These fuels together represented 85% of total Mexican CO_2 emissions from fuel combustion. All of them have low carbon emission factors apart from ‘heavy-fuel oil’ and ‘gas/diesel oil’, which have medium carbon emission factors (cf. Annex I).

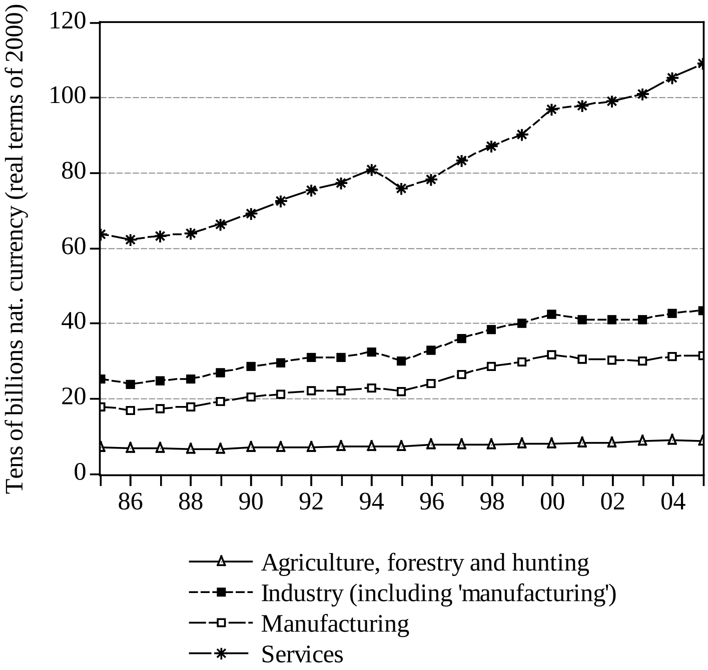

Figure 63. Mexico / Real value added by industry group (1985-2005)[59]

Mexican fuel emissions classified by carbon emission factor (cf. Annex I) are outlined in Figure 65. While high-CEF fuels grew at 12.4%/year from 1985 to 2005, fuels with low and medium CEF grew at 4%/year and 0.3%/year, respectively. Despite the faster growth of emissions from high-CEF fuels, their share in total emissions equalled 7.1% in 2005, whereas the share of fuels with low CEF accounted for 58.2% in that same year. Medium-CEF fuels were the only ones with a declining share during the period, from 45.7% in 1985 to 31.6% in 2005. Therefore, absolute emissions from medium-CEF fuels remained almost stable from 1985 to 2005, which indicates their substitution by low- and, particularly, high-CEF fuels. The predominance and increasing share of low-CEF fuels in total emissions may help explaining the decline in the Mexican GDP emission intensity.

[59] Value added by main industry groups in national currency values and constant prices (2000) are World Bank estimates obtained from the *United Nations Common Database / Key Global Indicators*. Available at: http://data.un.org/ (accessed: 23/02/09)

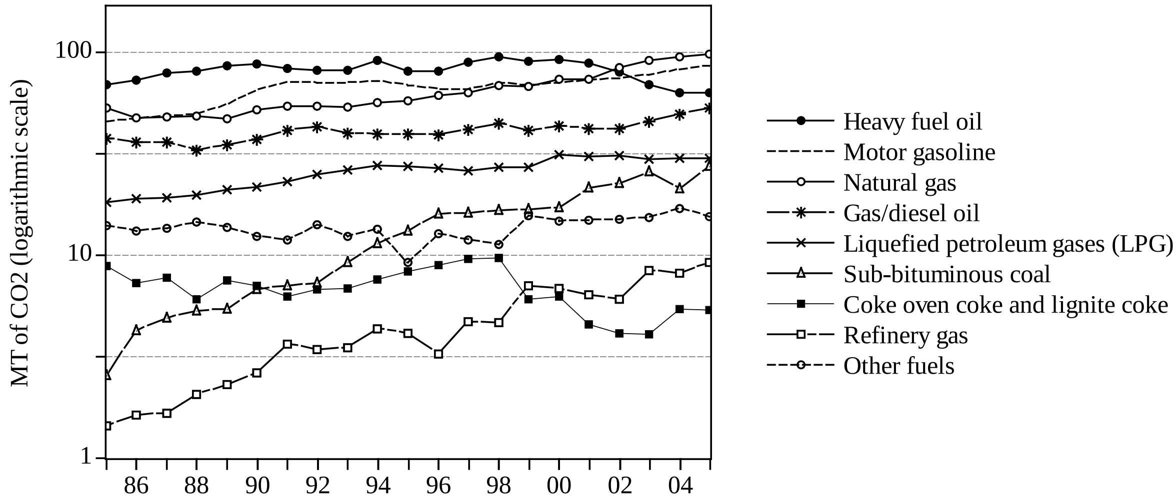

Figure 64. Mexico / CO_2 emissions by fuel type (1985-2005)

Figure 66 shows emissions from the covered Mexican manufacturing branches by carbon emission factor. All categories saw a decline in absolute emissions from 1985 to 2005, although the total manufacturing value added grew at 4.3%/year from 1987 to 2003. From 1985 to 2005, emissions of the covered branches declined at -1.3%/year. High-CEF fuels experienced the fastest decline (-1.9%/year), followed by fuels with medium CEF (-1.7%/year), and finally by low-CEF fuels (-0.8%/year). As a result, low-CEF fuels increased their share in the total covered emissions from 49.7% in 1985 to 56.2%, whereas fuels with high and medium CEF saw a decline in their shares from 21.1% and 29.2% in 1985 to 17.8% and 26% in 2005.

The fuel mix in the covered manufacturing branches mostly consisted of three fuel types: ‘natural gas’, ‘heavy-fuel oil’ and ‘coke oven, coke and lignite coke’, which together represented 95% of the total emissions in 2005. From 1985 to 2005, only ‘sub-bituminous coal’ and ‘gas/diesel oil’ saw positive growth rates, but together represented only 3.6% of the total emissions in 2005. Apart from ‘petroleum coke’, for which a relevant level of emissions was only detected as from 1999, the fastest declining fuels were ‘coke oven, coke and lignite coke’ (-2.2%/year), ‘heavy-fuel oil’ (-1.8%/year) and ‘natural gas’ (-0.8%/year). Hence, besides having experienced a decline in absolute emissions from 40.41 MT of CO_2 in 1985 to 29.95 MT of CO_2 in 2005, changes in the fuel mix of the covered manufacturing branches indicate a trend towards cleaner fuels, particularly towards ‘natural gas’.

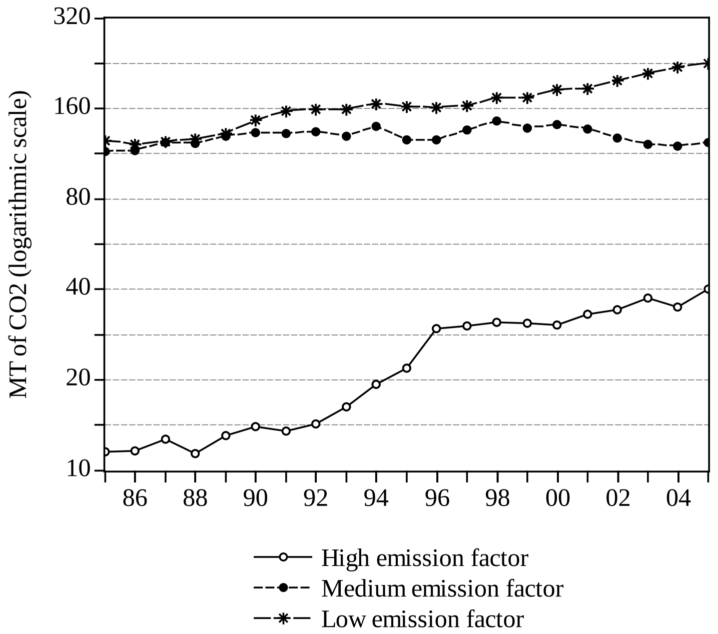

Figure 65. Mexico / CO_2 emissions by carbon emission factor (1985-2005)

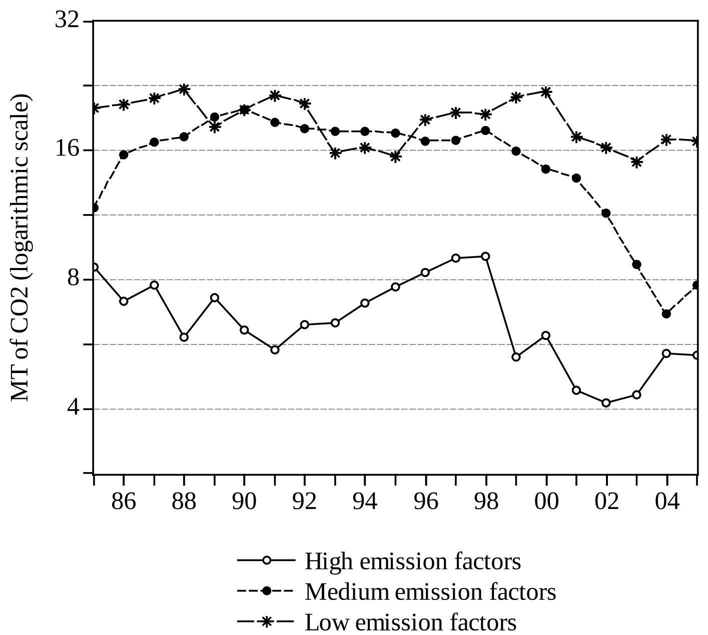

Figure 66. Mexico / Manufacturing CO_2 emissions by carbon emission factor (1985-2005)

The results for the covered manufacturing branches seem consistent with a 'clean' development trend in terms of fuel combustion. From 1987 to 2003 emission-intensive branches lost share in the total value added to cleaner ones, whereas the manufacturing emission-output ratio declined considerably and at a much faster rate than the ratio between the Mexican national emissions and the GDP.

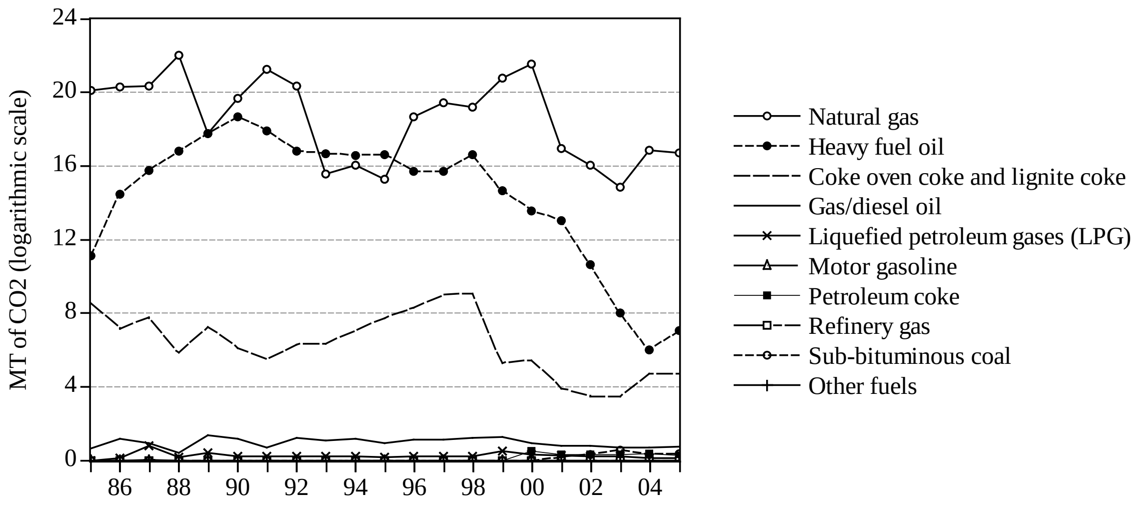

Figure 67. Mexico / Manufacturing CO_2 emissions by fuel type (1985-2005)

The results for Mexico seem consistent with the 'pollution haven' hypothesis for any of the covered branches. As a whole, structural effects contributed to a reduction in the emission-output ratio. The only two branches with some increase of emission intensity attributed to structural effects were 'food and tobacco' and 'machinery', which simultaneously were among the least emission-intensive branches. In addition, the results for the most emission-intensive branches indicate structural and technological effects contributing to a decline in the emission-output ratio.

5.5. Contrasting results across countries

Even though direct cross-country comparisons are restricted by methodological differences (c.f. section 3.2), branch and time coverage, contrasting some results allows for a general performance assessment of the manufacturing sectors in the covered countries.

Total amounts of manufacturing emissions by country are shown in Figure 68. Between 1985 and 2005 the Chinese total manufacturing emissions amounted to, on average, 3.2 times as much as those from Brazil, India and Mexico together. During this period, China ranked first in terms of manufacturing emission growth (5.4%/year), followed by Brazil (5%/year), India (3.8%/year) and Mexico (-1.3%/year), which was the only country with a reduction in CO_2 emissions from fuel combustion.

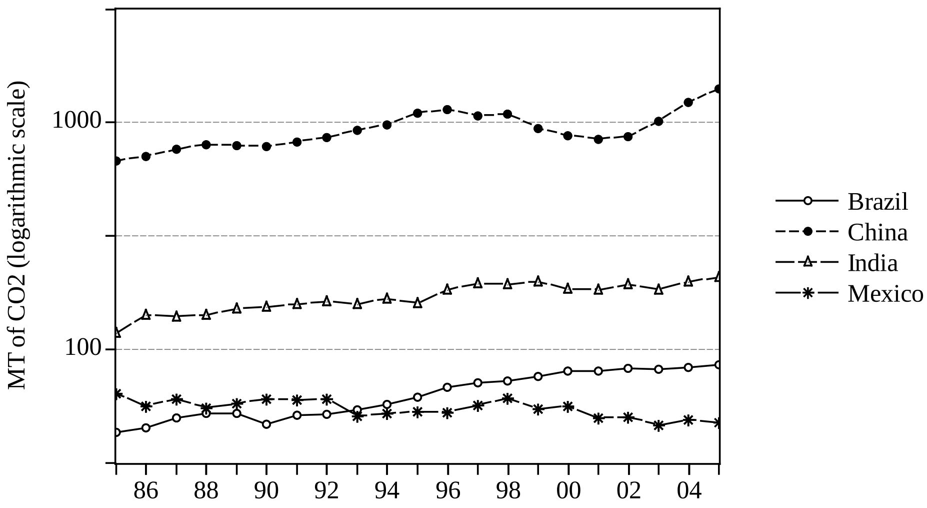

Figure 68. Manufacturing emissions by country (1985-2005)

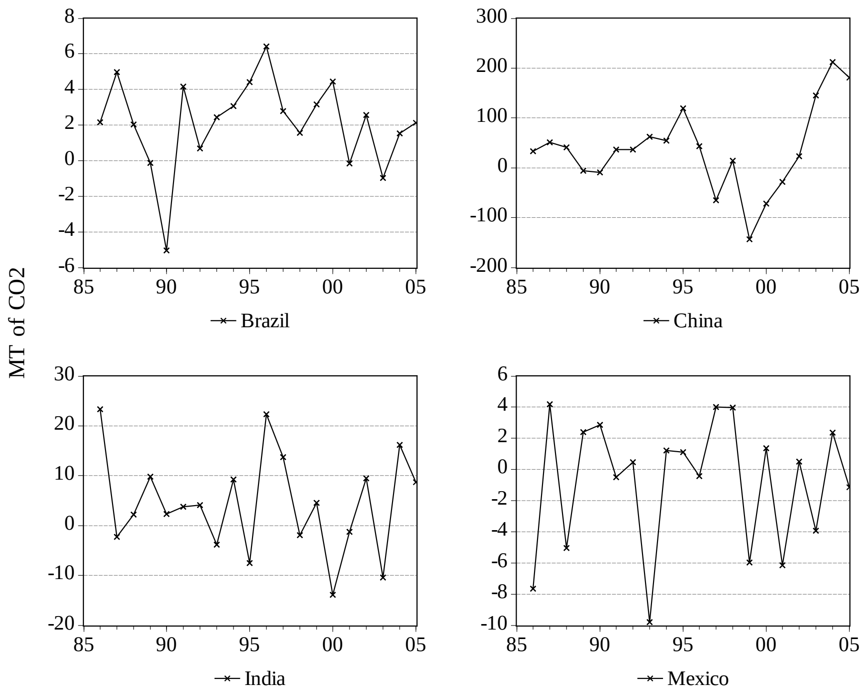

Figure 69. Manufacturing emission variation by country (1985-2005)

As shown in Figure 69, a considerable decline in manufacturing emissions occurred in China between 1995 and 1999. This reduction, however, was followed by persistently high emission growth rates until 2004. Individually and in proportional terms, the year-to-year variation in manufacturing emissions has been substantial for all countries, particularly for China and Mexico (Figure 69). In absolute terms, however, the variation in the Chinese manufacturing emissions makes those from the other three countries almost negligible, due to large differences in scale.

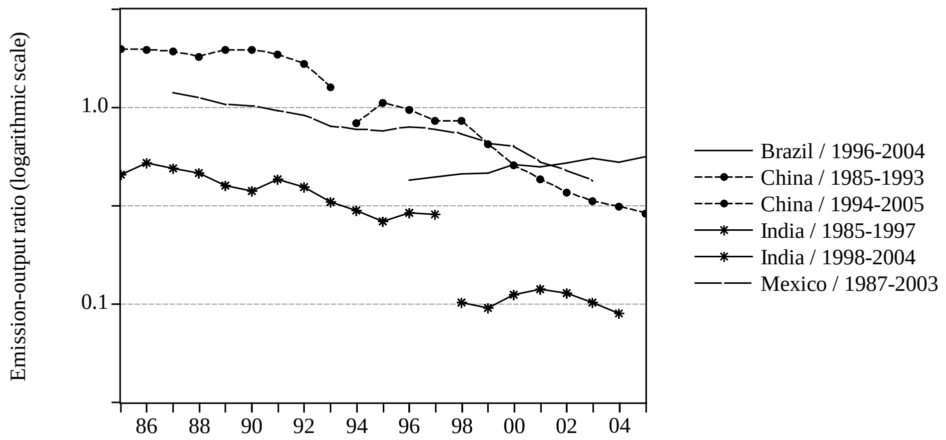

Figure 70. Emission-output ratio by country (1985-2005)

Apart from the Brazilian case, all countries saw a reduction in their manufacturing emission-output ratios (Figure 70). Environmentally negative structural effects predominated over technological effects only in the Brazilian case (Table 15), which was also the only country where manufacturing value added declined. This negative relation was similarly identified at the branch level for all countries and might reflect a lack of financial opportunities to invest in the reduction of emissions from fuel combustion.

Table 15. Decomposition results by country (1985-2005)

Country / period	ΔStructural	ΔTechnological	ΔTotal
Brazil / 1996 – 2005	0.1133 (84.9%)[60]	0.0201 (15.1%)	0.1334 (100%)
China / 1985 – 1993	0.2220 (-30.7%)	-0.9453 (130.7%)	-0.7233 (100%)
China / 1994 – 2005	-0.0995 (18.4%)	-0.4414 (81.6%)	-0.5410 (100%)
India / 1985 – 1997	0.0140 (-8.34%)	-0.1822 (108.34%)	-0.1682 (100%)
India / 1998 – 2004	0.0331 (-269.78%)	-0.0453 (369.78%)	-0.0123 (100%)
Mexico / 1987 – 2003	-0.2044 (26.75%)	-0.5597 (73.25%)	-0.7641 (100%)

Although structural effects had a negative impact on China from 1985 to 1993, they reverted from 1994 to 2005 and contributed to reduce China's emission-output ratio. Structural effects also contributed to a decline in the emission-output ratio in Mexico from 1987 to 2003. India saw environmentally negative structural effects from 1985 to 2005; however, stronger positive technological effects made possible a reduction of its emission-output ratio in the aftermath. In general, technological effects played an important role in the reduction of the emission-output ratio, except for Brazil (Table 15).

[60] Percentages in brackets represent the relative values of manufacturing emissions attributed either to technological or structural effects in relation to the emission-output ratio variation (ΔTotal).

From a branch-level perspective, and considering all the four covered countries, structural effects with an environmentally negative impact occurred mainly in ‘iron and steel’ and ‘non-metallic minerals’. These were also the most emission-intensive manufacturing branches during the period (Table 16). Technological effects with a positive environmental impact were mainly restricted to ‘chemical and petrochemical’ and, particularly, ‘iron and steel’. These branches, together with ‘non-metallic minerals’, were the largest net contributors to the decline of the manufacturing emission-output ratio in the covered countries.

Table 16. Ranking of the most emission-intensive branches by country

Country / reference year	1st	2nd	3rd
Brazil / 1996 (base year)	Non-ferrous metals	Iron and steel	Non-metallic minerals
Brazil / 2005 (end year)	Non-ferrous metals	Iron and steel	Non-metallic minerals
China / 1985 (base year)	Non-metallic minerals	Iron and steel	Chemical and petrochemical
China / 2005 (end year)	Non-metallic minerals	Iron and steel	Chemical and petrochemical
India / 1985 (base year)	Iron and steel	Non-metallic minerals	Non-ferrous metals
India / 2004 (end year)	Non-metallic minerals	Iron and steel	Paper, pulp and printing
Mexico / 1987 (base year)	Iron and steel	Chemical and petrochemical	Non-metallic minerals
Mexico / 2003 (end year)	Iron and steel	Chemical and petrochemical	Non-metallic minerals

At least in terms of emissions from fuel combustion, changes in the manufacturing sectors of Brazil, China and Mexico seem consistent with the ‘clean’ development trend hypothesis. The results for India, however, seem inconsistent with it. Brazil and India deserve particular attention here.

For Brazil, the manufacturing production saw a contraction in real value added, while becoming more intense in CO_2 emissions from fuel combustion. Although, no ‘clean’ development trend was found, the results for Brazil seem consistent with the ‘clean’ development trend hypothesis and the EKC, in the sense that output growth may be necessary for a decline in emissions per output unit. In the case of India, despite the reduction of its emission-output ratio, changes in value-added shares indicate a ‘dirty’ trend while real value added was growing. In addition, changes in the Indian fuel mix indicate a trend towards high-CEF fuels, mainly towards ‘other bituminous fuels’. Therefore, the results for India seem inconsistent with the ‘clean’ development trend hypothesis.

All in all, these results suggest that a ‘clean’ development trend cannot be taken as a natural rule. In addition, the sharp increase of emissions from high-CEF fuels in China as from 2002 weakens the case of an irreversible ‘clean’ development trend. A ‘clean’ or ‘dirty’ trend may change through the influence of a number of political-economic factors, from changes in prices for export and fuel substitutes to economic and environmental policies. In the analysis undertaken here, negative and stagnating production growth rates were often accompanied by increases in emission intensity.

Considering whether changes in manufacturing sectors are consistent with the 'pollution haven' hypothesis, only for Mexico the results seem inconsistent with a 'dirty' industrial relocation. All of Mexican structural effects contributed to a reduction in the emission-output ratio, and the only branches with environmentally negative structural effects were the least emission-intensive ones. Taking into account that the 'pollution haven' hypothesis may be true if environmentally negative structural effects can be found, the results of the decomposition analysis seem consistent with that hypothesis for a) 'iron and steel' in Brazil, China and India, b) 'non-metallic minerals' and 'chemical and petrochemical' in China and India, as well as for c) 'non-ferrous metals' in India.

For Brazil, China and India, branches with the largest environmentally negative structural effects also bundled most of the positive technological effects. This implies that if the 'pollution haven' hypothesis was true for some branches in these countries, it might have contributed to reduce their emission intensities as well as emission-output ratio. Direct investment may have stimulated the adoption of more efficient technologies and production processes than those previously in operation. Transfer of technology during the establishment of new plants might have had a positive impact in terms of lower emission intensity. Increasing economies of scale[61] may also help to explain part of the verified emission-intensity reduction. Further analysis is necessary concerning these aspects.

[61] Due to the assumption of constant economies of scale, decomposition allocates variations due to decreasing or increasing economies of scale to technological effects instead of structural effects, as one would expect. Therefore, increasing economies of scale will lead to an overestimation of environmentally positive technological effects.

6. Conclusion

This research sheds light on how changes in structure, fuel mix and fuel-saving technologies contributed to the variation in the intensity of production-related CO_2 emissions from fuel combustion in the manufacturing sectors of Brazil, China, India and Mexico between 1985 and 2005. For that, a divisia decomposition with the proportional allocation of the residual was carried out, using CO_2 emissions from fuel combustion and value-added data of eight manufacturing branches. Since the large majority of the existing emission decomposition studies have focused on high-income countries and at the country level, the application of the divisia decomposition to the manufacturing sectors of the selected developing countries at a branch-level represents an additional contribution of this research

Three specific questions guided this study, namely: a) Did technological effects play a significant role in the emission-intensity variation during the specified period? b) Can a 'clean' development trend be found for the selected countries? c) Are changes in the covered manufacturing sectors consistent with a 'dirty' industrial relocation?

In order to explain reductions in the manufacturing emission-output ratio (i.e. the emission intensity of the whole manufacturing sector), technological effects would represent declining emission intensities within manufacturing branches due to improvements in process technology (including changes in material and fuel inputs) and product design, which lead to less fuel combustion per unit of value added. Structural effects that lead to a decline in the emission-output ratio represent the growing importance of less emission-intensive branches in relation to higher emission-intensive branches in the total manufacturing value added. Such environmentally positive technological and structural effects would be consistent with a 'clean' development trend, understood as a change in the industrial structure from primary and more emission-intensive branches (ex.: metals, cement, iron casting) towards less emission-intensive branches (ex.: electronics assembly, textiles, pharmaceuticals). These changes, together with fuel-saving technological innovations, would decrease the emissions per output, resulting in lower manufacturing pollution intensity.

A 'clean' development trend does not necessarily invalidate a 'pollution haven' or industrial relocation hypothesis, which basically argues that due to less strict legislation enforcement and differences in marginal compliance costs for emission reduction, developing countries have a comparative advantage in pollution-intensive industries. Since developing countries are not formally committed to reduce emissions in international agreements, current climate policies may support such a comparative advantage even further. Therefore, pollution-intensive industries may relocate their plants from developed countries to developing countries, which would specialise in the production of greenhouse-gas-intensive goods. If this really took place form 1985 to 2005 in the selected countries, decomposition results should indicate considerable environmentally negative structural effects, which would implicate that an international agreement such as the Kyoto Protocol may contribute to redistribute emissions internationally. Without significant improvements in energy efficiency and environmental standards in developing countries, this redistribution may actually lead to an increase in global emissions. The present analysis shall contribute to discussions about these questions, as well as about the dynamics of manufacturing emissions in developing countries.

Structural effects leading to an increase in the emission-output ratio were found for Brazil, China and India. Such environmentally negative structural effects predominated over technological effects only in the Brazilian case, which was also the only country where real manufacturing value added declined. Although structural effects had a negative impact on China from 1985 to 1993, between 1994 and 2005 they reverted and contributed to a reduction in China's emission-output ratio. Structural effects also contributed to a decline in the emission-output ratio in Mexico from 1987 to 2003. India also saw environmentally negative structural effects from 1985 to 2005; however, stronger positive technological effects made possible a reduction of its emission-output ratio.

In general, with the exception of Brazil, **technological effects** seem to have played an important role in the reduction of the emission-output ratio. The Brazilian manufacturing sector was the only case in which technological effects had a negative contribution in this sense. Also, the GDP emission intensity only increased for Brazil.

Considering the four covered countries, structural effects with an environmentally negative impact occurred mainly in the branches 'iron and steel' and 'non-metallic minerals'. These were also the most emission-intensive manufacturing branches during the period. Technological effects with a positive environmental impact were mainly restricted to 'chemical and petrochemical' and, particularly, 'iron and steel'. These two branches together with 'non-metallic minerals' were the largest net contributors to the decline of the manufacturing emission-output ratio in the covered countries.

At least in terms of emissions from fuel combustion, changes in the manufacturing sectors of Brazil, China and Mexico seem be consistent with a **'clean' development trend** as output grows. The results for India, however, show the opposite. Although environmentally positive technological effects were found, the results for India indicate a change towards emission-intensive branches. This gives ground to the 'pollution haven' hypothesis and opposes the assumption of a 'clean' development trend in the EKC theory.

For Brazil, real manufacturing value added declined while the GDP was growing and the most emission-intensive branches were increasing their shares at the expense of cleaner ones. Although there was a significant change towards fuels with low carbon emission factors, particularly ‘natural gas’, emissions from high-CEF fuels increased considerably as from 1999 and became predominant over low- and medium-CEF fuels. The results are in line with the assumption that positive production growth rates are needed for ‘cleaner’ production, as a stagnating production went along with a ‘dirtier’ industrial structure and a widespread increase in the intensity of emissions per value-added unit. Hence, although no ‘clean’ development trend was identified for Brazil, the results are consistent with the ‘clean’ development trend hypothesis.

In China, the environmentally positive structural effects found between 1994 and 2005 indicate that the value-added shares of emission-intensive branches remained stable or contracted, whereas ‘cleaner’ branches experienced faster growth rates, with emphasis on ‘machinery’. This differed greatly from the first period, between 1985 and 1993, which saw a predominant growth of primary industries and seems to have provided the seedbed for the sharp growth rates of ‘cleaner’ branches as from 1994. In general, technological effects were largely predominant, playing a major role in the reduction of the emission-output ratio. These results are consistent with a ‘clean’ development trend for the case of the Chinese manufacturing sector.

In the case of India, despite the reduction of its emission-output ratio, changes in value-added shares indicate a dirty trend. Considering the significant structural effects leading to an increase in the emission-output ratio, the Indian manufacturing sector seems to have changed its structure towards more emission-intensive branches. In addition, changes in the Indian fuel mix indicate a trend towards carbon-intensive fuels, mainly towards ‘other bituminous fuels’. These results seem inconsistent with the ‘clean’ development trend hypothesis. Technological effects, however, remained the main drivers in the emission-output ratio reduction, which is consistent with that hypothesis. If the ‘clean’ development trend hypothesis does not fully apply to India’s manufacturing sector as indicated in the results obtained here, this may also be the case of other developing countries due to, for example, comparative advantages in emission-intensive production and natural resource endowment. In this case, specialization in emission-intensive industries may occur, as postulated by the ‘pollution haven’ hypothesis.

Mexico was the only country for which the manufacturing sector experienced a ‘strong’ decoupling between emissions and production growth. Total manufacturing emissions from fuel combustion declined, while value added grew significantly. The results obtained for the Mexican manufacturing sector seem consistent with the ‘clean’ development trend hypothesis, since emission-intensive branches lost share in total value added to cleaner ones, while the emission-output ratio declined markedly. Besides that, changes in the fuel mix of the covered branches indicate a trend towards cleaner fuels.

These results suggest that a ‘clean’ development trend cannot be taken as a natural rule. In addition, the sharp increase of emissions from carbon-intensive fuels in China as from 2002 weakens the case of an irreversible ‘clean’ development trend.

Considering whether changes in manufacturing sectors are in line with the **‘pollution haven’ hypothesis**, the decomposition results indicate that this may have been the case for Brazil, China and India, particularly regarding the branches ‘iron and steel’ and ‘non-metallic minerals’. Only for Mexico the results seem to be inconsistent with a ‘dirty’ industrial relocation during the period.

In the case of Brazil, the results may be consistent with the ‘pollution haven’ hypothesis for the branch ‘iron and steel’, which accounted for most of the increase in the emission-output ratio from 1996 to 2005. However, since Brazil is a major producer of iron ore, natural resource endowment may have played a decisive role.

For the case of China, the results seem consistent with the ‘pollution haven’ for ‘iron and steel’ and ‘non-metallic minerals’ from 1985 to 1993. From 1994 to 2005, though, structural effects in these branches contributed to a reduction in the emission-output ratio, while structural effects from ‘chemical and petrochemical’ led to an increase in the emission-output ratio. Considering that these three branches are the most emission-intensive ones in the Chinese context, some of its production growth may have been influenced by ‘dirty’ industrial relocation.

In India, the results seem consistent with the ‘pollution haven’ hypothesis to ‘iron and steel’ throughout the whole period, as well as to ‘chemical and petrochemical’ and ‘non-ferrous metals’ from 1985 to 1997, and for ‘non-metallic minerals’ from 1998 to 2004.

In all the selected countries branches with environmentally negative structural effects concentrated most of the verified positive technological effects, which contradicts the ‘race to the bottom’ scenario and suggests that the impacts of globalization and supposed ‘pollution havens’ may also have a positive side in terms of emission intensity.

Direct investment in the expansion of production capacities may have stimulated the adoption of more fuel-efficient technologies and processes than those already in use, leading to a positive impact in terms of lower emission intensity. Hence, even if there are signs that the ‘pollution haven’ hypothesis may apply to some branches in Brazil, China and India, it would not have necessarily led to a global environmental loss in terms of carbon emissions. Increasing economies of scale may also help to explain part of the verified emission-intensity reduction. However, decomposition provides no further insight into this question, since the assumption of fixed-economies of scale leads to the allocation of variations due to decreasing or increasing economies of scale to technological effects, instead of structural effects as one would expect. Additional empirical research is needed for more detailed answers.

In the context of climate change, the theory on the 'pollution haven' hypothesis might be extended by the incorporation of positive environmental impacts of industrial relocation to developing countries, as well as by exploring how national and international policies should address the determinants of a comparative advantage in 'dirty' industries. As improved data become available, analyses on industrial relocation among developing countries may also lead to new insights about the impacts of globalization on the relationship between industrial development and emissions.

One important limitation of this study is that its estimates of emissions per output unit, which define the 'cleanliness' of an industry, do not account for emissions generated across industries and along the entire production chain. Therefore, the emission intensity of branches such as 'machinery' is underestimated, considering its dependency on inputs from other branches. Another limitation refers to the assumption of constant economies of scale, which leads to the allocation of variations due to decreasing or increasing economies of scale to technological effects, instead of structural effects as one would expect.

Similarly to the results obtained in related decomposition studies concerning industrial countries, in China, India and Mexico technological change was the most important determinant in the emission-output ratio variation. Despite that, the results indicate that structural changes are also important sources of change in emissions, which is consistent with the literature questioning the EKC in this regard.

The various economic schools seem to agree that development requires growth, mostly industrial growth. How it should happen and which level of involvement governments should take, however, still remains under strong debate. Taking into account the global challenges arising from poverty and climate change, it seems reasonable to assume a stronger role for the state both in developed and developing countries in the coming decades. Depending on institutional capacity and policies, states can encourage restructuring, diversification, and technological dynamism beyond what market forces alone would generate. This stronger role, however, faces the risk of stimulating rent-seeking, inefficiency and ineffectiveness, which imply waste of resources.

Since developing countries are so far not formally committed to reducing carbon-dioxide emissions, international agreements such as the Kyoto Protocol may offer additional incentives to a 'dirty' comparative advantage and the redistribution of emissions in line with the 'pollution haven' hypothesis. The results suggest that a possible relocation of pollution-intensive industries may have its positive environmental impacts. However, without continuous improvements towards fuels with lower carbon emission factors, enhanced energy efficiency and environmental governance, this redistribution may speed up the increase in global emissions.

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Annex I – Fuels covered by carbon-emission factors (IEA, 2007a; IPCC, 2006)

Fuels covered in IEA, 2007a[62]	Tonnes of carbon[63] / Terajoule	Classification by carbon emission factor.
Gas works gas	12.1	Low carbon-emission factor
Coke oven gas	12.1	
Natural gas	15.3	
Refinery gas	15.7	
Ethane	16.8	
Liquefied petroleum gases (LPG)	17.2	
Natural gas liquids	17.5	
Motor gasoline	18.9	
Gasoline type jet fuel	19.1	
Aviation gasoline	19.1	
Kerosene type jet fuel	19.5	
Other kerosene	19.6	
White spirit and SBP	20	Medium carbon-emission factor
Refinery feedstocks	20	
Paraffin waxes	20	
Non-specified petroleum products	20	
Naphtha	20	
Lubricants	20	
Crude oil	20	
Gas/diesel oil	20.2	
Orimulsion	21	
Heavy fuel oil	21.1	
Coal tar	22	
Bitumen	22	
Municipal waste (non-renewable)	25	
Other bituminous coal	25.8	High carbon-emission factor
Coking coal	25.8	
Sub-bituminous coal	26.2	
Petroleum coke	26.6	
Patent fuel	26.6	
BKB/Peat briquettes	26.6	
Anthracite	26.8	
Lignite/brown coal	27.6	
Peat	28.9	
Oil shale	29.1	
Gas coke	29.2	
Coke oven coke and lignite coke	29.2	
Industrial waste	39	
Oxygen steel furnace gas	49.6	
Blast furnace gas	70.8	

[62] The fuel categories 'other hydrocarbons' and 'additive/blending components' were not included in the classification, since their carbon emission factors were not available at the IPCC's Emission Factor Database (EFDB), IEA, 2007a nor IPCC, 2006.

[63] Resulting carbon (C) emissions are multiplied by 44/12 (which is the molecular weight ratio of CO_2 to C) to find the total carbon dioxide (CO_2) emitted from fuel combustion (IEA, 2007b: 42).

Annex II – Country notes[64] for the IEA databases (IEA, 2007a; IEA, 2007c; IEA, 2007e)

Brazil

No comments were made concerning the 2007 *CO_2 Emissions from Fuel Combustion* (IEA, 2007b: 29).

Sources for IEA's reports on energy balances (IEA, 2007c) between 1971 and 2005 are based on direct official communication with the Ministry of Mining and Energy. No additional comments were made about the data for Brazil in the 2007 *Energy Balances of Non-OECD Countries* (IEA, 2007d: 43)

In all country cases, when statistics of electricity production from inputs of 'Combustible Renewables and Waste'[65] are available for the countries, they are shown in the corresponding column. These data, however, are not comprehensive. For example, much of the electricity generated from waste biomass in sugar refining remained unreported until the 2007 *Energy Balances of Non-OECD Countries* (IEA, 2007d: 37).

According to the IEA (2008a: 51), in 2008, significant revisions were made to time series of combustible renewables and waste for Brazil, after direct communication with the national administration. Volumes of vegetal waste previously reported as non-energy use were removed for consistency with international definitions. Some volumes of vegetal waste ("bagaço de cana"- sugarcane bagasse) reported under the energy sector by Brazil were incorporated for the first time in the IEA energy sector, resulting in increases in the total primary solid biomass figures.

China

For the report 2007 *CO_2 Emissions from Fuel Combustion* the IEA Secretariat has revised some of the net calorific values used to convert bituminous coal to terajoules in 2006. Hence, the estimates of carbon dioxide emissions for 2001 to 2003 are 6 to 8 per cent higher than those published in previous editions (IEA, 2007b: 29).

According to the IEA (2007d: 44), in the 2007 *Energy Balances of Non-OECD Countries*, the Chinese coal production statistics have been revised upward for the years 1990 to 2003 based upon the assumption that coal consumption statistics are more reliable than coal production statistics, and that the production-consumption relationship should maintain a better balance over time. However, it should be noted that these data are IEA estimates and in no case represent official data released by the Chinese government.

Coal production statistics refer to unwashed and un-screened coal. IEA coal statistics normally refer to coal after washing and screening for the removal of inorganic matter. In addition, coal calorific values have been revised.

Prior to the reforms undertaken in the 1990's, the sectoral classification of fuel consumption in the transition economies (Eastern Europe and the countries of the former USSR) and

[64] As put by the IEA (2007c: 35), "the country notes simply identify some of the more important and obvious deviations from IEA methodology in certain countries and are by no means a comprehensive list of anomalies by country".

[65] The IEA publishes production and primary supply of combustible renewables and waste for all non-OECD countries and all regions for the years 1971 to 2005. According to the IEA (2007c: 37), such data are often from secondary sources, inconsistent and may be of questionable quality, which makes comparisons between countries difficult. The historical data of many countries derive from surveys which were often irregular, irreconcilable and conducted at the local rather than national level making them incomparable between regions and time.

China differed greatly from that practised in market economies. Sectoral consumption was defined according to the economic branch to which the user of the fuel belonged rather than according to the purpose or use of the fuel. Consumption of gasoline in the vehicle fleet of an enterprise attached to the economic branch 'iron and steel' was classified as industrial consumption of gasoline in the iron and steel industry. Where possible, the data have been adjusted to fit international classifications. For example, all gasoline is assumed to be consumed in the 'transport' sector and is reported in the 2007 *Energy Balances of Non-OECD Countries* as such.

Sources 1990-2005:
Energy Balances of China, provided to the Secretariat by the State Statistical Bureau for 1990 to 2005.

Sources up to 1990:
Electric Industry in China in 1987, Ministry of Water Resources and Electric Power, Department of Planning, Beijing, 1988.

Outline of Rational Utilization and Conservation of Energy in China, Bureau of Energy Conservation State Planning Commission, Beijing, June 1987.

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Energy in China 1989, Ministry of Energy, People's Republic of China, Beijing, 1990.

China: A Statistics Survey 1975-1984, State Statistical Bureau, Beijing, 1985.

China Petro-Chemical Corporation (SINOPEC) Annual Report, SINOPEC, Beijing, 1987.

Almanac of China's Foreign Economic Relations and Trade, The Editorial Board of the Almanac, Beijing, 1986.

India

No comments were made concerning the 2007 *CO_2 Emissions from Fuel Combustion* (IEA, 2007a).

In the 2007 *Energy Balances of Non-OECD Countries* (IEA 2007c), due to new sources of information, the consumption of biomass in India has been revised and better allocated between sectors (IEA 2007d: 50). Differently from Brazil, China and Mexico, data for India is reported on a fiscal year basis.

Sources 1992-2005:
Data obtained through direct communication with the Secretariat from the Coal Controller's Organisation of the Ministry of Coal, the Ministry of Petroleum and Natural Gas, the Central Electricity Authority of the Ministry of Power and the Central Statistical Organisation of the Ministry of Planning and Programme Implementation. Additional sources are as follows:

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Mexico

No comments were made in the country notes of the 2007 *CO_2 Emissions from Fuel Combustion* (IEA, 2007a) for Mexico.

Since Mexico is a member of the OECD, its energy balances are presented in the IEA's *Energy Balances of OECD Countries* (2007e). Data are available starting as from 1971 and are partly estimated based on the publication *Balance Nacional - Energía*. The Mexican Administration submitted data directly by questionnaire for the first time in 1992. Therefore, some breaks in series may occur between 1991 and 1992 (IEA, 2007f: 40).

Coal: Data for coke oven gas and blast furnace gas are reported for the first time in 1999.

Combustible renewables and waste: Data on biogas are available from 1998.

Oil: Inputs of oil for auto-producer electricity and heat generation have been included in industry. Because of a change in the processing of the data, breaks in series occur between 1998 and 1999.

Gas: Natural gas reported in the IEA publications may be different from what is reported in the Mexican energy publications, as IEA includes only dry gas and excludes natural gas liquids. Distribution losses have been included in oil and gas extraction. Beginning with 1993, data have been submitted by the "Secretaria de Energia".

Electricity and heat: Electricity production from wind is available from 1994. Electricity output from solar photovoltaic and combustible renewables and waste are available from 1998. Starting in 1998, the CRE (Comisión Reguladora de Energia) has published new data for electricity generation by auto-producers. This may lead to breaks in the time series between 1997 and 1998. Prior to 1998, data reported in non-specified petroleum products for auto-producers include all types of combustible fuels. New auto-producer electricity plants fuelled with coal gases were put on-line in 1999. In the 2006 edition, the time series for electricity production from natural gas plants have been revised by the Mexican administration from 1990 onwards. Data for direct use of solar thermal are available from 1998. Some electricity consumption in the energy sector is included in the industry sector where it was generated (e.g. the chemical industry, as well as in industry non-specified).

Annex III – Correspondence table for aggregation and ISIC list

Aggregation used	ISIC Data set	Correspondence
1. Iron and steel	*ISIC Rev. 2*	Group 371
	ISIC Rev 3	Group 271 and Class 2731
2. Chemical and petrochemical	*ISIC Rev. 2*	Groups 351, 352
	ISIC Rev 3	Division 24
3. Food and tobacco	*ISIC Rev. 2*	Groups 311, 313, 314
	ISIC Rev 3	Divisions 15 and 16
4. Textile and leather	*ISIC Rev. 2*	Groups 321, 322, 323, 324
	ISIC Rev 3	Divisions 17, 18 and 19
5. Non-ferrous metals	*ISIC Rev. 2*	Group 372
	ISIC Rev 3	Group 272 and Class 2732
6. Non-metallic minerals	*ISIC Rev. 2*	Groups 361, 362, 369
	ISIC Rev 3	Division 26
7. Paper, pulp and printing	*ISIC Rev. 2*	Groups 341, 342
	ISIC Rev 3	Divisions 21 and 22
8. Machinery	*ISIC Rev. 2*	Groups 381, 382, 383
	ISIC Rev 3	Divisions 28, 29, 30, 31 and 32

ISIC List (Revision 2)

300	Total manufacturing	354	Misc. petroleum and coal products
311	Food products	355	Rubber products
313	Beverages	356	Plastic products
314	Tobacco	361	Pottery, china, earthenware
321	Textiles	362	Glass and products
322	Wearing apparel, except footwear	369	Other non-metallic mineral products
323	Leather products	371	Iron and steel
324	Footwear, except rubber or plastic	372	Non-ferrous metals
331	Wood products, except furniture	381	Fabricated metal products
332	Furniture, except metal	382	Machinery, except electrical
341	Paper and products	383	Machinery, electric
342	Printing and publishing	384	Transport equipment
351	Industrial chemicals	385	Professional & scientific equipment
352	Other chemicals	390	Other manufactured products
353	Petroleum refineries		

ISIC List (Revision 3)

151	Processed meat, fish, fruit, vegetables, fats
1511	Processing/preserving of meat
1512	Processing/preserving of fish
1513	Processing/preserving of fruit & vegetables
1514	Vegetable and animal oils and fats
1520	Dairy products
153	Grain mill products; starches; animal feeds
1531	Grain mill products
1532	Starches and starch products
1533	Prepared animal feeds
154	Other food products
1541	Bakery products
1542	Sugar
1543	Cocoa, chocolate and sugar confectionery
1544	Macaroni, noodles & similar products
1549	Other food products, n.e.c.
155	Beverages
1551	Distilling, rectifying & blending of spirits
1552	Wines
1553	Malt liquors and malt
1554	Soft drinks; mineral waters
1600	Tobacco products
171	Spinning, weaving and finishing of textiles
1711	Textile fibre preparation; textile weaving
1712	Finishing of textiles
172	Other textiles
1721	Made-up textile articles, except apparel
1722	Carpets and rugs
1723	Cordage, rope, twine and netting
1729	Other textiles, n.e.c.
1730	Knitted and crocheted fabrics and articles
1810	Wearing apparel, except fur apparel
1820	Dressing & dyeing of fur; processing of fur
191	Tanning, dressing and processing of leather
1911	Tanning and dressing of leather
1912	Luggage, handbags, etc.; saddlery & harness
1920	Footwear
2010	Sawmilling and planing of wood
202	Products of wood, cork, straw, etc.
2021	Veneer sheets, plywood, particleboard, etc.
2022	Builders' carpentry and joinery
2023	Wooden containers
2029	Other wood products; articles of cork/straw
210	Paper and paper products
2101	Pulp, paper and paperboard
2102	Corrugated paper and paperboard
2109	Other articles of paper and paperboard
221	Publishing
2211	Publishing of books and other publications
2212	Publishing of newspapers, journals, etc.
2213	Publishing of recorded media
2219	Other publishing
222	Printing and related service activities
2221	Printing
2222	Service activities related to printing
2230	Reproduction of recorded media
2310	Coke oven products
2320	Refined petroleum products
2330	Processing of nuclear fuel
241	Basic chemicals
2411	Basic chemicals, except fertilizers
2412	Fertilizers and nitrogen compounds
2413	Plastics in primary forms; synthetic rubber
242	Other chemicals
2421	Pesticides and other agro-chemical products
2422	Paints, varnishes, printing ink and mastics
2423	Pharmaceuticals, medicinal chemicals, etc.
2424	Soap, cleaning & cosmetic preparations
2429	Other chemical products, n.e.c.
2430	Man-made fibres
251	Rubber products
2511	Rubber tyres and tubes
2519	Other rubber products
2520	Plastic products
2610	Glass and glass products
269	Non-metallic mineral products, n.e.c.
2691	Pottery, china and earthware
2692	Refractory ceramic products
2693	Structural non-refractory clay; ceramic products
2694	Cement, lime and plaster
2695	Articles of concrete, cement and plaster
2696	Cutting, shaping & finishing of stone
2699	Other non-metallic mineral products, n.e.c.
2710	Basic iron and steel

2720	Basic precious and non-ferrous metals	3140	Accumulators, primary cells and batteries
273	Casting of metals	3150	Lighting equipment and electric lamps
2731	Casting of iron and steel	3190	Other electrical equipment, n.e.c.
2732	Casting of non-ferrous metals	3210	Electronic valves, tubes, etc.
281	Structural metal products, tanks, steam generators	3220	TV/radio transmitters; line comm. apparatus
2811	Structural metal products	3230	TV and radio receivers and associated goods
2812	Tanks, reservoirs and containers of metal	331	Medical, measuring, testing appliances, etc.
2813	Steam generators	3311	Medical, surgical and orthopaedic equipment
289	Other metal products; metal working services	3312	Measuring/testing/navigating appliances, etc.
2891	Metal forging/pressing/stamping/roll-forming	3313	Industrial process control equipment
2892	Treatment & coating of metals	3320	Optical instruments & photographic equipment
2893	Cutlery, hand tools and general hardware	3330	Watches and clocks
2899	Other fabricated metal products, n.e.c.	3410	Motor vehicles
291	General purpose machinery	3420	Automobile bodies, trailers & semi-trailers
2911	Engines & turbines (not for transport equip.)	3430	Parts/accessories for automobiles
2912	Pumps, compressors, taps and valves	351	Building and repairing of ships and boats
2913	Bearings, gears, gearing & driving elements	3511	Building and repairing of ships
2914	Ovens, furnaces and furnace burners	3512	Building/repairing of pleasure/sport
2915	Lifting and handling equipment	3520	Railway/tramway locomotives & rolling stock
2919	Other general purpose machinery	3530	Aircraft and spacecraft
292	Special purpose machinery	359	Transport equipment, n.e.c.
2921	Agricultural and forestry machinery	3591	Motorcycles
2922	Machine tools	3592	Bicycles and invalid carriages
2923	Machinery for metallurgy	3599	Other transport equipment, n.e.c.
2924	Machinery for mining & construction	3610	Furniture
2925	Food/beverage/tobacco processing machinery	369	Manufacturing, n.e.c.
2926	Machinery for textile, apparel and leather	3691	Jewellery and related articles
2927	Weapons and ammunition	3692	Musical instruments
2929	Other special purpose machinery	3693	Sports goods
2930	Domestic appliances, n.e.c.	3694	Games and toys
3000	Office, accounting and computing machinery	3699	Other manufacturing, n.e.c.
3110	Electric motors, generators and transformers	3710	Recycling of metal waste and scrap
3120	Electricity distribution & control apparatus	3720	Recycling of non-metal waste and scrap
3130	Insulated wire and cable	3999	Total manufacturing

Annex IV – Country notes for the value-added databases

The data used in this analysis are mostly those reported by national statistical authorities in response to the UNIDO country questionnaire. They have been supplemented with data published in national statistical publications and with UNIDO estimates[66]. According to Yamada (2004: 4), for the elaboration of the INDSTAT database UNIDO treats the data reported by national statistical offices (NSOs) as follows:

a) Pre-filling of the out-going *UNIDO General Industrial Statistics Questionnaire* with previously reported statistical and metadata for their possible revision by the NSO.
b) Upon receipt of the questionnaire completed by the NSO and returned to UNIDO: (i) manual and computerised detection and, if possible, correction of incoherent data and dubious data; (ii) adjustment of reported statistics to desired statistics; and (iii) if appropriate, re-description of the provided metadata for international comparability.
c) If the validity of the dubious data cannot be judged, NSOs are enquired for clarification, so that UNIDO can make the necessary corrections.
d) Filling data gaps: Imputation of missing data by utilizing data for related variable(s) or other available supplementary data; for selected variables, computer-based estimation of missing data by estimating inter-variable relations as country-specific time-series regression equations.

Inter-country differences in the reporting of industrial statistics derive mainly from three factors: (i) the use of national classifications which do not conform to the ISIC; (ii) incomplete coverage or total absence of national data relating to certain variables, branches or years; and (iii) variations in concepts or definitions used. Such differences may also emerge within time series for individual countries and, thus, affect the continuity of a country time series (UNIDO, 2003: 12).

The measure of value added normally reported by NSOs is the *census concept*, which is defined as the value of census output less the value of census input. The census concept covers: (a) value of materials and supplies for production (including cost of all fuel and purchased electricity); and (b) cost of industrial services received (mainly payments for contract and commission work and repair and maintenance work). Estimates are normally gross of depreciation and other provisions for capital consumption (ESDS, 2007: 4). Valuation may be in factor values, excluding all indirect taxes falling on production and including all current subsidies received in support of production activity, or in producers' prices, including all indirect taxes and excluding all subsidies. Data concerning value added for the countries approached by this study can be detailed as follows:

[66] Available at: http://www.unido.org/index.php?id=o3533 (accessed: 30/08/2008).

	Data sources (IBGE, 1996-2006; UNIDO, 2006; OECD, 2005a)	**Country notes**
Brazil	1996-2004: Data provided by the national statistical office in Rev. 3 of the ISIC.	Valuation: Factor values Adjusted for non-response: Yes Type of enumeration: Complete enumeration of local units with 5 to 29 persons engaged; stratified random sampling for local units with 30 or more persons engaged. Method: Data are collected by enumerator through specially designed questionnaires. Scope: Local units with 5 or more persons engaged. Reference period: Calendar year. Deviations from ISIC: None reported. Source: Annual industrial survey. IBGE, 1996-2006.
China	1985-1993: Data added/adjusted by UNIDO based on national publications. 1994-2005: Data provided by national statistical offices through questionnaires.	Valuation: Not defined[67] Adjusted for non-response: n.a. Type of enumeration: n.a. Method: n.a. Scope: n.a. Reference period: n.a.. Deviations from ISIC: n.a. Source: UNIDO, 2006.
India	1985-1997: Data provided by national statistical offices through questionnaires. 1998-2004: Data added/adjusted by UNIDO based on international publications and UNIDO estimates, which consist of converted data from ISIC Rev.3 to ISIC Rev.2	Valuation: 1979 to 1997 – Factor values 1998 to 2003 – Producers' prices Adjusted for non-response: Yes Type of enumeration: Factories employing 100 or more workers are completely enumerated. For factories with less than 100 workers, stratified uni-stage sampling is used. Estimates for the whole country are calculated on the basis of province data.

[67] As put by the National Bureau of Statistics of China, value added is defined as follows:

Value-added of industry = gross industrial output – industrial intermediate input + value-added tax

Gross industrial output refers to the total achievements of industrial production during a given period and includes the value of finished products, income from external processing, and value of change in semi-finished products at the end and at the beginning of the reference period. *Industrial intermediate input* refers to purchased goods and paid services consumed during the industrial production of enterprises. Industrial intermediate input includes five components, namely: i) direct consumption of materials, ii) industrial intermediate input in manufacturing cost, iii) industrial intermediate input in management cost, iv) industrial intermediate input in marketing cost and v) expenditure on interest. Available at: http://www.stats.gov.cn/ (accessed: 30/08/2008).

		Method: The survey is carried out by mail and field contacts. Scope: Factories using power and employing 10 or more workers on any day of the reference period and all factories employing 20 or more workers. Reference period: Fiscal year (01 April to 31 March). Deviations from ISIC: None reported. Source: UNIDO, 2006.
Mexico	1987-2003: Data provided by national statistical offices through questionnaires according to the ISIC Rev.3.	Valuation: 1987 to 2003 – Basic prices Adjusted for non-response: Yes Type of enumeration: Non-probabilistic sampling, using the Definitive Directory of manufacturing establishments based on the XVI Industrial Census, 2004. Method: The inquiry is conducted by mail and interviews. Scope: Factories employing 15 or more workers, except for cross-border assembly plants (maquilas). Reference period: Calendar year Deviations from ISIC: None reported Source: OECD, 2005a.

Annex V – Affidavit

I hereby declare that I have written this dissertation by myself and that it has never before been presented for any academic award. All used sources have been fully specified.

Hiermit erkläre ich, dass ich diese Dissertation selbständig verfasst habe. Deren Inhalt ist für keine andere Diplom- oder ähnliche Prüfungsarbeit verwendet worden. Alle benutzten Quellen wurden vollständig angegeben.

Eduardo Wirthmann Ferreira