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Growth, trade and environmental performance in China: 1980-2009

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Growth, Trade and Environmental Performance in China: 1980-2009

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CERTIFICATION

I, Ying Liu, declare that this thesis, submitted in partial fulfilment of requirements for the award of Doctor of Philosophy, in the School of Economics of the Faculty of Business, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Ying Liu

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ABSTRACT

Thirty years of economic reforms have transformed China from a poor and stagnating centrally planned economy into a socialist market economy with unprecedented rates of economic growth, fuelled in large part by international trade and foreign direct investment. However, this achievement has produced equally unprecedented rates of energy consumption with the associated threats to environmental sustainability.

The primary objective of this thesis is to examine the environmental performance of China during the period of 1980-2009. In particular, we examine the rates and trends in absolute and per capita emissions of four types of industrial pollutants: carbon dioxide (CO_2), sulphur dioxide (SO_2), chemical oxygen demand (COD) and production wastes, through the prism of relevant economic theories. Specifically, three hypotheses were tested: (1) an income-related environmental hypothesis; (2) a trade-related environmental hypothesis; and (3) an energy-related environmental hypothesis.

CO_2 is an air pollutant which is having a global impact, and therefore two entirely different methodologies, a production-based decomposition analysis and a consumption-based input-output analysis, have been adopted. The objective is to estimate the amount of CO_2 pollution and the determinants of that pollution not only at the domestic level but also the amount that is relocated due to increased global trade. The production-based decomposition analysis revealed that economic growth was the major factor driving the rapid growth of CO_2 emissions from China. This was especially so for China's industrial sector and industrial provinces. Conversely, improvements in energy intensity played a big role in lowing CO_2 emissions. Given the fact that a major part of China's productive output is exported, the consumption-based input-output analysis showed that in 2007 China would be responsible for 38% less CO_2 emissions than is the case using the production-based decomposition analysis. A few sectors are considered as highly emissions-embodied and highly energy-intensive and these sectors need attention if China's environmental performance is to improve.

Reductions in pollutants emissions are also subject to consumer preferences. The income-related environmental hypothesis posits that increasing per capita incomes will eventually result in decreased pollution as citizens express a growing demand for improved environmental quality (known as the Environmental Kuznets Curve

hypothesis, EKC). This transformation may be achieved via a combination of appropriate technological progress, structural change and foreign trade. We apply the relatively new panel unit root and cointegration analyses to test the EKC hypothesis for China. The results show that a statistically significant EKC relationship between two local pollutants (SO_2 and production wastes) and economic growth exists for the country as a whole and for a few coastal provinces.

COD is a commonly used method of measuring the amount of organic materials in lakes and rivers. Reductions in COD in China have already been evidenced (Dean, 2002). In this thesis we decompose the trade-related components of COD into scale, technique and composition effects by using simultaneous equation methods. The direct composition impact was found to be significantly positive for COD growth. However, the indirect impact was negative and significant, indicating that the technique effect outweighed the scale effect. This result also provides some support for the EKC hypothesis in that rising incomes were associated with falling COD growth due to improved production techniques. Moreover, this indirect impact was higher than the direct impact and so we find a net negative impact of trade on COD growth. This suggests that the increasing per capita income resulting from increased international trade is contributing to improving water quality in China.

Based on the major findings, we recommend some relevant policies as follows: i) improvement of energy efficiency; ii) movement towards renewable energy and cleaner industrial and service sectors; iii) establishing a sound social security system; iv) adaptation of market-based instruments to lower emissions; v) encouragement of reforestation programs; vi) harmonising regional economic growth with environmental protection in the western areas by learning new cleaner production technology; vii) further trade liberalisation policy, but moving from ‘dirty’ production to clean production; and viii) strengthening and enforcing the environmental regulations.

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ABBREVIATIONS

Two-stage Least Squares	**2SLS**
Average of Individual Cross-sectionally Augmented ADF	**ACDF**
Augmented Dickey-Fuller	**ADF**
Akaike Information Criterion	**AIC**
Aerometric Information Retrieval System	**AIRS**
Asia-Pacific Economic Cooperation	**APEC**
Agriculture, Forestry, Animal Husbandry & Fishery	**ARG**
Association of Southeast Asian Nations	**ASEAN**
Balance of Emissions Embodied in Trade	**BEET**
Manufacture of Building Materials and other Nonmetallic Mineral Products	**BNM**
Biochemical Oxygen Demand	**BOD**
Chinese Academy of Engineering	**CAE**
Chinese Communist Party Central Committee	**CCPCC**
Carbon Dioxide Information Analysis Centre	**CDIA**
Clean Development Mechanism	**CDM**
Carbon Emission Factor	**CEF**
China's Energy Investment Corporation	**CEIC**
Coking, Gas and Petroleum Processing	**CGP**
Methane	**CH_4**
Chemical Industry	**CMI**
China National Offshore Oil Corporation	**CNOOC**
China National Petroleum Corporation	**CNPC**
Carbon Monoxide	**CO**
Carbon Dioxide	**CO_2**
Chemical Oxygen Demand	**COD**
Carbon Oxidisation Factor	**COF**
Consumer Price Index	**CPI**
Construction	**CSI**
Dickey-Fuller	**DF**
US Department of Energy/Energy Information Administration	**DOE/EIA**
Dynamic Ordinary Least Square	**DOLS**
Energy Conservation Law	**ECL**
Error Correction Term	**ECT**
Emissions on a Domestic Consumption basis	**EDC**
Emissions Embodied in Domestic Production	**EDP**
Emissions Embodied in Imports	**EEI**
Emissions Embodied in Exports	**EEX**
Production and Supply of Electric Power, Heat Power and Water	**EHW**
Economic Input-Output Life Cycle Assessment	**EIO-LCA**
Environmental Kuznets Curve	**EKC**
Energy Research Institute, National Development and Reform Commission of	

China	**ERI/NDRC**
Export-Import Bank of China	**EXIM**
Manufacture of Foods, Beverages & Tobacco	**FBT**
Foreign Direct Investment	**FDI**
Foreign-invested Enterprise	**FIE**
Fully Modified Ordinary Least Square	**FMOLS**
Gross Domestic Production	**GDP**
Global Environmental Monitoring System	**GEMS**
Gross Regional Product	**GRP**
Global Trade Analysis Project	**GTAP**
Global Warming Potential	**GWP**
Heckscher-Ohlin	**HO**
Index Decomposition Analysis	**IDA**
International Energy Agency	**IEA**
Institute of Energy Economics, Japan	**IEEJ**
International Monetary Fund	**IMF**
Input-Output	**I-O**
Intergovernmental Panel on Climate Change	**IPCC**
Im, Pesaran, and Shin	**IPS**
Levin, Lin, and Chu	**LLC**
Logarithmic Mean Divisia Index	**LMDI**
Manufacture of Machinery and Equipment	**MEM**
Ministry of Environmental Protection	**MEP**
Mining	**MNI**
Manufacture and Processing of Metals and Metal Products	**MPM**
Multi-Region Input-Output Model	**MRIO**
Ministry of Science and Technology of China	**MST**
Million tons	**Mt**
Nitrogen Dioxides	$\mathbf{N_2O}$
North American Free Trade Agreement	**NAFTA**
The National Development and Reform Commission	**NDRC**
The National Energy Administration	**NEA**
The National Energy Commission	**NEC**
The National Environmental Protection Agency	**NEPA**
Nitrogen Oxides	$\mathbf{NO_X}$
Organisation for Economic Co-operation and Development	**OECD**
Ordinary Least Squares	**OLS**
Other Manufacture	**OMI**
Real Estate, Leasing and Business Services, Financial Intermediation and Other Services	**OSI**
Pollution Haven Hypothesis	**PHH**
Perpetual Inventory Method	**PIM**
The People's Republic of China	**PRC**
Renmingbi	**RMB**

Structural Decomposition Analysis	**SDA**
State Development Planning Commission	**SDPC**
State Environmental Protection Agency	**SEPA**
State Economic and Trade Commission	**SETC**
Special Economic Zones	**SEZs**
Schwarz Information Criterion	**SIC**
China National Petrochemical	**Sinopec**
Sulphur Dioxide	**SO_2**
State Owned Banks	**SOBs**
State Owned Enterprises	**SOEs**
Suspended Particulate Matter	**SPM**
Single-region Input-Output Model	**SRIO**
Tons of Coal Equivalent	**TCE**
Tons of Oil Equivalent	**TOE**
Terms of Trade	**TOT**
Transport, Storage, Post, Information Transmission, Computer Services & Software	**TPT**
Township and Village Enterprises	**TVEs**
Manufacture of Textiles, Wearing Apparel & Leather Products	**TWL**
United Kingdom	**UK**
United Nations Conference on the Human Environment	**UNCHE**
United Nations Framework Convention on Climate Change	**UNFCCC**
United States	**US**
Vector Error Correction Model	**VECM**
World Development Indicators	**WDI**
Wholesale and Retail Trades, Hotels and Catering Services	**WHC**
World Health Organisation	**WHO**
World Trade Organisation	**WTO**

Chapter One

Introduction

1.1 Background of the Study

China introduced economic reforms in 1978 and accelerated the reforms in the 1990s. Reforms were initiated in the agricultural (rural) sector and then extended to state-owned enterprises (SOEs), non-SOEs, and outward-oriented policies, including trade and foreign direct investment (FDI). After three decades of economic reforms and opening up, China has transformed itself from a centrally planned economy to a socialist market economy, with the high annual GDP growth rate of around 10%. China is expected to continue to enjoy rapid economic growth in the years ahead. International trade and foreign investment continue to play a major role in China's booming economy, especially after joining the World Trade Organisation (WTO), although they were influenced by the global crisis in 2008-2009. Accompanying the 30-year reform, China has experienced huge structural changes – rapid and widespread industrialisation and expansion of the service sector, due to the rapid accumulation of capital and the growth of domestic market in 1980s and 1990s, and the increase in exports and the great inflow of FDI in 2000s.

However, the rapid economic growth and industrialisation in China have raised concerns relating to energy consumption and domestic and cross-border environmental pollution. In 2009, China was the second largest energy consumer in the world, with a heavy reliance on coal and oil. Although the amounts of most pollutants (such as sulphur dioxide or SO_2, industrial wastewater, industrial chemical oxygen demand or

COD, and discharge of industrial solid waste) have diminished in recent years, China is still the largest emitter of SO_2 and carbon dioxide (CO_2). Therefore, reducing overall pollution and saving energy while implementing rapid economic growth are challenges that China is confronting.

This study selects the most prevalent and important environmental quality indicators in China, especially for the analysis of greenhouse gas emissions [1]. The global environmental problems, such as climate change and ozone depletion are, very likely, due to the observed increase in anthropogenic greenhouse gas emissions, especially emissions of CO_2, which is a global stock pollutant with a lifetime of about 125 years. During the last three decades, China has experienced a rapid growth of CO_2 emissions, which is accounting 24% of global emissions in 2009. Now China is the world's largest CO_2 emitter and the emissions are expected to increase, due to continuous economic growth and a heavy reliance on coal consumption. China is facing more criticism for the increasing emissions it is producing. Therefore, for the purpose of reducing CO_2 emissions, it is very important and necessary to incorporate CO_2 emissions in this study. Firstly, we will identify the main factors driving the rapid growth in CO_2 emissions from the production-based accounting approach. Besides the sectoral decomposition analysis which has been used in several studies (see Chapter Five), we will provide a comparative analysis across China's provinces as well, due to the obvious regional differences, which will help to draw specific policies to reduce emissions for each province. Moreover, the consumption-based accounting approach will be applied to see who owns the responsibility for CO_2 emissions produced in China. The intention is to

[1] According to OECD (2008), the key environmental indicators include climate change (CO_2 and greenhouse gas emission intensities), ozone layer, air quality (SO_2 and NO_X emissions intensities), waste generation, freshwater quality, freshwater resources, forest resources, fish resources, energy resources and biodiversity. ANZECC (2000) grouped core atmospheric quality indicators under four issues: climate variability, enhanced greenhouse effect (CO_2, CH_4, N_2O, HFC_S, PFC_S and SF_6), stratospheric ozone and outdoor air quality.

show the outcome from both production-based and consumption-based accounting in a comprehensive way.

Besides CO_2, China is also the world's largest emitter of SO_2, which is the most important air pollution problem in China. SO_2 and its atmospheric products (e.g. sulphate, sulphuric acid) have significant local and regional effects on the atmospheric environment, as well as adverse effects on human health (Lu *et al*., 2010). The production of wastes (wastewater, waste gas and solid waste) is the more relevant environmental indicator, because "*more waste means more disposal loads, more management costs and more environmental externalities*" (Khajuria *et al*., 2011, p.1). As for local pollutants, the existing studies found more evidence of the EKC (see Chapter Two). However, the estimation technique they used has often been criticised, for example, for a simultaneity bias, multicollinearity, and a homogeneity problem. Although few studies addressed these problems, they have been measured on a cross-country basis, or on country-level time series data. This study will adopt the relatively new panel cointegration and causality technique to examine the EKC model in China, which can overcome some econometric weaknesses. For example, a single-country panel data set with a relatively large time dimension can alleviate the problems of heterogeneity, cross unit cointegration and cross-section dependence; the stationarity properties of the variables are investigated by using the first and second generation unit root and cointegration tests; and a fully modified ordinary least square (FMOLS) method is applied, which allows for serial correlation and endogeneity of regressors in the cointegration equation.

COD is the most prevalent measure of water pollution in China, which can leads to algal blooms and indicates the presence of water-borne pathogens (Hu, 2010). Since the monitoring stations are on rivers, a decline in concentrations of this pollutant can quickly be measured if emissions are stopped. China has some effective programs to improve water quality, such as the water pollution levy system. Therefore, COD is the only pollutant to show a reduction trend during the past 20 years. Following Dean (2002), we extend the time period to 2009 to see the impact of trade on China's water quality.

1.2 Objective and Methodology

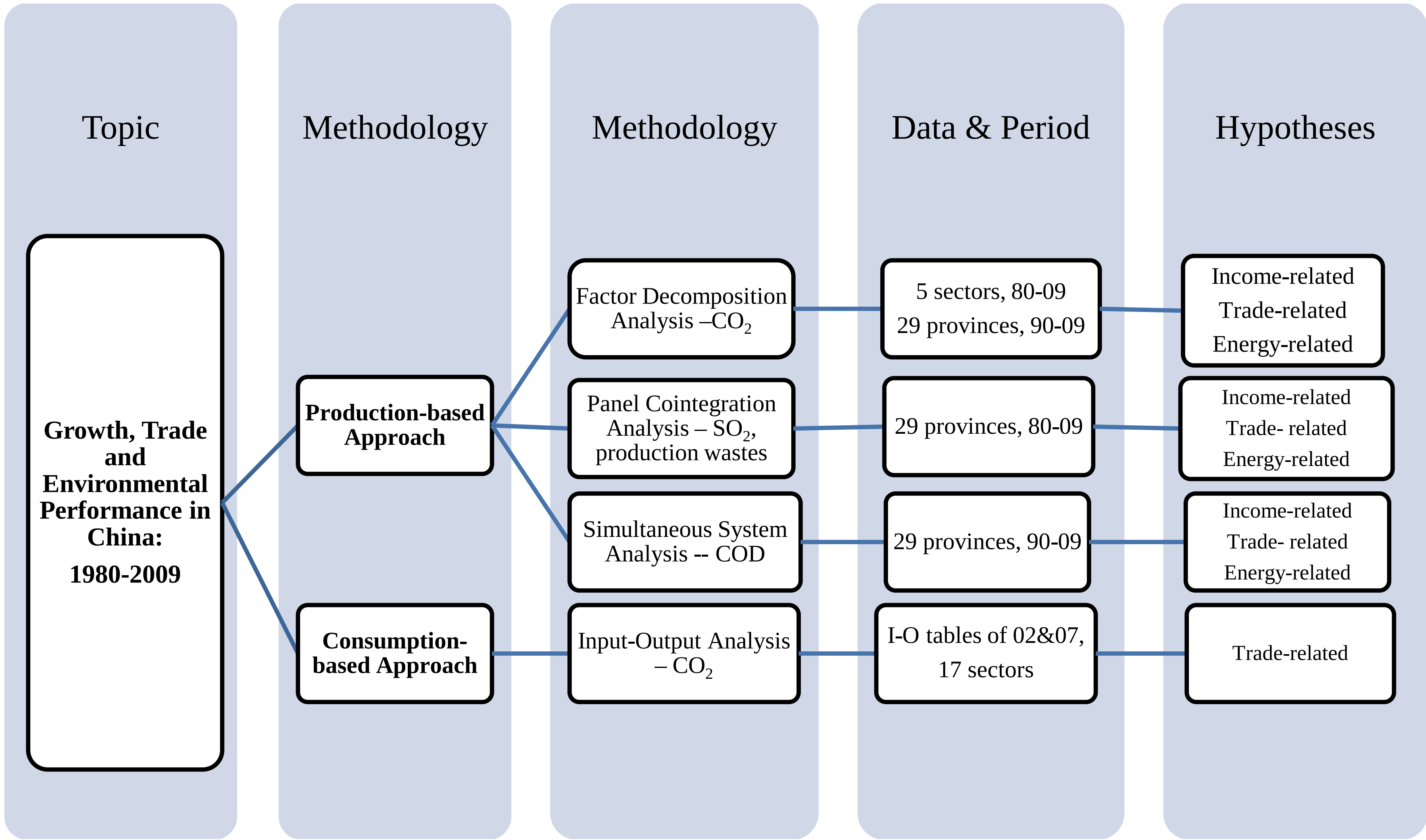
The main objective of this thesis is to examine the environmental performance of China during the period 1980-2009. In particular, we examine the rates and trends in absolute and per capita emissions of four types of industrial pollutants: CO_2, SO_2, COD and production wastes, through the prism of relevant economic theories. Specifically, three hypotheses were tested (See Figure 1.1 showing the framework of study):

(1) The income-related environmental hypothesis: increasing per capita incomes will eventually result in a positive impact on the environment (the EKC hypothesis);

(2) The trade-related environmental hypothesis: increasing international trade will eventually result in a positive impact on the environment via income and technique effects; and,

(3) The energy-related environmental hypothesis: increasing energy efficiency will eventually result in a positive impact on the environment via increasing per capita incomes and technological innovation.

Figure 1.1: Framework of Study



CO_2 Emissions

- ***Method 1: Factor Decomposition Analysis (Production-based Accounting)***
- ***Method 2: Input-Output Analysis (Consumption-based Accounting)***

This study will identify the major factors influencing the rapid growth of CO_2 emissions in China from 1980 to 2009, at both aggregate and disaggregate (sectoral and provincial) levels. Firstly, we will estimate the sectoral and provincial CO_2 emissions, following the IPCC manual. Then, we will break CO_2 emissions into five contributing factors to investigate their impacts, namely economic growth, population growth, economic structural change, carbon emission coefficient and energy intensity. The Logarithmic Mean Divisia Index (LMDI) method will be adopted. Ang *et al.* (1998), Ang and Liu (2001), and Ang (2004) argue that the LMDI should be preferred to other decomposition methods due to its advantages, such as path independency, ability to handle zero values and consistency in aggregation. One of the significant features of this study is the calculation of sectoral and provincial CO_2 emissions over the long term; and provincial CO_2 decomposition is provided because of consideration of provincial differences, which may help to draw up specific policies.

The problem of carbon leakage has been raised recently due to the accelerating rate of globalisation. Ahmad and Wyckoff (2003) and Peters and Hertwich (2008a) argue that a measure based on domestic consumption is fairer. This study will investigate the impact of foreign trade on CO_2 emissions at the sectoral level, using the consumption-based approach. Environmental extended input-output analysis (Leontief and Ford, 1970; Miller and Blair, 2009) is recognised as a well established approach (Wiedmann, 2009), and widely used to investigate greenhouse gas emissions embodied in international trade flows. A single-country input-output model will be applied to calculate the CO_2 emissions embodied in China's exports and imports, based on recent input-output tables for 2002 and 2007. Unlike most existing studies, which assume that the emission intensity of imported production is the same as that of domestic production, we assume the average emission intensity for China's top 20 import trading partners is representative of those of China's imported production. And the processing trade is also taken into account.

SO_2 Emissions and Production Wastes (wastewater, waste gas and solid waste)

– ***Method 3: Panel Cointegration Analysis***

A quadratic EKC model will be used to examine the long-run and short-run relationship between economic growth, foreign trade, energy consumption and environmental quality. This study focuses on a panel of 29 Chinese provinces, observed over period 1980-2009. The panel data regression model will be estimated. The results will be interpreted in the light of the hypotheses formed in our study.

The significance of this study is as follows: (a) this is the first study to adopt the relatively new panel cointegration method to analyse China's environmental performance; (b) it employs a single-country panel data set which has a relatively large time dimension, in order to alleviate the problems of heterogeneity, cross-section cointegration and cross-section dependence; (c) it uses the second generation panel unit root and cointegration tests to examine the stationarity properties of all variables; (d) it performs the panel FMOLS method, which is asymptotically efficient and allows for serial correlation and endogeneity of regressors in the cointegration equation; (e) it uses the panel vector error correction model (VECM) to test the direction of causality.

COD

– Method 4: Simultaneous Equations Analysis

This study will investigate the impact of foreign trade on China's water quality. Following Dean (2002), a simultaneous equations system, which incorporates the multiple effects of foreign trade on the environment, will be used on pooled Chinese provincial data from 1990 to 2009. The two-stage least square (2SLS) method will be used. The trade openness variable in the emission growth equation captures the direct impact of trade on the environment, while the income variable in the emission growth equation and the trade openness variable in the income growth equation together capture the indirect impact of trade on the environment. When the net impact (net values of these two impacts) is negative, hypothesis (2) can be accepted. We will add the energy consumption variable in both emission and income growth equations to capture its impact. We extend the analysed time period to see the recent situation, and the differences between our estimates and Dean (2002)'s.

The data used in this study are mainly from the *China Statistical Yearbook*, the *China Environmental Statistical Yearbook*, the *China Energy Statistical Yearbook* and the *Comprehensive Statistical Data and Materials on 60 Years of New China*. The provincial dataset of SO_2 emissions and production wastes is from 1980 to 2009, and the provincial COD dataset is from 1990 to 2009. We estimate the sectoral CO_2 emissions from 1980 to 2009, and provincial CO_2 emissions from 1990 to 2009 by using the International Panel on Climate Change (IPCC) manual. These datasets are advantageous for several reasons. Firstly, China is one of the few developing countries that have had an extensive air and water pollution levy system in place for many years. Secondly, China also has undertaken extensive trade reforms since 1980, which resulted in a huge increase in international trade. Furthermore, 30 or 20 years of data pooled across the provinces or sectors should yield a close approximation to the experience of one developing country.

1.3 Structure of the Thesis

This thesis is divided into nine chapters. The second chapter is a literature review, including both theoretical and empirical studies.

Chapter Three gives a picture of China's economic reforms and performance by examining how the Chinese economic structure has changed from the 1980s to the present time.

Chapter Four presents the problems of energy consumption and environment in China due to rapid economic growth and industrialisation.

In Chapter Five, China's CO_2 emissions are calculated firstly for each sector and province. A factor decomposition method is then used to identify the main factors influencing the rapid growth of CO_2 emissions at both aggregate and disaggregate levels, based on domestic production activities.

In Chapter Six, the problem of carbon leakage is examined. The consumption-based approach will be used to calculate China's embodied CO_2 emissions in international trade based on recent input-output tables.

In Chapter Seven, the EKC model is used to test the long-run and short-run relationship between China's economic growth, foreign trade, energy consumption and environmental pollution (three production wastes and SO_2 emissions) from 1980 to 2009. The criticisms raised against the econometric methodology used in the EKC literature will firstly be discussed. The recent econometric techniques will be incorporated to overcome some of these difficulties in this chapter.

The focus in Chapter Eight is on the COD, which is the most prevalent measure of water quality in China. A simultaneous equations system will be used to capture the effect of trade through direct impact via the composition effect, and indirect impact via the scale and technique effects.

Chapter Nine presents a summary of major findings and policy recommendations from previous chapters, and ends with limitations and recommendations for future studies.

Chapter Two

Review of Literature on the Impact of Trade and Income on the Environment

2.1 Introduction

The EKC is a hypothesised relationship between per capita environmental quality indicators and income (the income-related environmental hypothesis). It states that pollution increases initially at the early stage of economic growth, but after a certain level of income has been reached, the trend reverses, and hence at high income levels economic growth leads to lower pollution. This implies that there is an inverted U-shaped relationship between environmental quality indicators and income per capita. Recently, researchers have connected the EKC with policy-making, technological progress, structural change, international trade and energy use (Harbaugh *et al*., 2000; Lieb, 2002; Millimet, 2000; Cole, 2000b). On this basis, this literature gives possible reasons for the EKC shape. This chapter also addresses all the EKC-related methodologies. This includes production-based approach (for example, Grossman and Krueger, 1995; Antweiler *et al.*, 2001; and Zhang, 2000a), consumption-based approach (for example, Wyckoff and Roop, 1994; and Weber and Matthews, 2007), and trade- and energy-related literature (for example, Cole and Elliot, 2003; and Copeland and Taylor, 2004).

This chapter is organised as follows: in section 2.2, we review the theoretical literature, describing the EKC model, explaining the relationship between trade and environment, and then listing the possible reasons which explain the EKC shape; section 2.3 surveys the empirical literature, including the traditional EKC studies, decomposition studies, consumption-based accounting studies, and trade- and energy-related studies; and section 2.4 concludes.

2.2 Theoretical Literature

2.2.1 Income and Environment

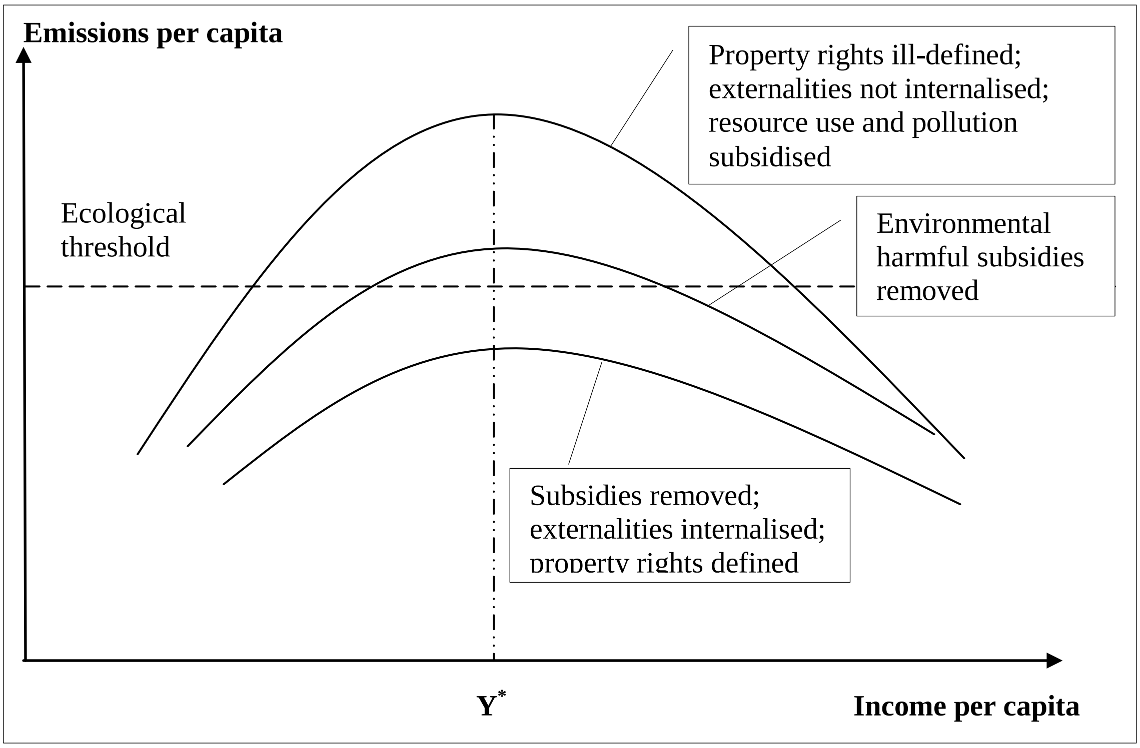
The debate over the relationship between economic growth and environmental quality has been ongoing for several decades. Many environmentalists believe that economic growth necessarily results in a degradation of environmental quality, and the relationship is monotonically rising (Cole, 1999), because growing economic activity (increasing production and consumption) requires more inputs (energy, natural resources) and then generates more pollution, which degrades the environment, despite rising incomes (Georgescu-Roegen, 1971; Meadows, *et al.*, 1972; Daly, 1993). Lopez (1994) and Stokey (1998) argue that if this is the case, growth must sooner or later come to a halt since the world's capacity to absorb pollution is only limited; unless there is pollution-saving technological progress that allows production to increase without causing additional pollution.

However, in the early 1990s, Grossman and Krueger (1991)[2] found evidence that while some pollutants rise with income at low levels, a turning point is reached at a higher income level and further income growth subsequently leads to lower pollution (see Figure 2.1). Panayotou (1995) first called this inverted U-shaped pattern between income and pollution an Environmental Kuznets Curve (EKC) after the original Kuznets curve, which presents an inverted U-shaped relationship between income inequality and income, proposed by Kuznets (1955). Some EKC studies point out that

[2] Before Grossman and Krueger (1991), there was hardly any empirical evidence concerning the relationship between economic growth and the environment.

pollution can be considered as merely a transitional phenomenon in the course of economic growth. Beckerman (1992) and Cole (1999) argue that in the long run, the surest way to improve the environment is to become rich, because only economic growth can provide the recourses with which to tackle environmental problems.

Figure 2.1: The Environmental Kuznets Curve (EKC)



Note: Y* indicates the turning point which signifies that at this income level emissions per capita begin to decrease.
Source: Panayotou, 1997.

Panayotou (1997) argues that if such an EKC relationship also exists for many pollutants as an inevitable results of structural and behavioural changes accompanying economic growth, a steep EKC is neither economically nor environmentally optimal. In order to avoid deterioration of environmental quality beyond an ecological threshold (as shown in Figure 2.1), Panayotou (1997) recommends the removal of environmentally harmful subsidies on energy and transport, better-defined and enforced property rights, full-cost pricing of resources to reflect growing scarcities, and the internalisation of environmental costs through pollution taxes and tradable permits.

The standard EKC is a simple quadratic function of the logarithmic of income[3], which is expressed as follow:

$$\ln(Ep)_{it} = \alpha_i + \delta_t + \beta_1 \ln(GDPp)_{it} + \beta_2 \left[\ln(GDPp)\right]_{it}^2 + \varepsilon_{it} \quad (2.1)$$

where Ep and $GDPp$ indicate per capita emissions and GDP, respectively. α_i and δ_t are intercepts parameters which vary across regions i and years t. ln indicates natural logarithms, and ε_{it} is an error term. βs jointly defines the relationship between per capita emissions and per capita GDP. The inverted U-shaped curve derived from the above formula requires β_1 to be positive and β_2 to be negative; while the turning point income suggests where emissions are at a maximum, which is given by $\tau = exp\left(\frac{-\beta_1}{2\beta_2}\right)$.

In the empirical literature, some other covariates have been included in the EKC model, such as population density, population growth, or income inequality. However, trade has attracted more attention, because the impact of free trade on the environment is complicated when environmental externalities are considered[4]. In the next section, we will briefly explain the relationship between trade and the environment.

[3] The earliest studies use a quadratic/cubic EKC in levels. Stern (2004) argues that, because of more economic activities, more use of resources and inevitably more production of waste, regressions that allow levels of indicators to become zero or negative are inappropriate. A logarithmic dependent variable will impose this restriction.

[4] In the standard Heckscher-Ohlin model (HO), there is no change in the overall use of the environment. Generally, countries with abundant environment will specialise in pollution-intensive goods due to free trade. However, following the Stolper-Samuelson theorem, the price of using the environment is bid up when externalities are internalised, and then firms will shift to clean goods by using environmentally friendly techniques.

2.2.2 Trade and Environment

Grossman and Krueger (1991) also investigate the potential effects of the North American Free Trade Agreement (NAFTA) on the environment. They suggest that trade liberalisation may affect the environment through scale, composition and technique effects, which is widely cited by other researchers.

Antweiler *et al.* (2001) develop this framework further in their study on the impact of free trade on the environment. They assume a small open economy that produces two goods X and Y, using labour (L) and capital (K) as inputs, supposing production of X is capital-intensive and generates pollution, and production of Y is labour-intensive and generates no pollution at all. The trade frictions β influence the price of product. The price of X (p_X) depends on β and the world price (p^w). Good Y is taken as the numeraire ($p_Y = 1, and\ p_X = \beta p^w$). The government sets a pollution tax (τ). Total pollution can be expressed as:

$$Z = \varepsilon\varphi S \tag{2.2}$$

where ε is the emissions per unit of X, φ is the share of X in total output, and S represents the scale of the economy. Therefore, the percentage change in the demand for pollution is given as following:

$$\hat{Z} = \hat{S} + \hat{\varphi} + \hat{\varepsilon} \tag{2.3}$$

where $\hat{S}$ represents the scale effect, $\hat{\varphi}$ is the composition effect, and $\hat{\varepsilon}$ is the technique effect.

Scale effect: trade liberalisation has a positive effect on a country's economic and output growth, because it opens access to previously restricted markets and encourages foreign direct investment (FDI) in productive assets. A rapid expansion in the scale of economic activity may place more stress on the environment, because it requires more inputs and more natural resources to satisfy the increased production. Moreover, as a by-product, more output implies more waste and emissions. Assuming constant technique and composition effects, the scale effect likely leads to raised pollution. However, Kirkpatrick and Scrieciu (2008) argue that there are a number of other factors which make it difficult to isolate the pure scale effect and identify a strong pattern in the commonly assumed detrimental relationship between increasing economic activities and environmental performance. Nevertheless, it is acknowledged increasingly that scale of production increases environmental degradation, which indicates a negative impact on the environment.

Technique effect: trade liberalisation promotes output growth and increases income, and most countries tend to switch more resources into environmental protection by stricter regulations and advanced technologies. In order to respond to market and institutional incentives, producers may discard the old input-intensive methods and invest in more environmentally sustainable production technologies which have a positive effect on both the economy and the environment. Moreover, trade liberalisation can encourage and facilitate access to environmental know-how and technology, through imports of environmentally friendly goods and/or cleaner production techniques embodied in FDI (OECD, 2000; Hoekman *et al.*, 2002). Therefore, the technique effect improves the quality of the environment, showing a positive impact.

Composition effect: trade liberalisation can affect the structure of the economy. Depending on the comparative advantages between trading partners, trade liberalisation may encourage a country to specialise in some goods and limit others, and then change the type and level of pollution across regions. Therefore, the composition effect may have a positive or negative impact on environmental quality due to change in the range of goods. If a country has a comparative advantage by producing environmentally beneficial goods and specialises in this, trade liberalisation will be good for the environment. If a country has a comparative advantage by producing environmentally damaging goods, trade liberalisation will increase environmental degradation. The composition effect can capture a part of the pollution haven hypothesis, which is introduced in the next section. Even if the pollution haven hypothesis fails, the composition effect may generate other results. For example, with increases in the level of income the demand for cleaner goods increases, which might push producers to shift production and then reduce pollution.

Generally, the scale and technique effects are considered negative and positive, respectively; while the composition effect appears to be ambiguous. Therefore, trade may influence the EKC relationship both positively and negatively.

2.2.3 Explanations of EKC

The rising part of the EKC can be explained by the fact that more production causes more pollution. When economic activities increase, more material is transformed into other goods, into waste, and pollution (Neumayer, 1998, p.162). This scale effect explains why pollution increases with income at low levels. The declining part of the EKC can be explained by several reasons, such as the increase in demand for environmental quality, technological progress, structural change and foreign trade.

Demand for Environmental Quality

The first reason for the downturn of the EKC is that demand for environmental quality increases with income, assuming environmental quality is a normal good[5]. Only when basic needs have been met are additional resources devoted to treating pollution. Rising income makes these resources available, and makes environmental quality more important (Eglin, 1995; Vogel, 1999). Selden and Song (1994) point out that environmental awareness, the fear of environmental health hazards and the concern for reduced life expectancy grow correspondingly with rising income.

Due to the increased demand for environmental quality with rising income, people increase their support for environmental policies, and push government to implement stricter regulations, which is an effective way of bringing down pollution (Hettige *et al.*, 1996). In addition, relatively advanced political institutions are necessary to internalise externalities and to enforce regulations and thus to cause the downturn of the EKC. However, it is believed that advanced social, legal and fiscal institutions may only be feasible in developed countries (Baldwin, 1995; Andreoni and Levinson, 2001). Evidence is found that higher GDP makes policy decisions more environmentally friendly (Congleton, 1992), and rich democratic countries have lower pollution levels (Torras and Boyce, 1998; Harbaugh *et al.*, 2000). Therefore, increasing demand for environmental quality and ensuring better policy measures may cause the turn in EKC.

Technological Progress

The second reason explaining the EKC is technological progress. With rapid economic growth, more capital is invested in installation of modern technology or replacement of

[5] Some researchers argue that environmental quality is a luxury good (Ansuategi *et al.*, 1998; Neumayer 1998; Vogel, 1999; De Bruyn, 2000). However, the empirical evidence shows that income elasticity of demand for environmental quality is smaller than one, though positive, suggesting environmental quality is a normal good (Kristom and Riera, 1996). Moreover, Lieb (2002) proposes a theoretical model showing that when income grows by one percent, pollution must decline for the downturn of the EKC, but not necessarily by more than one percent. Therefore, environmental quality should be a normal, not luxury good.

old technology (Neumayer, 1998). Technological progress can move in an environmentally friendly direction with appropriate policies (Lieb, 2002). For example, policy induces the use of end-of-pipe technology that has been important for the reduction of heavy metals emissions (De Bruyn, 2000). Smulder and Bretschger (2000) argue that policy-induced technology shifts explain the EKC. At the early stage, after introduction of a labour-saving but polluting technology, pollution increases; an emissions tax will be imposed when pollution has raised public concern; and then this tax will induce the development of clean technologies, which causes pollution to drop immediately. Hence, technological progress is important for the relationship between growth and environmental quality. Once cleaner technology is available, economic growth may not increase pollution.

Structural Change

The most common explanation of the EKC is structural change (Millimet, 2000). It is believed that there is almost no pollution when people live at subsistence level production; as the country grows, agriculture intensifies and industry starts to develop, which leads increasingly to greater pollution; and when the country becomes prosperous, an expanding service sector may cause pollution to fall again. Furthermore, the structure within the industrial sector changes as well. When income rises, the composition of manufacturing firstly shifts from light to heavy industry, for example from relatively clean industries (food and textiles) to high-polluting industries (chemicals, minerals, metals and machinery); while at higher income levels, high-tech industries and research activities, which are far less polluting, begin to expand (Syrquin, 1988; Panayotou, 1995; Dinda *et al.,* 2000). Hence, structural change – the rise and fall of heavy industry – could explain the EKC.

However, De Groot (1999) and Cassou and Hamilton (2000) argue that structural change alone, without policy and technological progress, cannot explain the EKC, although it helps to reduce emissions. Many researchers add an additional variable (ratio of manufacturing to GDP) in the EKC model to examine whether or not structural change is important. Some studies find it is positive (Rock, 1996; Panayotou, 1997; Cole, 2000a), others conclude that the effect of structural change is small or even insignificant (Grossman *et al.*, 1994; Suri and Chapman, 1998).

Furthermore, decomposition analysis[6] provides more evidence of structural change and technological progress. Basically, the emissions change can be broken into scale effect, composition effect and technique effect. Due to the scale effect, economic growth leads to more pollution; the composition effect shows how structural change affects emissions; and the technique effect describes how changes in emission intensities caused by new technology influence emissions. Decomposition analysis has been widely used in CO_2 and energy consumption studies (e.g. Howarth *et al.*, 1991; Ang and Lee, 1994; Sun, 1998; Stern, 1999; Ang, 2006; Vinuya *et al.*, 2010). They find that the composition effect is small and even increases emissions, while the technique effect is large and always decreases emissions. Torras and Boyce (1998) conclude that there is only one reason structural change can explain the downturn of the EKC: the polluting sector no longer produces, but imports from overseas. This will be discussed in the "Foreign Trade" section.

Foreign Trade

With increases in trade and investment liberalisation, some countries will specialise in producing dirty goods and export them to others. This can lead to high pollution in these

[6] More detail will be discussed in Chapter Five.

countries, and low pollution in the countries which specialise in and export clean goods, but import dirty goods. The possible determinants of a country specialising in clean or dirty goods depend on the differences in each country. First, according to the standard Heckscher-Ohlin (HO) trade theory, trade patterns can be determined by capital and labour endowments. Assuming manufacturing industry is capital intensive and more polluting than others, the country with a higher capital/labour ratio will specialise in dirty goods, while the country with a lower capital/labour ratio will specialise in clean goods. Second, natural resource endowment is one of the determinants. There is no doubt that a country will export its abundant natural resources, and foreign trade is indeed likely to damage the environment. Third, the levels of environmental regulations are different among countries, depending on the differences in the demand and supply of environmental quality. When countries liberalise their trade and investment, those with less demand for environmental quality will set low environmental regulations, while others with more demand for environmental quality will set stringent regulations. The countries with low regulations, usually the middle-income countries, want to attract more foreign investment and share more international market by producing and exporting dirty goods. And in order to decrease the production cost, the dirty industries will migrate to those countries with weak environmental regulations, from high-income countries with stringent regulations. Therefore, migration leads to low pollution in high-income countries and high pollution in middle-income countries, known as the Pollution Haven Hypothesis (PHH), which can partially explain the EKC.

Saint-Paul (1995) analysed the consequence of migration for the EKC. He assumes that there are two goods (dirty and clean), and pollution is strictly local and tied to the production of the dirty good. He finds that low-income countries only produce the dirty good; the richer of two low-income countries can produce more and will suffer from more pollution; middle-income countries produce both goods; the richer of two middle-income countries produces less of the dirty goods because the demand for environmental quality rises with income; and high-income countries fully specialise in producing the clean goods and imports its consumption of the dirty goods.

Further evidence shows that production of dirty goods may grow faster in developing countries than in developed countries through migration (Low and Yeats, 1992; Perrings and Ansuategi, 2000), while the consumption of dirty goods rises faster than their production in developed countries (Rothman, 1998), due to imports from developing countries. Most EKC studies analyse production-based measures of pollution. Rothman (1998) argues that consumption-based measures[7] should be used instead. He analyses the ecological footprint – a consumption-based measure – and finds a monotonically rising relationship between income and pollution. Hence, recent research has begun to raise doubt about the existence of the EKC by using production-based measure: economic growth may not reduce pollution, but only relocate it. Moreover, Cole (2000b) argues that trade itself is polluting, being responsible for one eighth of world oil consumption. And international trade contributes substantially to energy-related environmental damage (Ekins *et al.*, 1994).

Therefore, foreign trade, especially migration of dirty industries, may explain the EKC in cross-country studies, but hardly in single-country studies. Furthermore, migration causes serious problems in developing countries, when they attempt to reduce pollution. Because they cannot relocate the polluting production process, the only way to lower the pollution is abating it by cutting production and consumption.

[7] Consumption-based accounting approach will be detailed in Chapter Six.

Summarising, the crucial explanation of the EKC is increasing demand for environmental quality and technological progress with appropriate policy, while structural change and migration of dirty industries may partially help to explain the EKC.

2.3 Empirical Literature

Since the studies of Grossman and Krueger (1991), hundreds of empirical studies have been done to test whether the EKC actually exists between economic growth (usually measured by real per capita Gross Domestic Product, GDP) and environment (usually measured by air/water quality indicators), and if so, to find the turning point. The EKC studies can be classified into two major groups, cross-country and single-country studies, through parametric or non-parametric approaches. The empirical studies of trade and energy impact on the environment are surveyed in this section, as well. For CO_2 emissions, literature addressing both the production and consumption accounting approaches is surveyed.

2.3.1 Cross-country EKC Studies

Due to insufficiently long time series of environmental data, a cross-country approach is adopted in earlier studies. Both concentrations and emissions[8] of air and water pollution are used to measure the environmental quality.

[8] There are two main differences between concentrations and emissions data. First, they provide different information. Concentrations can provide more information about the impact of a particular pollutant on human health, while the information emissions provided is more on wider environmental issues, such as climate change or acid deposition. Second, concentrations data tend to be 'noisier' than emissions data and require the inclusion of a number of dummy variables to capture site-specific effects, such as the nature of the observation site, the type of measuring equipment, the average temperature and the level of rainfall (Cole and Elliott, 2003).

Grossman and Krueger (1991; 1995), the first two influential EKC empirical studies, use air quality indicators (per capita concentrations of SO_2, dark matter and suspended particulate matter or SPM) from the Global Environmental Monitoring System [9] (GEMS) to examine the relationship between urban air quality and economic growth. The data of these two studies are taken from a number of the cities around 43 countries from 1977 to 1988. Both of them incorporate several empirical specifications, such as a time trend, population density, type of land use and the location of city. The differences are that (1) the 1991 paper uses the quadratic form of GDP per capita in the regression, while the 1995 paper incorporates the cubic form; (2) the 1991 paper includes either a dummy variable for each $2,000 interval of GDP per capita or a polynomial of current GDP per capita, while the 1995 paper includes a polynomial of current and lagged GDP per capita. However, they generate similar results. They conclude that the EKC exists between SO_2 and dark matter and GDP per capita, suggesting that the concentrations of SO_2 and dark matter first increase with increases in GDP per capita and then begin to decrease after the GDP per capita of $4,000 - $6,000 was reached; while for SPM there are some studies with a U-shaped curve and others with monotonically decreasing with GDP per capita. Besides the air pollutants, Grossman and Krueger (1995) also test the EKC for several water pollutants. They find evidence supporting EKC for COD and biochemical oxygen demand (BOD) with the turning point of $8,000, and the U-shaped curve for dissolved oxygen (DO). Using the GEMS data set several studies confirm the inverted-U pattern, such as Shafik and Bandyopadhyay (1992), Panayotou (1997), Torras and Boyce (1998), Barrett and Graddy (2000), and Bradford *et al.* (2000).

Following the methodology of Grossman and Krueger (1995), Harbaugh *et al.* (2002) combine the GEMS data and the Aerometric Information Retrieval System (AIRS) to

[9] The GEMS dataset is a panel of ambient concentrations from a number of locations in cities around the world.

extend the data set, which is from 1972 to 1992. They re-examine the evidence of EKC for three common air pollutants (per capita concentrations of SO_2, smoke, and SPM) by applying both panel data fixed and random-effects models. Comparing with Grossman and Krueger (1995), they test a number of alternative specifications: adding explanatory variables, using time dummies instead of a time trend, using logs instead of levels, and averaging the observations across monitors in each country. They conclude that the evidence for EKC is "much less robust than previously thought", because the relationship between pollutant and income could be either an inverted U-shaped or a U-shaped curve, depending on the specification used. And they also find that the turning points are much higher than the value in Grossman and Krueger (1995). However, if the trade intensity and a democracy index are included in the regression, the turning points are just half of the value in Grossman and Krueger (1995). Therefore, they state that the turning point of the EKC is affected significantly by the forms of function, the control variables, the combination of cities/countries, and the time period included in the data set.

Besides concentrations data, emissions data are widely used to test the EKC hypothesis in recent cross-country studies. Generally, the existence of the inverted U-shaped curve is found and the estimated turning points for emissions tend to be at higher levels than for concentrations.

Using the emissions data for 22 Organisation for Economic Cooperation and Development (OECD) and eight developing countries during the period of 1979-1987 from the World Resource Institute, Selden and Song (1994) report the EKC pattern between four air pollutants (per capita emissions of SO_2, SPM, NO_X (nitrogen oxides), and CO (carbon monoxide)) and income, while they find the turning points are in the \$6,000 - \$10,000 income range.

Stern and Common (2001) estimate EKC for SO_2 emissions for 74 developed and developing countries from 1960 to 1990. This data base is produced by Lefohn *et al.* (1999) from the US Department of Energy and contains a large range of income levels and more data than other studies. They report that the turning points for the whole world, OECD, and non-OECD countries, are at \$29,000, \$48,920, and \$303,133 respectively, which are much higher than previous studies, suggesting that including more low-income data in the sample might generate a higher turning point (Stern, 2004).

Compared with the local pollutants, which are more likely to display an inverted U-shaped relationship with income, for the global pollutant (CO_2) the EKC hypothesis only holds for countries with sufficiently high income and the turning point is at a level beyond the income of most countries. Galeotti *et al.* (2006) consider the CO_2 emissions per capita for both OECD, and non-OECD countries, using two different datasets, one from the International Energy Agency (IEA) data base and the other from the Carbon Dioxide Information Analysis Centre (CDIA) data base. The EKC curve is only found for the group of OECD countries, with a turning point of US \$16,586. Similarly, Cole *et al.* (1997) report the existence of an inverted U-shaped relationship between the per capita emissions of CO_2 and income for 11 OECD countries, with a turning point of US\$62,700.

The semi- or non-parametric analysis[10] is also used to investigate the existence of EKC. Bertinelli and Strobl (2005) use a semi-parametric estimator on a sample of 108 countries (of which 82 are developing countries) over the period of 1950-1990. The result does not reject a linear relationship between per capita emissions of CO_2 and per capita GDP. For low incomes, the relationship is upward sloping, then flattening out, and increasing again at high incomes. Using a non-parametric approach, Azomahou *et al.* (2006) analyse a sample of 100 countries over the range 1960-1996, accounting for limited heterogeneity by including country-specific effects and *a priori* allowing the effect of income on CO_2 emissions per capita to vary over time. The result indicates a stable monotonic increasing relationship for all levels of income. Vollebergh *et al.* (2005) restrict their analysis to data of 24 OECD countries from 1960-2004, and find that once country-specific heterogeneity is allowed for, the non-parametric technique generates an inverted U-shaped relationships for the highest income countries in the sample. Therefore, the evidence from the semi- or non-parametric studies suggests that considerable heterogeneity in the relationship between income and emissions exists across countries.

Most EKC studies adopt the traditional estimation technique, which is modelling emissions indicators as a quadratic and/or cubic function of income. However, there are several limitations for such a testing method: (1) Simultaneity bias – not only does income influence pollution, pollution also has an effect on income. A simultaneity bias in the regression may impair the results. (2) Multicollinearity – when the explanatory variables are highly correlated, small changes in the data can have dramatic effects on the results (Green, 1997). However, multicollinearity is completely disregarded by most

[10] Semi- or non-parametric analysis aims at identifying the shape of the income-emissions relationship without resorting to *a priori* specifications of the functional form, raising concerns on the homogeneity assumption of the EKC.

EKC studies. (3) Stochastic trends – the data for EKC analysis is always time series, and it is necessary to consider whether the data is stationary or nonstationary, because the EKC regression could be a spurious regression, if there is no cointegration among nonstationary variables.

Within the realms of parametric modelling, another group of the empirical EKC studies has identified the problem arising from the presence of unit root type nonstationarity, which is relevant for both parametric and non-parametric approaches. Perman and Stern (2003) apply panel unit roots and cointegration tests to examine Stern and Common (2001)'s data and models. Individual and panel unit root tests suggest both emissions and income variables – log SO_2 emissions per capita, log GDP per capita and its square – have stochastic trends in most countries. The results of cointegration tests are not clear. An individual cointegration test indicates that most individual country EKC regressions cointegrate, but without correct signs. A panel cointegration test shows that cointegration is found in all countries, but the U-shaped relation displays in many countries. Neither individual nor panel cointegration tests provide the evidence to support the EKC hypothesis.

Narayan and Narayan (2010, p.662) recently proposed a new method to test the EKC hypothesis for 43 developing countries from 1980-2004 – "*the way of judging whether developing countries have reduced carbon dioxide emissions over time with growth in times is comparing the short-run income elasticity with the long-run income elasticity.*" This method avoids the problem of multicollinearity in the estimation because the equation does not include the income square or income cubed variables. Firstly, several panel unit roots and cointegration tests have been applied. The results reveal that CO_2 emissions per capita and income are both integrated of order one and cointegration. The presence of cross-section dependence is detected. Subsequently, the dynamic ordinary least square (DOLS) technique is used to estimate the short- and long-run income elasticities. They conclude that, based on analysis of individual countries, the long-run elasticity is smaller than the short-run elasticity for 15 out of 43 countries, which supports the EKC hypothesis; while the same results are only found for the Middle Eastern and South Asia panels. Using the same methodology, Jaunky (2011) investigates 36 high-income countries for the period 1980-2005. Based on individual countries, the result provides evidence of an EKC for five countries only; while for the whole sample the lower long-run income elasticity does not support EKC, but indicates that, over time, CO_2 emissions per capita are stabilising in the rich countries.

2.3.2 Single-country EKC Studies

Although some cross-country studies support the EKC hypothesis, they still cannot prove that the EKC exists in one single country. And some researchers claim that the cross-country version of EKC is just a statistical artefact, so examining the individual country should be more valuable (Vincent, 1997; Stern *et al.*, 1994). Some studies tend to examine the relationship between economic growth (GDP per capita) and environmental quality (pollution emissions per capita) using parametric or non-parametric analysis within one country. However, the results are also mixed.

Some researchers conclude that they cannot find evidence to support the EKC hypothesis. For example, Vincent (1997) examines whether EKC exists in Malaysia, choosing both air indicators (per capita SPM) and water indicators (per capita emissions of COD and BOD) from the late 1970s to early 1990s. He finds no pollutants exhibit EKC, and there is no statistically significant relationship between water pollutants and income. De Bruyn (1998) reports that SO_2, NO_X and CO_2 emissions per capita are increasing monotonically with income in Netherland, Germany, UK, and USA. Considering six air pollutants (CO_2, SO_2, N_2O, CH_4, and NO_X) in Spain for the period 1980-1996, Roca *et al.* (2001) fail to find the statistical evidence to support the EKC for any of them. Similar results are reported by Egli (2002), Roy and Van Kooten (2004), and Yue *et al.* (2007) following other individual countries over time.

Numbers of studies provides empirical evidence in support of the EKC relationship between emissions and income. Giles and Mosk (2003) examine the relationship between income and CH_4 emissions per capita in New Zealand for the period 1895-1996. Based on both the traditional quadratic/cubic model and non-parametric model, they find evidence for the EKC hypothesis. Millimet and Stengos (2000), and Millimet *et al.* (2004) use the semi-parametric partially linear model to examine US emissions, and find the inverted U-shaped curves for SO_2 and NO_X. Using a smooth transition model, Aslanidis and Xepapadeas (2004) find an N-shaped curve for SO_2 emissions in the US from 1929-1994.

The other group of single-country studies deals with the testing of a causal relationship between per capita emissions and economic growth. Liu (2006) conducts Granger-causality tests on real per capita GDP and four air emissions (CO_2, SO_2, NO_X, and CO) for Norway. He finds that a long-run causal relationship runs from GDP to CO2 and CO emissions, while a short-run causal relationship is found from SO_2 and NO_X emissions to GDP. Soytas *et al.* (2007) investigate the long-run causality between CO_2 emissions per capita, energy use per capita, and income in the US. They do not find evidence of causality between either income and CO_2 emissions, or income and energy use. Soytas and Sari (2009) find similar results in Turkey.

2.3.3 Decomposition Analysis Studies[11]

Factor decomposition analysis provides more evidence of the impact of structural change and technological process on the environment. Howarth *et al.* (1991) use the Laspeyres index and Divisia index to characterise energy consumption in the manufacturing sector in eight OECD countries during 1973-1987. Scholl *et al.* (1996) explore the impact of transport activity, the mix of travel models, energy intensity, CO_2 intensity and fuel mix[12] on the growth of CO_2 emissions in nine OECD countries. He concludes that travel-related activity is the dominant source of emission growth.

Using the Divisia index approach, Lin and Chang (1996) investigate emissions of CO_2, NO_X and SO_2 from Taiwan's major economic sectors during the period of 1980-1992. They find that economic growth is the major factor influencing the variation of emission intensities, while the impact of fuel mix is small. Using the same approach, Shrestha and Timilsina (1996) examine CO_2 intensity in 12 Asian countries during 1980-1990. They include three factors in estimation: fuel mix, fuel quality and generation efficiency from thermal power plants.

Adopting the adaptive weighted Divisia index, Greening *et al.* (1998) analyse the energy consumption and carbon intensity of the freight sector of 10 OECD countries. Zhang (2000a) analyses the impact of fuel mix, energy saving, economic productivity and population expansion on the growth of CO_2 emissions in China from 1980-1997. Paul and Bhattacharya (2004) identify four key factors (including pollution coefficient, energy intensity, structural changes and economic activity) influencing the energy-related CO_2 emissions from Indian major economic sectors during the period 1980-

[11] The differences in decomposition methods are discussed in Chapter Five.
[12] Fuel mix refers to the share of primary fuels consumption in total energy consumption.

1996. Their results show that the most important component of CO_2 emission is economic growth.

Steenhof (2006) uses the Laspeyres index method to decompose electricity demand in the industrial sector into industrial activity, structural share and energy intensity. He finds that industrial activity and fuel shift are the major factors in increasing the demand for electricity in China. In another paper, Steenhof (2007), the decomposition analysis is used to quantify factors leading to changes in the volume of CO_2 emitted from electricity generation in China. He finds that the gain in the efficiency of thermal generators is the most important factor for the decline in emission intensity.

Recently, the LMDI method has been widely used to decompose energy-related CO_2 emissions. Bhattacharyya and Ussanarassemee (2004) analyse the changes in industrial energy intensities and CO_2 intensities in Thailand during 1981-2000, and then identify the factors affecting these two intensities. They conclude that both intensities have declined to some extent over the period 1981-2000. For further analysis, they split the whole period into several sub-periods. They found that the impact of each factor on the CO2 intensities is different in the sub-periods.

Lee and Oh (2006) decompose the changes of CO_2 emissions in 15 Asia-Pacific Economic Co-operation (APEC) countries between 1980 and 1998. They find that although GDP and population are key factors influencing the growth of emissions in all countries, in the high-income countries falling energy intensity, the share of fossil fuels and a change in the fossil fuel mix all reduce emissions, which partially offset the impact of the growth in the economies.

Akbostanci *et al.* (2008) analyse the CO_2 emissions of Turkish manufacturing industry at the four digit level by using four fuel groups for the period 1995-2001. They find the main causes of change in emissions are the changes in total industrial activity and energy intensity.

Vinuya *et al.* (2010) decompose the growth in US CO_2 emissions by state between 1990 and 2004. They conclude that improving the efficiency of energy use, lowering the share of fossil fuels in total energy consumption and the lowering of emission intensity of fuels all contribute to offsetting the effect of GDP per capita and population growth in CO_2 emissions across the US.

2.3.4 Trade and Environmental Quality Studies

Before 1991 a more systematic analysis of the relationship between trade and environmental quality did not exist. Grossman and Krueger (1991) divided the resultant impact into three independent effects: scale effect, technique effect and composition effect.

Grossman and Krueger (1991) first use the notion of scale, composition, and technique effects arising from trade liberalisation to investigate the environmental impact of NAFTA. They set up a HOS model and regress US imports from Mexico in 135 industries on factor shares. On the basis of their estimation, the authors find that any income gains created by NAFTA would tend to lower pollution in Mexico, but there is no relationship between the intensity of pollution and the pattern of US imports from Mexico. After combining the evidence on scale, composition, and technique effects, they conclude that the competitive advantages created by lax pollution controls in

Mexico play no substantial role in motivating trade and investment flows, and trade liberalisation via NAFTA should be good for the Mexican environment.

Following Grossman and Krueger (1991)'s methodology, Cole and Raynor (2000) calculate coefficients of scale, composition, and technique effects in order to measure the environmental impact of the Uruguay Round trade liberalisation. They find that the emissions of all five pollutants（SO_2, NO_X, CO, CO_2 and SPM) increase in developing and transition regions because of the Uruguay Round, while in developed regions emissions of three pollutants (SO_2, CO and SPM) decrease and two (NO_X and CO_2) increase. They conclude that the environmental impact will be considerably greater if the Uruguay Round affects the rate of economic growth.

Beghin *et al.* (1995) analyse the impact of trade liberalisation with better terms of trade (TOT) with the US, Canada and Mexico on several pollutants and are able to find a positive scale effect of liberalisation on pollution, whereas composition and technique effects are negative, and the overall impact of trade liberalisation is negative. Hence, they conclude that trade openness is beneficial for the environment. In another study, Beghin *et al.* (2002) analyse the impact of trade reform in Chile's unilateral liberalisation on various pollutants, without making a distinction between scale, technique, and composition effects, and conclude that trade liberalisation would lead to an increase in pollution. Madrid-Aris (1998) investigates the implication of trade liberalisation under NAFTA for Mexico, California, and the US. He neither distinguishes between scale and composition effects, nor estimates the technique effect. However, he concludes that there is a positive relationship between trade liberalisation and pollution, and then that trade liberalisation has a detrimental effect on the environment.

Antweiler *et al.* (2001) develop a theoretical model to divide the impact of trade on pollution into scale, technique, and composition effects and then estimate and add up these effects using sulphur dioxide data for 43 countries over 1971-1996. They further estimate a reduced form equation for SO_2 concentrations. Among other things, they control for relative factor endowments, scale of production activity, determinations of policy, and openness to international trade. They find that if openness to international markets raises both output and income by 1%, pollution concentrations fall by approximately 1%. Therefore, they conclude that freer trade is good for the environment. Copeland and Taylor (2004) also conclude that where trade liberalisation increases the level of economic activity, the net impact on the environment is beneficial, but this finding is based on SO_2 concentrates only.

In contrast to the existing literature, Antweiler *et al.* (2001) give to the role of theory in developing and examining the hypotheses, and in the use of a consistent data set to estimate all three effects of trade.

Trade liberalisation can have an indirect impact on the environment through the effect of increasing national income on environmental quality. There have been a growing numbers of studies seeking to identify the effect of trade liberalisation on environmental quality. These studies estimate several pollutants and the results show that trade liberalisation has multiple simultaneous effects on environmental damage.

Using Antweiler *et al.* (2001)'s approach, Cole and Elliot (2003) attempt to examine the determinants of the trade-induced composition effect. Using national emissions data, they find trade liberalisation is good for the environment by reducing SO_2, which confirms the results of Antweiler *et al.* (2001); and they obtain similar results on composition effects for CO_2. But they find different results for BOD and NOx. The results for SO_2 and BOD suggest further liberalisation will reduce per capita emissions, while for NOx and CO_2 trade liberalisation is likely to increase emissions. Cole and Elliot (2003) conclude that their results for pollution intensities are more optimistic, and for all four pollutants trade liberalisation will reduce the pollution intensity of output. Copeland and Taylor (2004) argue that in a model with many pollutants and goods, the relative importance of pollution haven versus factor endowment motives cannot be expected to be the same across all pollutants.

Frankel and Rose (2002) examine the effect of trade on the environment. There are two major contributions: 1) controlling income and other relevant factors; 2) addressing the endogeneity of income and trade. From the gravity model, they find that trade is determined by GDP, population, land area and the distance between the pair of countries in question (physical distance as well as dummy variables indicating common borders, linguistic links, and landlocked status). Using these gravity instruments for trade and income, the study focuses on SO_2, N_2O, particulate matter, industrial CO_2 emissions, deforestation, energy depletion and rural clean water access. Their results show that there is a negative relationship between three types of air pollution (SO_2, N_2O and particulate matter) and openness, while only carbon dioxide pollution is found to worsen with trade liberalisation.

2.3.5 Consumption-based Accounting Studies[13]

Previous studies are based on the production-based accounting approach, the effectiveness of which has been questioned. A fairer measure based on domestic consumption has recently been gaining recognition, and has been used to provide a

[13] The difference between production- and consumption-based accounting methods, and the importance of the consumption-based method, are discussed in Chapter Six.

more complete and impartial picture of responsibilities for carbon reduction between developing and developed countries.

Environmental extended input-output (I-O) analysis (Leontief and Ford, 1970; Victor, 1972; Miller and Blair, 2009) is recognised as a well established approach and a useful top-down technique that allows pollution and resource use to be assigned to final demand in a consistent framework (Wiedmann, 2009). In recent years, there have been a number of studies that attempt to investigate environmental pressures, especially greenhouse gas emissions, embodied in international trade flows, by applying either the single-region input-output model (SRIO, such as OECD – Wyckoff and Roop, 1994; Brazil – Machado *et al.*, 2001; Denmark – Munskgaard and Pedersen, 2001; Italy – Mongelli *et al.*, 2006; Finland – Maenpaa and Siikavirta, 2007; US – Ghertner and Fripp, 2007; Shui and Harriss, 2006) or the multi-region input-output model (MRIO, such as Weber and Matthews, 2007; Peters and Hertwich, 2008a; McGregor et al., 2008; Ahmad and Wyckoff, 2003).

An earlier study, Wyckoff and Roop (1994), investigates the amount of CO_2 embodied in a group of manufacturing goods imported into the six largest OECD countries (USA, Canada, France, UK, Germany and Japan) during the period 1984-1986. Based on individual I-O tables for these countries, they find that about 13% of total CO_2 emissions are embodied in imported manufacturing goods, and conclude that the measures of greenhouse gas abatement policy will be misleading if only relying on domestic emissions. If emission control measures are implemented domestically, the cost of domestic goods would rise. This will encourage imports from other countries which do not have such measures. The environmental burden on these other countries will increase as they increase production to satisfy demand in the domestic country.

Munksgaard and Pedersen (2001) demonstrate the consequences of using both production- and consumption-based approaches to investigate the possibility of reducing CO_2 emissions in Denmark. By subtracting total emissions based on two approaches, the authors developed the concept of "CO_2 trade balance", and their results show that Denmark's CO_2 trade balance changed significantly from a surplus of 0.5 million tonnes in 1966 to a deficit of 7 million tonnes in 1994.

Machado *et al.* (2001) evaluate the impact of foreign trade on energy and CO_2 emissions for Brazil, using a commodity-by-industry IO model. The model incorporates energy commodities in physical units and non-energy commodities in monetary units for the year of 1995. Their results indicate that Brazil is not only a net exporter of energy and of carbon embodied in non-energy goods, but also that each dollar earned with exports embodied 40% more energy and 56% more carbon than each dollar spent on imports.

Adopting a SRIO method, Sanchez Choliz and Duarte (2004) analyse the embodied emissions in Spanish international trade. They compute the exports and imports of the Spanish economy in terms of the direct and indirect CO_2 emissions generated in Spain and abroad, and the re-exported emissions are considered. They find that the biggest CO_2 importers are other services, construction, transport materials and food, while the most relevant CO_2 exporters are transport materials, mining and energy, non-metallic industry, chemical and metals.

Mongelli *et al.* (2006) estimate carbon leakage, which is the emissions related to the import of intermediate goods from developing countries using the SRIO model for Italy. They find the carbon embodied in imports in 2000 accounts for almost 18% of the overall emissions in Italy. They identify that the most carbon-intensive sectors are iron, steel and other metals manufacturing, basic chemicals, artificial and synthetic fibres and pulp and paper products. Furthermore, they calculate the carbon embodied in these sectors imported from developing countries, and find that it accounts for more than 7% of the total imported emissions.

Tunc *et al.* (2009) estimate CO_2 emissions for the Turkish economy using an extended SRIO model for the year 1996. They identify the sources of CO_2 emissions and find that manufacturing industry and the agriculture and husbandry sectors are the major contributors of emissions. Their results show that the "CO_2 responsibility (which takes into account the CO_2 embodied in imports and links these to the foreign trade volume)" is 341.7 Mt (17% are due to imported goods to be used in domestic production and 5% are due to imported goods to satisfy private and public consumption). Tunc *et al.* (2009) conclude that consumer-related environmental policies for CO_2 reduction will not necessarily be more effective than policies aimed at producers, since the major part of CO_2 responsibility – domestically and imported – arises as a result of the production process.

Maenpaa and Siikavirta (2007) investigate the impact of different assumptions concerning the emissions embodied in imports in the case of Finland. Using the domestic emission intensities and the ratio of embodied emissions in imports in relation to domestic products from the OECD study (Ahmad and Wyckoff, 2003) in Finland's 1999 I-O table, the authors find the difference between these two methods is small: the net export of CO_2 emissions changes from 4.2 to 3.6 Mt. Moreover, the results for 1990-2003 show that Finland has increasingly been a net exporter of greenhouse gas emissions.

Ghertner and Fripp (2007) combine an Economic Input-Output Life Cycle Analysis Model with trade data for 1998 to 2004 to analyse the environmental impact of US trade. They generate the US balance of emissions embodied in trade (BEET) for Global Warming Potential (GWP), energy and other emissions. They assume the environmental intensity of production of US trading partners varies in different scenarios, and model the amount of leakage of environmental impact through trade. Their results show that with reasonable assumptions about the environmental intensity of imports and exports, the US had large and growing BEET between 1998 and 2004; especially in 2004, this leakage exceeds 10% for all studies impacts and exceeds 20% for GWP.

Using the more comprehensive MRIO model, Ahmad and Wyckoff (2003) estimate the CO_2 emissions embodied in the international trade for 24 countries (including 20 OECD countries, Brazil, Russia, India and China). The authors create an indicator of CO_2 emissions related to domestic demand as a complement to the more common indicator of CO_2 emissions associated with domestic product. Their results show that estimates of emissions which were generated to satisfy domestic demand in the OECD in 1995 were 5% higher than emissions related to domestic production. They conclude that for many countries, the emissions associated with consumption are often 10% greater than those associated with domestic production. Davis and Caldeira (2010) present a global consumption-based CO_2 emissions inventory from a fully MRIO model constructed from 2004 global economic data disaggregated into 113 countries and 57 sectors. They find that 23% of global emissions were traded internationally, while China and other emerging markets were the primary exporters.

The MRIO is also applied in single-country studies. Weber and Matthews (2007) use an MRIO model of US and its seven largest trading partners (Canada, China, Mexico, Japan, Germany, UK and Korea) to examine the environmental impact of changes to US trade structure and volume from 1997 to 2004. Their results show that increased imports and shifting trade partners led to a large increase in embodied emissions in the US. They find the overall CO_2 embodied in imports has grown, and a large portion (20-40%) is from China. Wilting (2008) uses a full MRIO model to investigate pressures from international supply chains associated with consumption in the Netherlands. Based on the GTAP database[14], the model distinguishes 12 world regions, and considers six greenhouse gases emissions and land use. The author finds that the value-added related to Dutch consumption mainly originates in the Netherlands, while half of the greenhouse gas emissions and more than 90% of land use for Dutch consumption occur in other countries. McGregor *et al.* (2008) calculate the CO_2 emissions embodied in international trade flows between Scotland and the rest of the UK by using an MRIO model. They report that around 45% of emissions generated in Scotland are exported to the rest of UK.

2.4 Lessons from Existing Studies

Theoretically, the EKC only show the relationship between per capita income and emissions directly, while the trade impact on the environment can be decomposed into scale, technique and composition effects. Based on the theoretical survey, we found that the crucial explanations of the EKC is that higher incomes lead to an increased demand for environmental quality and technological progress with appropriate policy, while structural change and foreign trade may help to explain the EKC partially, which is supported by the findings of empirical survey.

[14] "*GTAP (Global Trade Analysis Project) is a global network of researchers and policy makers conducting quantitative analysis of international policy issues. Products from GTAP include data, models and utilities for multi-region, applied general equilibrium analysis of global economic issues. The GTAP project is coordinated by the Center for Global Trade Analysis, Purdue University, USA*" (Wiedmann, 2009, p.214).

For the global pollutant, CO_2 emissions, both production- and consumption-based accounting approaches have been adopted. The EKC and factor decomposition analyses are the most popular production-based accounting methods. The majority of traditional EKC studies find a monotonically rising relation with income. Due to the limitations of traditional EKC studies, cointegration analysis is adopted to test the EKC hypothesis by several researchers. However, only the single-country studies find the evidence to support an inverted-U shape curve based on long-term time-serial data. Unlike the EKC studies, factor decomposition analysis decomposes the changes in CO_2 emissions into several factors, without considering the econometric issues. The studies of factor decomposition analysis show that economic growth is the major driver to increase CO_2 emissions; the impact of economic structural change is small and may even increase emissions, whereas the impact of energy intensity, which represents improvement in technology, is large and always decreases emissions. Hence, technological progress is much more important for reducing emissions.

Climate change and carbon reduction are important global issues. However, the production-based accounting approach analyses CO_2 emissions based on domestic production activities only, and ignores foreign consumption, which is not fair for some developing countries. Recently, a more effective and fairer consumption-based accounting approach has been used to provide a more complete and impartial picture of responsibilities for carbon reduction between developing and developed countries. By using the SRIO or MRIO model, researchers estimate the carbon leakage, and demonstrate that reduction of CO_2 emissions in developed countries is due to foreign trade and the relocation of dirty industries to developing countries.

For local pollutants, the EKC is only observed for local air pollutants with immediate effects, such as SO_2, SPM, NO_X, and CO. For the water pollutants, many EKCs are found, while several insignificant relationships are also obtained. Selden and Song (1994) and Grossman (1995) argue that those pollutants are addressed at the lowest income levels, because they cause the highest health risks and their abatement is relatively cheap. Arrow *et al.* (1995) and Huesemann (2001) point out that in most cases emissions reductions are due to local environmental policy reforms; but such reforms often ignore international and intergenerational consequences, because the incentives to take them into account are likely to be weak. Earlier studies adopt the traditional estimation technique to test the EKC hypothesis; while recently, cointegration analysis has become more popular, since it takes into account some econometric issues, such as the simultaneity bias, multicollinearity and stochastic trends. The ambiguous impact of foreign trade on the environment is found from the empirical studies.

Based on the theoretical and empirical survey, we found that i) the traditional EKC studies ignore the econometric issues and do not adopt recent methods, so the results are not very reliable; ii) many studies recommend policies to mitigate CO_2 only based on the production-based approach. One would reject to this approach, because it ignores foreign consumption of Chinese production; iii) most existing single-region consumption-based studies ignore the emission intensity differences, which overestimates the embodied emissions in imports due to the higher emissions intensity of China; iv) the research period of most existing Chinese studies (trade-environment studies) end in early to 2000s, which cannot reflect the current situation; and v) the existing studies address the major issues separately, and so do not give a comprehensive picture.

The next chapters deal with China's economic reforms and growth performance, which give some indications of the level of environmental pollution.

Chapter Three

The Economic Reforms and Performance of China[15]

3.1 General Background

The People's Republic of China (PRC), commonly known as China, is located in East Asia and contiguous to the western Pacific Ocean. At 9.6 million square kilometres, China is the third largest country in the world after Russia and Canada, and borders fourteen countries[16]. China's official administration partition is composed of 22 provinces (Hebei, Shanxi, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shangdong, Henan, Hubei, Hunan, Guangdong, Hainan, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, and Qinghai), five autonomous regions (Inner Mongolia, Guangxi, Tibet, Ningxia, and Xinjiang), four direct-controlled municipalities (Beijing, Tianjin, Shanghai, and Chongqing), and two special administrative regions (Hong Kong and Macao). The capital of China is Beijing.

China is the most populous country in the world with over 1.3 billion people in 2009, and with a growth rate of approximately 0.49 per cent has nearly a fifth of the world's population. The Han majority, as well as 55 minority groups, have been living in China for over 5000 years. There are seven major Chinese dialects (Mandarin, Wu, Yue, Min, Xiang, Hakka and Gan) and many sub-dialects. Mandarin is the official language and is spoken by over 70 per cent of the population.

[15] This chapter is important. As a background chapter, it provides a historical and economic overview on China's development, including the major reforms and economic growth and trade performances from 1980 to 2009. They are part of research topic which are closely related with other chapters (economic growth and trade openness are two major variables in Chapter 5, 7 and 9) and address income part of the EKC hypothesis.
[16] They are Afghanistan, Bhutan, India, Kazakhstan, North Korea, Kyrgyzstan, Laos, Mongolia, Myanmar, Nepal, Pakistan, Russia, Tajikistan and Vietnam.

China adopted a socialist system of economic organisation, after its formation in 1949. After the economic reforms of 1978, China has greatly narrowed the developmental gap between itself and developed nations. As one of the world's fastest growing economies, China currently has the world's fourth largest GDP, and is the world's largest exporter.

This chapter will provide a historical and economic overview on China's development since 1949, and is organised as follows: section 3.2 briefly introduces the transition process of the Chinese economy; section 3.3 presents the major reforms in different sectors; section 3.4 shows China's economic growth and international trade performances; and finally, this chapter is summarised in section 3.5.

3.2 The Transition Process of the Chinese Economy

Chinese economic development experienced two major stages (Wu, 2005; Naughton, 2006), as follows:

1) Pre-reform (1949-1978): socialist heavy-industry-priority development stage;
2) Post-reform (1979 to present): market transition stage.

The later stage can be further categorised as follows:

1979-1992: the first phase of gradualist, dual-track[17], decentralising reform;

1993-2001: the second phase of more fundamental and thorough reform;

2002-present: an open economy after accession to the WTO.

17 Dual-track refers to the coexistence of a traditional plan and a market channel for the allocation of a given good.

3.2.1 Pre-reform (1949-1978)

During the pre-reform period, China followed a socialist development strategy concentrating on heavy industry. To implement this strategy, a planned economic system was used. The central government gave overwhelming priority in the First Five Year Plan (1953-1957), the Second Five Year Plan (1958-1962) and the policy of the Great Leap Forward (1958-1960), to channelling the maximum feasible investment into heavy industry in order to rapidly transform China from an agrarian economy to a modern and industrialised society. However, the irregular and haphazard backyard production drive failed to achieve the intended objectives, as it turned out enormous quantities of expensively produced industrial goods, and resulted in a turbulent economy in the late 1950s to early 1960s. The ten-year Great Proletarian Cultural Revolution launched in 1966 severely shook China's economy and left some problematic legacies.

3.2.2 Post-reform (1979-present)

Economic reforms and opening up were launched at the end of the 1978 "Third Plenum of the 11^{th} Session of Central Committee", which extended the Chinese market transition over 30 years. During this period China's economy has now been transformed from a planned economy to a socialist market economy[18].

China's economic reforms and the opening up process can be roughly divided into three main phases. The first phase of gradualist, dual-track, decentralising reform (1979-1992) focused on the rural sector. Reform was decentralised, shifting power and resources from the hands of central planners to local actors while core interests were

[18] "Socialist market economy" indicates that the government plays a major role in the country's economic development by allowing the reasonable use of free market forces.

protected. During the 1980s, China tried to promote rapid urban economic reform at the national level, by lessening the mandatory national plan to expand the autonomous right of state-owned enterprises, letting enterprises contact the market more directly, combining central planning with market-oriented reforms to increase productivity, living standards, technological quality, employment, and decrease the budget deficit. Reforms began in the agricultural, industrial, fiscal, financial, banking, price setting and labour systems (Perry and Wong, 1985). In the early stage, China's opening up strategy was focused on the coastal area, from the opening up of 14 coastal cities to establishment of special zones, from Hainan's opening to Shanghai Pudong's development. By 1993, China had successfully moved from a command economy to a functioning market economy.

Although the first stage of reform led to impressive economic growth and development, these were considered insufficient and so the Chinese government accelerated its pace towards a socialist market. Therefore, the second phase of more fundamental and thorough reform (1993-2001) was launched according to the decision of November 1993[19]. China attempted several radical reforms, including unification of exchange rates and convertibility under the current account; the overhaul of the tax and fiscal system, with the separation of national and local tax administrations; reorganisation of the central bank and establishment of cross-province branches; and the beginning of privatisation of small-scale state-owned enterprises and the laying off of excess state employees.

[19] The decision of November 1993 refers to the "Decision on Issues Concerning the Establishment of a Socialist Market Economic Structure", adopted by the Third Plenum of the Fourteenth Congress of the Chinese Communist Party. It indicates the beginning of a new direction of economic reform. For the first time and in essence, it decides to abolish the planning system altogether and set the goal of reform to be the establishment of a modern market system eventually to incorporate international institutions recognised as "best practice" (Wu, 2005).

The period 1997-2001 is recognised as the key stage in the establishment of the socialist market economic system. During this period, a modern enterprise system was established which met the requirements of a market economy. Under this system, property rights were affirmed and business affairs were separated from government; a unified, open, competitive and orderly market system was developed; a macro-economic control system was established, which often mainly adopted indirect governance measures; a diversified distribution system was established; and a social security system in respect of social insurance, social relief, social welfare, social mutual aid and medical insurance was established. During the second stage of reform, China's economy grew at the rate of about 11% per year, which is much higher than that achieved in the earlier stage of reform.

At the beginning of 2000s, China faced pressing needs for further reform for two main reasons. First, China's economic growth slowed down in 1998-1999 due to the Asian financial crises and the sluggishness of reforms in key areas. Secondly, China's proposed membership of the WTO in December 2001 produced additional pressure for Chinese reforms. Following the broad outline of the 10^{th} Five-Year Plan (2001-2005), the third phase of "all-round, well-off society" reforms (2002 to present) were described in official statements from the 16^{th} Party Congress in November 2002 and the 10^{th} National People's Congress in March 2003. The style of policy-making became more consultative and deliberate than before, and policy-making focused on improving per capita incomes with attention to their distribution and the sustainability of growth.

The Decision on Issues Regarding the Improvement of the Socialist Market Economic System[20], approved in November 2003, was a document which indicated that China's economic, social and political reforms would continue to advance in an all-round way in the future (Wu, 2005). During this period, government again paid more attention to the effectiveness and means of macro-economic regulation. These have included the transformation of government function, financial reforms, securities market regulations, urban land developments, public goods and the construction of the social security system. In addition, reforms were introduced to eliminate institutional obstacles and the external negative effects of enterprise development, as well as to protect the legal rights of workers.

3.3 Major Economic Reforms

This section will discuss in detail the major reforms in each economic sector, including rural (agricultural) reform, enterprise (SOEs and non-SOEs) reform, trade reform and FDI reform, during the past 30 years. The major policy changes are listed in the Appendix Table A3.1.

3.3.1 Rural Reform

In the early stage of reform, reducing poverty by increasing the income of rural household was the priority. During the period from 1979 to 1985, two major policies were adopted in the agricultural sector: price increases for agricultural products in 1979, and a reaffirmation of the right to self-management of collectives in 1981 (Nicholas,

[20] This decision set out China emphasis on 'balanced' economic development, between rural and urban areas, across regions (domestically and internationally), and in the social and environmental spheres. China also accelerates reform of the financial/banking sector and at the same time strengthens the performance of the state-owned enterprises. Further, China strengthens the rule of law regarding strengthening private property rights through a constitutional amendment (CCPCC, 2003).

1983). A national program, Household Responsibility System, allowed farmers to undertake and operate their agricultural business independently on state-owned land; to retain surpluses from individual plots of land rather than farming for the collective, which gave motivation for individuals to make an effort in increasing productivity, creating profit, and cost-saving. As a result, rural household income increased remarkably in the early 1980s, and rural real per capita income more than doubled. Between 1983 and 1985, grain output growth jumped to 4.1% annually from a previous 2.2% (Wu, 2005).

Rural reform was followed by the development of rural industries, known as Township and Village Enterprises (TVEs). From 1978, the government encouraged non-agricultural activities in rural areas. During the 1980s and the first half of the 1990s, TVEs as publicly owned enterprises experienced a golden age of development. TVEs played an important role in rural reform, such as increasing incomes, absorbing rural labour released from farms, and then narrowing the urban-rural gap. TVEs employment grew from 28 million in 1978 to a peak of 135 million in 1996, with a 9% annual growth rate. The share of TVEs' output to GDP increased from less that 6% in 1980 to 26% in 1996[21]. After 1996, TVEs underwent a further dramatic transformation: privatisation.

3.3.2 Enterprise Reform

State-owned industrial enterprises (SOEs) were the core of the old command economy, which produced 77% of industrial output in 1978[22]. Owing to the poor performance, low profitability, and inferior competitiveness of SOEs, enterprise reform measures

[21] Data are calculated by author based on *China Statistical Yearbook* (various issues).
[22] Collective enterprises, which were nominally owned by the workers in the enterprises but were actually controlled by local government, produced 23% of output

with the main theme of "expanding enterprises autonomy and profit retention to enterprises" was extended nationwide in 1979. These reform measures gradually disengaged SOEs from a traditional planned economy and let them begin to participate in and adapt to market competition with non-state enterprises (Wu, 2005). The adoption and modification of Company Law in 1994 was a milestone of reform. This law stipulated that traditional SOEs must convert into the legal form of a corporation and provide a pertinent framework. Tens of thousands of SOEs and collective firms were shut down. Forty percent of the SOEs workforce and more than two third of the collective workforce were laid off.

In 1996, it was reported that over half of China's SOEs were inefficient. As a result, President Jiang announced plans to sell, merge, or close the vast majority of SOEs. Then a new policy called "grasping the large, and letting the small go" was adopted. The largest, typically centrally controlled, firms were restructured and financed but kept under state control, while firms owned by local government were privatised or closed down. Over 50% of SOEs closed down in the following five years. In 2000, the majority of large SOEs were profitable. Further actions were taken by the Chinese government by creating an agency charged with exercising the government's ownership rights and boosting the performance of these enterprises by 2003.

During the reform period, the individual business sector first emerged in the rural areas, such as contracted family farms and TVEs, which developed rapidly and had become an important component of Chinese economy in 1980s and early 1990s. In the late 1980s, the share of non-SOEs (including individual businesses, private enterprises and foreign-invested enterprises) increased steadily. In 1997, "*keeping public ownership as the mainstay of the economy and allowing diverse forms of ownership to develop side by* *side*" was confirmed as China's basic system for the primary stage of market socialism (Wu, 2005, p.188). Non-SOEs were recognised as an important part of a socialist market economy. Since 1998, with the implementation of the guidelines of the 15th National Congress for readjusting the layout of the state sector and improving ownership structure, the share of non-SOEs has grown rapidly.

The SOEs' share of total industrial output steadily declined from 77% in 1978 to only 33% in 1996, while collective enterprises reached their maximum share of value in 1996, accounting for 36% of output[23]. During this period, the industrial economy became less state-run but was dominated by publicly owned firms, while the non-SOEs accounted for one third of output. Since 1998 the National Statistics Bureau has only reported data on the output of the above-scale firm[24]. From 1998 to 2009, the SOEs share of this above-scale industrial sector continued to gradually decline (accounting for 8.3% in 2009), while the share of collective firms dropped dramatically (only 1.7% in 2009). The non-SOEs, which had taken over the largest share of the economy and become the fundamental driving force in China's economic growth, continued to gain in importance. Recently, the government has concentrated its holdings in energy and natural resources.

3.3.3 Trade Reform

Since 1978, China has undergone a significant transition from a plan-oriented foreign trade system to a market-oriented foreign trade system by conducting a series of reforms, which include tariff reform, non-tariff reform and other export promotions.

[23] Data are calculated by author based on *China Statistical Yearbook* (various issues).
[24] Above-scale firms are SOEs AND Non-SOEs with an annual output value of more than 5 million RMB (US$600,000).

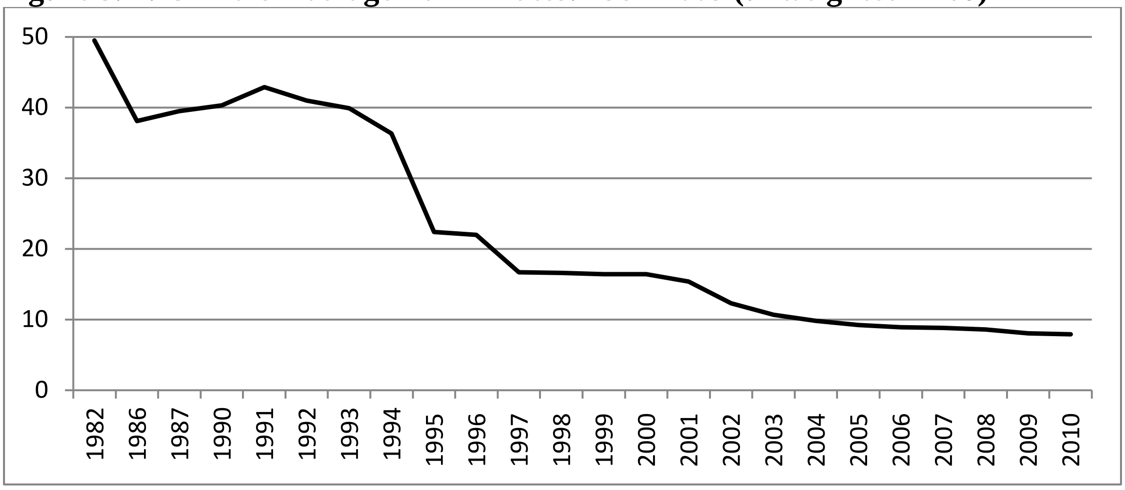
Tariff Rate Reforms

According to Yang (1997), the simple average tariff rate for all items was 52.9%, with a rate of 92.3% for agricultural products and 47.7% for industrial products during the pre-reform period. Since 1978, the overall tariff structure has been adjusted in accordance with the changes in economic development, especially the introduction of the second Costumes Import and Export Tariff Schedule in 1985[25]. The second tariff schedule was established with decreasing rates in order to match the government's policy in opening up the markets and protecting domestic production at the same time. Figure 4.1 shows that the average tariff rate in the second half of the 1980s ranges around 38-40%. From the late 1980s to the early of 1990s, the tariff rates remained almost the same and peaked at 43% in 1991, which coincided with the government's intervention in import substitution strategy.

In 1992, the third revised tariff schedule took place, which modified the classification of commodities[26], and the tariff rate started to decline again[27]. Moreover, membership in the WTO was a powerful motivating factor to lower the tariff barriers voluntarily from the mid-1990s. As can be seen from Figure 3.1, the average tariff rates decreased significantly from 41% in 1992 to 8.1% in 2009.

[25] The first'Costumes Import and Export Tariff Schedule' was introduced in 1951.
[26] The standard of classification of goods switched from "Customs Cooperation Council Nomenclature" to a widely used "Harmonized Commodity Description and Coding System".
[27] China lowered tariff rates in 16 categories covering 225 products in 1991, for 3371 goods at the end of 1992.

Figure 3. 1: China's Average Tariff Rates: 1982-2009 (unweighted in %)



Source: World Bank, 2011.

Non-Tariff Reforms

Non-tariff barriers, an important government intervention to protect domestic producers, include quotas, licenses, prices and import examination. In the late 1980s and early 1990s, the government relied on these barriers to a large extent to curtail imports. For example, the number of restricted categories of imported products increased from 13 to 53, accounting for 46% of total imports. Since 1992, these non-tariff barriers have been relaxed and/or dismantled gradually to comply with the relevant regulation of the WTO and to implement its commitments under the Protocol of Accession of 2001. In 1992, China eliminated the regulatory import tax (a separate surcharge over the applicable tariffs) which had been imposed on 18 categories of goods. The number of import goods subject to licensing was reduced rapidly from 35 categories at the end of the 1990s to two in 2004, and then licensing was abolished in 2005. The import quotas were eliminated at the end of 2004. The import prohibitions have been reduced progressively. However, for reasons of public safety and the environment, in line with international conventions and WTO rules, China still maintains some import prohibitions.

Export Promotions

Since the beginning of reforms, China has taken some measures to promote exports. One of those was the duty drawback system, which was introduced in 1985. It is a redemption of duty paid on imported inputs used in the production of exports and enables the producers to achieve export competitiveness (Ianchovichina, 2005). In 1987, the duty drawback system was extended to allow for duty-free imports of all raw materials and intermediate inputs used in the production of exports, and later to imported capital goods when the equipment was needed to fulfill processing contracts (Ianchovichina, 2005). Mah (2007) and Zhang and Song (2000) noticed that the duty drawback system, which is the most important factor of export promotion, has been widely and actively used in China under the WTO system.

Financial incentives were provided to promote exports. During the 1980s and 1990s, the state owned banks (SOBs) allocated most of their loans to the SOEs, and a large proportion of the lending was designed to promote exports. For instance, the SOBs' share of loans to the SOEs was between 86-95% during 1981-1999, while the share of SOEs' exports to total exports reached 48-67% during 1995-2000 (Mah, 2007). The establishment of the Export-Import Bank of China (EXIM) in 1994 provided export credits to promote exports and imports of, in particular, capital goods such as mechanical and electronic products, as well as providing export insurance[28] to exporters.

After entrance to the WTO, China has tried to make its export promotion policies consistent with WTO regulations. Most tax and financial benefits directly targeting export promotion have been gradually removed. For example, the direct subsidies on agricultural and industrial products were abolished from 1991 to 2002. The current

[28] In 2001, the China Export and Credit Insurance Corporation was established and in charge of credit insurance, investment insurance and export-related guarantees.

export promotion measures are duty drawback, export insurance, tax benefits provided to foreign-invested enterprises exporting their products and the producers of high-tech products, and under-valuation of currency (Mah, 2007).

In addition to the above financial measures, the establishment of Special Economic Zones (SEZs) to attract FDI and devaluation of the Chinese currency (RMB) also played a significant role in export promoting, as discussed in the following sections.

3.3.4 Foreign Direct Investment (FDI) Reforms

Since China began accepting foreign investment in 1978, the FDI reform has experienced five phrases: the experimental period (1978-1983), speed-up stage (1984-1991), peak stage (1992-1993), adjustment stage (1994-2000) and post-WTO stage (2001-present).

At the beginning of the reform, in order to strengthen the legislation relating to FDI, “The Equality Joint Venture Law” and “Regulation for the Implementation of the Law on Chinese-Foreign Equity Joint Venture” were established in 1979 and 1983, respectively. During this period, FDI was carefully regulated with preferential treatments and allocated to four Special Economic Zones (SEZs)[29] in Fujian and Guangdong Provinces, which were established in 1981. However, due to the rigid restraints on FDI outside the SEZs and strict regulation of foreign ownership, the progress of FDI was slow in this period.

[29] Three SEZs are in Guangdong province: Shenzhen, Shantou and Zhuhai; one is in Fujian province: Xiamen.

In the mid-1980s, a number of new laws and regulations were launched, and restrictions on FDI were further relaxed. Fourteen coastal cities[30] were opened up for foreign investment. Compared to SEZs, these cities enjoyed autonomy in making economic decisions. The government allowed for foreign-invested enterprise (FIE) with pure foreign ownership, and more incentives for FDI were given, such as enterprise autonomy, profit remittances, labour recruitment and use of land and infrastructure (Chen *et al.*, 1995; Mah, 2007). In the late 1980s, more regions were opened up for FDI, including Yangtze River Delta (surrounding Shanghai) and Pearl River Delta (surrounding Guangdong, Fujian, Liaoning and Shandong) which received much more preferential treatment than those in the SEZs and the fourteen coastal cities. Due to the passage of a law on Chinese-Foreign cooperative joint venture in 1988, foreign investors were encouraged to allocate their investment in China.

In the early 1990s, China switched its emphasis from the south to Shanghai and aimed at developing Shanghai into an international hub for finance, economy and trade. High-technology, established manufacture and financial companies were encouraged to set up in Shanghai. The rate of FDI increased in 1992 after Deng's Southern Tour. Export-oriented FDI and FIEs with advanced technology were particularly encouraged in this period. More industries were opening up for FDI, such as financial, banking and insurance, wholesales and retails, shipping, and accounting and information consultancy sectors. FDI started to be directed into the interior of the country from this period.

FDI reached its historical high point in 1994 and then declined rapidly around the same year. The factors that encouraged increases in FDI were a greater sectoral openness and

[30] The fourteen coastal cities comprise Shanghai, Tianjin, Dalian (Liaoning province), Qinghuangdao (Heibei province), Yantai (Shandong province), Qingdao (Shandong province), Lianyungang (Jiangsu province), Nantong (Jiangsu province), Ningbo (Zhejiang province), Wenzhou (Zhejiang province), Fuzhou (Fujian province), Guangzhou (Guangdong province), Zhanjiang (Jiangsu province), Beihai (Guangxi province).

the government development strategy in agriculture, hydropower, communications, energy and raw material sectors; and the provision of favourable tax measures and financial support. In the meantime, the government issued policy to tighten the procedures in terms of approval of contracts and registration of foreign enterprises, and enhance the penalties if agreements were not fulfilled, which slowed down the growth of FDI.

The accession to the WTO in 2001 has advantages for China as it attracts more FDI. For example, the restructure of the legal system improved China's investment and economic environment; foreign investors were becoming more interested in bringing capital into Chinese industries; and industrial tariff rates were reduced, trading rights and systems were granted and improved over time, which attracted more FDI inflows into China.

3.3.5 Exchange Rate

The foreign exchange rate was fixed at an overvalued level and acted only as a function of a translator or an accounting device during the planned economy period (Zhang, 2001). China has adjusted the value of its currency (RMB) since economic reform in 1978. The value of the Yuan decreased repeatedly over a long period in response to economic fundamentals. The exchange rate was adjusted from 1.5 Yuan/US$ in 1980 to 5.77 Yuan/US$ in 1993[31]. In 1994, China unified its exchange rates by aligning official and swap centre rates, and set up the first interbank currency market in Shanghai. The value of RMB was fixed around 8.28 Yuan/US$ and the central bank intervened to manage it.

[31] Data are from Zhang (2001).

Due to entrance to the WTO and the huge trade surplus with the US and the rest of the world, China revalued the RMB and revised rules governing its currency in 2005. China has changed to "a managed floating exchange rate with reference to a basket of currencies[32]". The RMB appreciated from an average 8.28 Yuan per US dollar in 2000 to 7.60 in 2007[33]. During the Global Financial Crisis in 2008, the central bank effectively pegged the RMB against the dollar at 6.83 to help economic growth. In 2009, China took a step towards internationalising the RMB by launching a pilot program that allowed selected Chinese regions to pay for imports and exports in RMB. China resumed the foreign exchange rate reform and increased currency flexibility.

3.4 Economic Performance during Post-reform Period

Since beginning economic reforms and opening up 30 years ago, China's economy has experienced an unprecedented boom. This section will present China's economic performance during the post-reform period, including economic growth, economic structural changes, international trade and FDI.

3.4.1 Growth Performance

Economic growth can be visualised as an increase in the total amount of goods and services available. This is measured by the growth of GDP, which is the total of all the value added in an economy. Figure 3.2 shows the GDP growth rate from 1978 to 2010[34]. After the beginning of reform in 1978, thanks to the improvement of efficiency

[32] The main currencies in the basket are the US dollar, euro, Japanese yen and Korean won; others include the Singapore dollar, sterling, Malaysian ringgit, Russian rouble, Australian dollar, Thai baht and Canadian dollar.
[33] Data are from Lee (2010).
[34] Before the reform of 1978, China's GDP growth rate was extremely volatile and hit the bottom in 1960-1962 at negative 21% due to the devastation of agriculture during "Great Leap Forward" and in 1967-1968 at around negative 5% mainly due to the "Great Proletarian Cultural Revolution in the late 1960s. In the 1970s, the growth was relatively stable and remained at a positive value (except 1976).

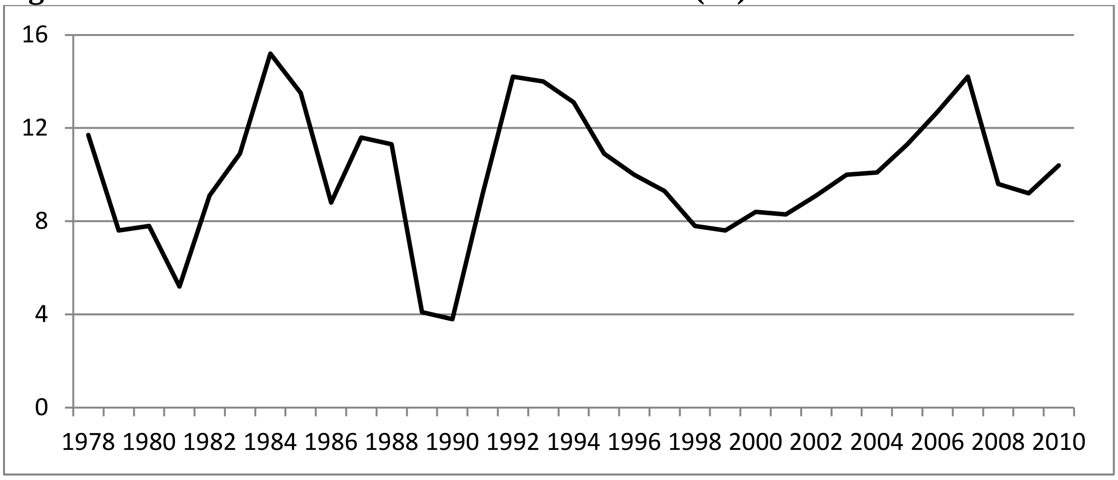
in the rural sector and the rapid development of Township and Village Enterprises, China's GDP kept positive growth in the late1970s and 1980s. There have been four repeated business cycles, which occurred in 1978-1983, 1984-1986, 1987-1990 and the early 1990s [35], reflecting China's repeated policy shifts from decentralisation to recentralisation. The overheating economy brought excess demand, over-saving and over-investment at the expense of current output, resulting in the economic policy shift back to a program of recentralisation (Feltenstein and Iwata, 2005). In the 1980s, the average growth rate was around 10%. Due to the global economic recession, the growth rate dropped to 3.8% in 1990, but then grew markedly to a peak of 14.2% in 1992[36]. Since then, the growth rate has gradually subsided and remained at a stable position with the average of 10.6% in the 1990s[37]. Due to the Asian crisis, the growth rates fall below 8% in 1998 and 1999, the lowest since the early 1990s. However, owing mainly to the recovery of the world economy and the beginning of new reform, the growth rate began to increase steadily in the 2000s with the average of 10.5%, although it fell from 14% in 2007 to 9.6% in 2008 to 9.2% in 2009, largely because of the global economic crisis and the continuous deterioration of global conditions.

[35] 1978-1982: disbanding the communes and restoring family farming jacked up agricultural output;
1983-1985: the first wave of foreign investment into China and non-state enterprises started to develop, resulting in double-digit real GDP growth;
1989-1991: growth slowed down because of the overheating economy, inflation and reduction of foreign investment. This was a consequence of the Beijing Massacre of June 1989;

[36] 1992: Deng Xiaoping's Southern Tour massively stimulated FDI inflows into coastal areas. Record GDP growth and trade followed.

[37] 1993: Zhu Rongji was appointed to address the overheating economy. Growth rate subsided in following years, resulting in a 'soft landing'.

Figure 3. 2: Annual GDP Growth Rate: 1978-2010 (%)



Source: *China Statistical Yearbook* (various issues).

As shown in Figure 3.2 and Table 3.1, China grew rapidly between 1952 and 1978, but growth accelerated after reform in 1978. The average annual GDP growth increased from 6.00% in the pre-reform period to 9.97% in 1979-2009. This shows that China doubles the size of its economy every eight years. At the same time population growth decreased from 1.90% to 1.06%. As a result, the growth rate of per capita GDP more than doubled, jumping from 4.10% to 8.82% annually.

Table 3.1: Growth Rate of Real GDP, Population and Real GDP Per Capita (%)

	GDP	Population	GDP per capita
1952-1978	6.00	1.90	4.10
1979-2009	9.97	1.06	8.82
1979-1992	10.64	1.43	7.99
1993-2001	9.41	0.96	8.37
2002-2009	11.00	0.56	10.38

Source: Author's calculation based on *China Statistical Yearbook* (various issues) and World Bank (2012).

3.4.2 Structural Changes

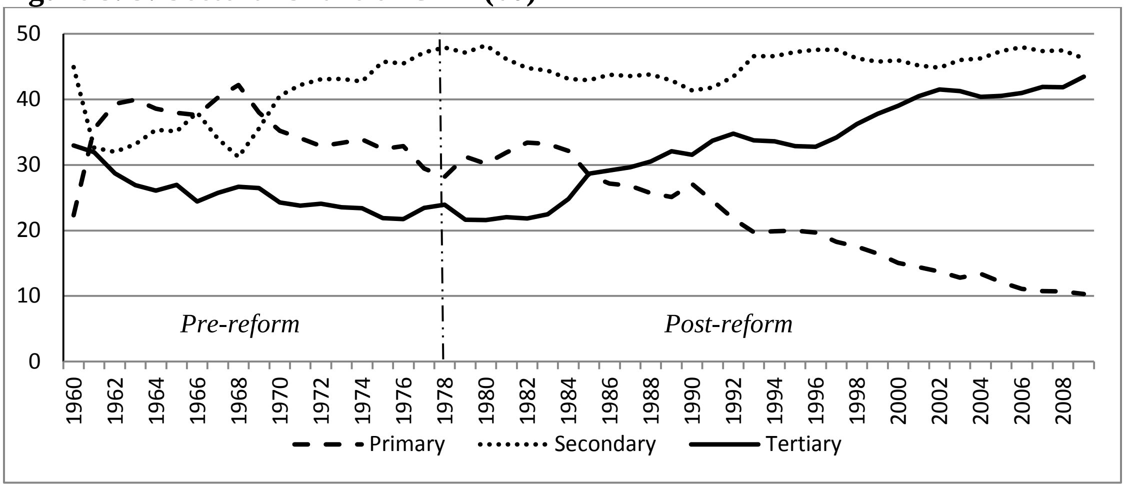
Structural change can be viewed through the changing shares of total GDP produced by the primary (agriculture), secondary (industry and construction) and tertiary (service) sectors[38]. Similar to the other developing countries, the share of the primary sector to GDP continuously decreases in China, while both secondary and tertiary sectors increase (see Figure 3.3). In 1960, the agriculture sector contributed around 22% to GDP, and the secondary and tertiary sectors contributed to 45% and 33%, respectively[39]. Before the reform, China was a predominantly agrarian economy, with 70.5% of the labour force and 28.2% of GDP in the agriculture sector in 1978. Due to the three-stage reforms[40], the situation has changed as China has undergone rapid and widespread industrialisation and expansion of the service sector. In 2009, the primary sector shares in employment and GDP went down respectively to 38.1% and 10.3%; while the secondary sector increased to 27.8% and 46.2%, and the tertiary sector went up to 34.1% and 43.4% (see Table 3.2 and Figure 3.3). However, at the beginning of the reform, the shares of the tertiary sector, both in terms of employment and of GDP, were very low, due to the priority of reforms occurring in "productive sectors", such as agriculture and industry, over "unproductive sectors", such as the tertiary sector. The market economy and private ownership have gradually increased in the last decades.

[38] The primary sector includes farming, forestry, animal husbandry, fishery and water conservancy; the secondary sector includes industry and construction; the tertiary sector refers to transport, post and telecommunications, and wholesale, retail trade and catering service (*China Statistical Yearbook*, 2012)

[39] The policy of 'Great Leap Forward' (1958-1960) devastated agriculture. After the 'Great Leap Forward', the share of agriculture continuously increased to 42% in 1968, and then declined to 28% in 1978.

[40] The reform occurred in the following order: the first stage of reform (in 1978) mainly concerned agriculture; the second stage (in the 1980s and 1990s) mainly involved industry, the services, property rights and institutions; and the third stage (in the late 1990s and 2000s) mainly involved banking, finance and international economic relations.

Figure 3. 3: Sectoral Share of GDP (%)



Source: World Bank, 2011.

Table 3.2: Sectoral Employment Share of Total Employment (%)

Sector	**1970**	**1978**	**1985**	**1990**	**1995**	**2000**	**2003**	**2005**	**2007**	**2009**
Primary	80.8	70.5	62.4	60.1	52.2	50.0	49.1	44.8	40.8	38.1
Secondary	10.2	17.3	20.8	21.4	23.0	22.5	21.6	23.8	26.8	27.8
Tertiary	9.0	12.2	16.8	18.5	24.8	27.5	29.3	31.4	32.4	34.1
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: *China Statistical Yearbook*, 2010.

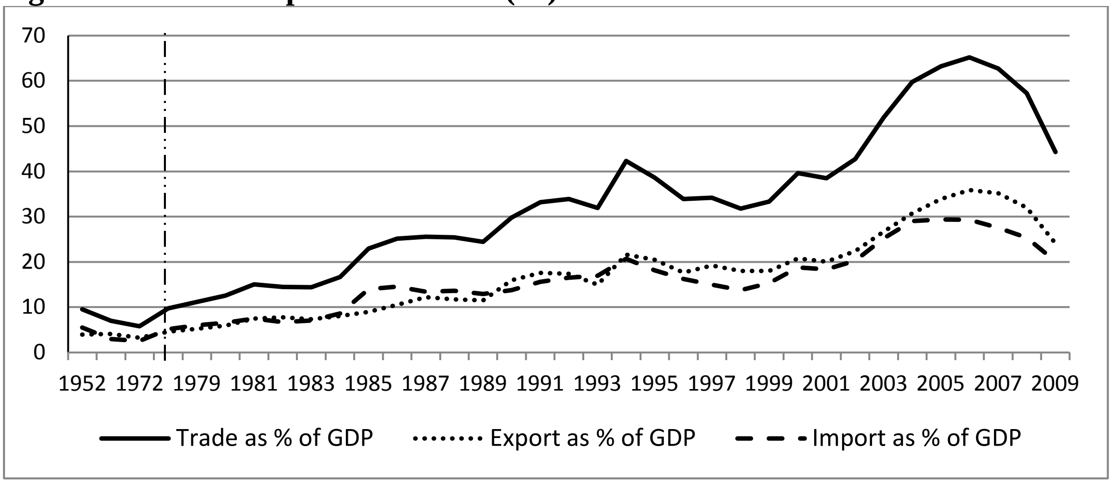
Generally, China's structural change has gone through two distinct stages: rapid accumulation of capital and the growth of domestic market were the major drivers during 1978 and the mid 1990s; the rapid rise of exports and the great inflow of FDI after entrance into WTO (Valli and Saccone, 2009). In the late 2000s, the increase in exports brought about a recovery of the employment share of industry and a slowing down in the rise of the tertiary sector's share. The reasons could be that some traditional industries, such as textiles, clothing and leather articles, grew rapidly; and several large joint ventures with foreign enterprises entered into new sectors, such as the information and communication technology and automobile sectors.

In addition to the major change in the main sectors – primary, secondary, tertiary – there was also a significant structural change within industry and within the tertiary sector. In 1980, the major industrial sectors were: textiles, clothing, food and beverages, bicycles, etc., with a small part of steel, chemicals and fertilisers; while electricity and telecommunication services were uncommon, and residential constructions were curtailed. During the last two decades, the situation changed radically. For example, since the mid-1990s, electrical and non-electrical machines and chemicals surpassed textiles; the growth in production quantities of high-tech products such as PCs and mobiles was much higher than for textiles; and residential and non-residential constructions were booming, especially in big urban areas.

3.4.3 Trade Performance

Before 1978, China exported just raw materials and a few simple manufactured goods and imported strategic minerals and other necessities not available domestically. Since 1979, 30 years of economic reforms and liberalisation have produced a dramatic increase in China's foreign trade with the rest of the world, especially after 2002, transforming China into a major trading power. China overtook Germany in 2010 to become the world's largest exporter, and also the world's second largest importer after the US.

Figure 3.4: Trade Dependence Ratio (%)



Source: *China Statistical Yearbook*, 2010.

With the continuous growth of foreign trade, China's trade dependence ratio[41] also increased. Figure 3.4 shows the pattern of aggregated foreign trade, exports and imports as a percentage of GDP. The trade dependence ratio never exceeded 10% before 1978 and was at only 5% in 1972. Over the past 30 years, the situation has changed dramatically. From 1980 to the early 1990s, the ratio of imports to GDP was higher than the exports to GDP ratio most of the time, mainly due to China's combination of import substitution and export expansion policies. The import substitution strategy was to stimulate domestic industrialisation, which led to higher imports from 1985 to 1990. The trend of imports exceeding exports ceased in 1993 when China decided to emphasise export expansion.

The overall trade to GDP ratio increased rapidly and converged quickly to the world average in the 1980s and the early 1990s, from 12% in 1980 to 42% in 1994 (see Figure 3.4). The trade share stabilised through the late 1990s, although it dropped slightly to 32% during the period of the Asian financial crisis in 1997-1998. Since 2002, trade has

[41] The trade dependence ratio is the index used to measure the degree of opening up and dependence of an economy on the international commodity market, usually by the ratio of total volume of imports and exports to GDP, ratio of exports to GDP, or ratio of imports to GDP.

surged again, such that China is now acknowledged as a global trading power. In 2007, China's total goods trade amounted to 63% of GDP. Although the ratio fell sharply to 44% in 2008-2009, it was far more than other large economies such as the US, Japan and India, which have trade/GDP ratios of around 20%.

The composition of trade has shifted from primary products to manufactures, which were 50.3% of exports (65.2% of imports) in 1980 but 91.2% of exports (83.3% of imports) in 2002 and 94.7% of exports (71.2% of imports) in 2009 (see Table 3.3). Among the manufactured goods, the percentages of chemicals and textiles (both export and import) decreased, while the share of machinery increased rapidly. China's top ten exports and imports in 2001 and 2009 are listed in Table 3.4. Major exports included electrical machinery (such as computers and parts), machinery, knitted apparel and iron and steel, while major imports included electrical machinery, mineral fuel and machinery.

Table 3.3: Composition of China's Exports and Imports (% of total)

	1980		**1990**		**2002**		**2005**		**2009**	
	Exp.	**Imp.**	**Exp.**	**Imp.**	**Exp.**	**Imp.**	**Exp.**	**Imp.**	**Exp.**	**Imp.**
Primary Goods	**50.3**	**34.8**	**25.6**	**18.5**	**8.8**	**16.7**	**6.4**	**22.4**	**5.3**	**28.8**
--Food	16.5	14.6	10.6	6.3	4.5	1.8	3.0	1.4	2.7	1.5
--Beverages	0.4	0.2	0.6	0.3	0.3	0.1	0.2	0.1	0.1	0.2
--Raw Materials	9.4	17.8	5.7	7.7	1.4	7.7	1.0	10.6	0.7	14.1
--Mineral Fuels	23.6	1.0	8.4	2.4	2.6	6.5	2.3	9.7	1.7	12.3
--Oil, Fat and Wax	0.3	1.2	0.3	0.2	--	0.6	--	0.5	--	0.8
Manufactured Goods	**49.7**	**65.2**	**74.4**	**81.5**	**91.2**	**83.3**	**93.6**	**77.6**	**94.7**	**71.2**
--Chemicals	6.2	14.5	6.0	12.5	4.7	13.2	4.7	11.8	5.2	11.1
--Textiles, Rubber, Minerals	22.1	20.8	20.3	16.7	16.3	16.4	16.9	12.3	15.4	10.7
--Machinery, Equipment	4.7	25.6	9.0	31.6	39.0	46.4	46.2	44.0	49.1	40.5

Source: *China Statistical Yearbook*, 2010.

Table 3.4: Major Chinese Exports and Imports in 2001 and 2009 (% of total)

2001		2009	
Top 10 Exports			
Mechanical and Electrical Products	49.4	Mechanical and Electrical Products	42.0
Garments(Excluding Knitwear and Crochet)	7.4	High and New-tech Products	22.2
Garments, Knitted or Crocheted	5.2	Automatic Data Processing Machines	7.2
Toys	2.1	Garments, Knitted or Crocheted	2.8
Plastic Articles	2.1	Garments(Excluding Knitwear and Crochet)	2.5
Leather Shoes	1.8	Telephone Sets	2.4
Furniture	1.6	Ships	1.6
Cotton Cloth	1.3	Parts for Auto Data Processing Equipment	1.5
Coal	1.1	Furniture	1.4
Aquatic and Seawater Products	1.1	Rolled Steel	1.3
Top 10 Imports			
Mechanical and Electrical Products	57.6	Mechanical and Electrical Products	57.6
Iron Ore	5.6	High and New-tech Products	5.6
Rolled Steel	4.3	Crude Oil	4.3
Automatic Data Processing Machines and Components	2.4	Iron Ore	2.4
Petroleum Products Refined	1.8	Automatic Data Processing Machines and Components	1.8
Aircraft	1.5	Rolled Steel	1.5
Paper and Paperboard (Unchopped in Shape)	1.3	soybean	1.3
Soybean	1.3	Copper and Copper Alloys	1.3
Polyethylene in primary Forms	1.2	Petroleum Products Refined	1.2
Parts of Motor Vehicles	1.2	Motor Vehicles(including a Complete Set of Spare Parts)	1.2

Source: Author's calculation based on *China Statistical Yearbook*, various issues.

China's major trading partners in 2009 included the 27 European countries that make up the European Union (EU27)[42], the United States, Japan, and the 10 Asian countries that constitute the Association of Southeast Asian Nations (ASEAN)[43] (see Table 3.5). China's largest export markets were the US, EU and Hong Kong, while the top sources for imports were Japan, EU27 and ASEAN. China maintained substantial trade surplus with EU27, US and Hong Kong, but deficits with Japan, ASEAN, Korea and Taiwan.

[42] EU 27 includes Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom (IEA, 2011).

[43] ASEAN members are Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam.

Table 3.5: China's Trade with Main Partners in 2009 ($ billions)

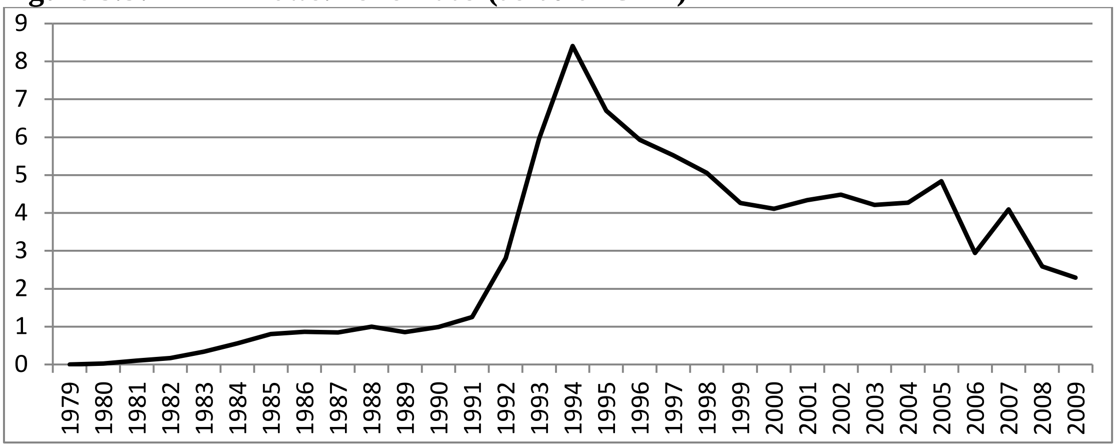
Country	Total Trade	Exports	Imports	Trade Balance
EU 27	316.0	207.3	108.8	98.5
US	298.3	220.8	77.5	143.3
Japan	228.8	97.9	130.9	-33.0
ASEAN	213.0	106.3	106.7	-0.5
Hong Kong	174.9	166.2	87.0	157.5
Korea	156.2	53.7	102.5	-48.9
Taiwan	106.2	20.5	85.7	-65.2

Note: rankings according to total trade in 2009.
Source: *China Statistical Yearbook*, 2010.

3.4.4 FDI Performance

Figure 3.5 shows the share of FDI inflows as the percentage of GDP from 1978 to 2009, which is consistent with the progress of FDI reform (see section 3.3.4). The ratio of FDI to GDP was very low and increased from 0.02% in 1980 to 0.8% in 1985, due to China's immature investment environment. As laws and regulations were established and restrictions on FDI further relaxed, FDI increased but the ratio remained around only 1% in the second half of the 1980s. From 1992 to 1994, the ratio remarkably reached around 8% because of the accelerated FDI reform and because more industrial sectors and regions were opening up for FDI. The ratios dropped sharply to 6% in 1995 and 4% in 2000 in the FDI adjustment period. The ratio of FDI to GDP was stable around 4.5% in the 2000s, while due to the economic crisis it fluctuated recently.

Figure 3.5: FDI Inflows: 1978-2009 (as % of GDP)



Source: Data of 1979-1981 are calculated based on *China Statistical Yearbook*, various issues; others are from World Bank, 2011.

Cumulative FDI in China at the end of 2009 was $942 billion. China became one of the world's largest destinations of FDI in 2009. Table 3.6 shows the major investors during the last 30 years. In terms of cumulative FDI for 1979-2008, about 38.9% came from Hong Kong, 10% from the British Virgin Islands and 7.3% from Japan; while in terms of annual data, Hong Kong was the largest source of FDI inflows in 2009 (51.2% of total).

Table 3.6: Major Foreign Investors: 1979-2009 ($ billions and % of total)

Country	Cumulative utilised FDI: 1979-2008		Utilised FDI in 2009	
	Amount	% of total	Amount	% of total
Total	**899.1**	**100.0**	**90.0**	**100.0**
Hong Kong	349.6	38.9	46.1	51.2
British Virgin Islands	90.1	10.0	11.3	12.5
Japan	65.4	7.3	4.1	4.6
US	59.7	6.6	2.6	2.8
Taiwan	47.7	5.3	1.9	2.1
Korea	41.9	4.7	2.7	3.0
Singapore	37.9	4.2	3.6	4.0

Source: *China Statistical Yearbook*, 2010.

Table 3.7 shows the share of sectoral FDI to total FDI in China and it highlights the large share of FDI allocated to the "industry" sector. During the 1990s and the first half of the 2000s, the share of FDI in the "industry" sector has increased and reached 73.3% in 2005, while it declined to 54.9% in 2009. More precisely, under the 'industry' sector, the manufacturing sector is the main FDI recipient, which accounts for more than half of the total FDI in 2009. During the 1980s, FDI concentrated on traditional labour-intensive manufacturing; from 1992, it shifted to capital and tech-intensive manufacturing; and from mid-1990s, IT industry attracted more foreign investors, which was consistent with China's structural changes. And relatively large shares of FDI were allocated to the real estate sector and the other services sector in 2009, which account for about 18.7% and 11.9%, respectively.

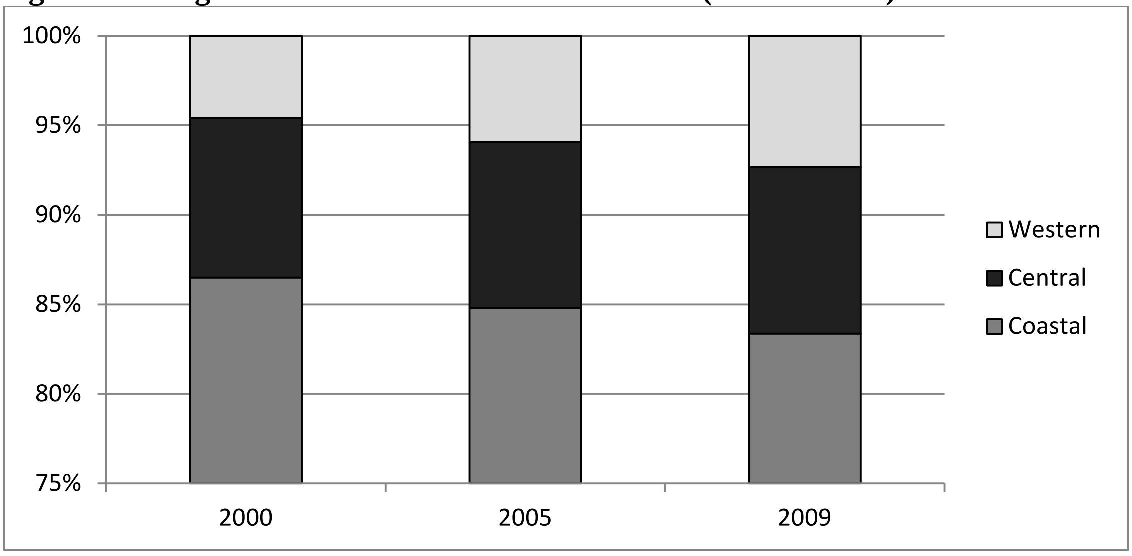
Table 3.7: Sectoral FDI Inflows in Selected Years (as % of total)

Sector	1993	1995	2000	2005	2009
Agriculture	1.1	1.9	1.7	1.2	1.6
Industry [a]	47.5	67.5	70.4	73.3	54.9
Mining	--	--	*1.4*	*0.6*	*0.6*
Manufacturing	--	--	*63.5*	*70.3*	*51.9*
Production and Supply of electricity, gas and water	--	--	*5.5*	*2.3*	*2.3*
Construction	3.6	2.1	2.2	0.8	0.8
Transportation	1.4	1.9	2.5	4.7	5.3
Wholesale and retail trades, hotels and catering services	4.3	3.8	2.1	2.7	6.9
Real Estate	--	19.5	11.4	9.0	18.7
Other Services [b]	1.4	4.4	9.7	8.4	11.9

Note: [a] Before 1997, the statistical yearbook only published aggregated data in the "Industry" sector;
[b] The "Other Services" sector includes education, health, scientific and financial services.
Source: Author's calculation based on *China Statistical Yearbook*, various issues.

The allocation of FDI across Chinese provinces has been extremely unbalanced since the beginning of reforms, due to the process of opening up. At the beginning of reform, FDI was only permitted in four SEZs. From the mid-1980s, more regions were opening up for FDI. The coastal region is the major recipient of FDI in the last 30 years, although its share of total FDI decreased slightly in the 2000s. As shown as Figure 3.6, during the 2000s, around 83%-86% of FDI was allocated in the coastal region; while the shares in the central and western areas have increased, from 13% in 2000 to 17% in 2009.

Figure 3.6: Regional FDI Inflows in Selected Years (as % of total)



Source: Author’s calculation based on *China Statistical Yearbook*, various issues.

3.5 Conclusion

After three decades of economic reforms and opening up, China has transformed itself from a centrally planned economy to a socialist market economy. Based on policy shifts and economic development, the post-reform period can be classified into three periods: 1979-1992, 1993-2001, and 2002 to the present. Starting from rural reforms, it quickly expanded to every part of the economy, including enterprise reforms, FDI reforms and trade reforms.

As a result of this 30-year reform process, China has experienced huge structural changes – rapid and widespread industrialisation and expansion of service sectors. Initially these were driven by rapid capital accumulation and the growth of the domestic market in the 1980s and 1990s. Since then China’s accession to the WTO, the resultant increase in trade and the great inflows of FDI have been the main drivers of economic development.

These reforms have boosted growth in GDP, trade and FDI. From 1978 to 2009, China's GDP grew at an average annual rate of 9.9%, and over 500 million people were lifted out of poverty. China is now the world's largest exporter and manufacturer, and the second largest economy (World Bank, 2012). China is expected to continue to enjoy rapid economic growth in the years ahead. International trade and foreign investment continue to play a major role in China's booming economy, although they were influenced by the global crisis since 2008.

However, the rapid economic growth and industrialisation in China have brought challenges in energy use and environmental sustainability. At the beginning of the reforms, the energy and environmental institutions were set as a part of China's political economic system. In order for China's growth to be sustainable, the institutions and significant policy have experienced continuous changes during the reform period. The next chapter will introduce China's energy and environmental reform and performance in detail.

Chapter Four

Energy--Environmental Regulation and Performance in China

4.1 Introduction

China has undertaken significant structural and policy reforms over the last 30 years, as discussed in the previous chapter. However, the resultant annual average growth rate of around 10% has given rise to problems of energy consumption, environmental pollution at home, cross-border pollution and mounting CO_2 emissions. China consumed 19.5% of the world's total energy production in 2009 (46.9% of world coal production, 10.4% of oil, 3% of natural gas, 18.8% of hydroelectricity and 2.6% of nuclear energy)[44]. Due to the heavy reliance on coal consumption (70% of national total energy consumption), China is now the world's largest emitter of CO_2 and SO_2 (IEA, 2011).

This chapter will outline China's energy and environmental problems and is organised as follows: section 4.2 introduces China's energy and environmental institutions and policies; section 4.3 shows China's energy consumption across sectors and regions; section 4.4 presents China's environmental problems; and section 4.5 concludes.

4.2 Energy Institutions and Policies in China

While energy consumption has received much more attention, its institutional basis and implementation of policies have frequently changed, especially after the reforms in

[44] Data are from BP Statistical Review of World Energy (2010).

1978. These changes have played an important role in shaping China's energy system (World Bank, 1997).

4.2.1 Energy Institutions

Energy institutions are essential play part of the Chinese policy-making, and it should not be ignored. Since the economic reforms began in the late 1970s, China's energy institutions have experienced continuous changes to promote low energy intensity. This section will introduce the development of Chinese energy institutions.

During the 1980s, China experienced rapid economic development and a shortage in energy supply. The Chinese government tried to restructure energy institutions to promote low energy intensity. During the decade, the organisation of the energy sector was fluid, and two major reorganisations occurred in 1981-1983 and in 1985-1989. These changes tended to reinforce the separation of energy production and distribution from government administration (Appendix Table A4.1 summarises the major changes during the period). The state-owned energy corporations were formed as substitutes for central government management. They were responsible for energy production in the coal, oil, and electricity sectors, and were supervised by the Ministry of Energy (See Appendix Figure A4.1), which increased competition and efficiency in energy production and reduced the assistance from the central government. China's Energy Investment Corporation (CEIC) was formed with responsibility for investment in national projects in the energy sectors in 1988.

Since the early 1980s, because of the establishment of energy conservation institutions and programs, China's energy intensity has successfully declined (Levine and Liu, 1990; Sinton *et al.*, 1998; and Chen, 2011). More than 200 energy conservation technology centres were set up across the country, which provided technology consultation, monitoring, and training in energy conservation, mainly related to energy use in industrial sectors (Liu *et al.*, 1994).

The institutional reforms from 1980 to 1992 were characterised by reduced central control and increasing autonomy of energy corporations (Yang *et al.*, 1995). The central government could not control energy production and consumption of energy efficiently. Therefore, between 1993 and 1998 the central government took back some control rights (Xu, 2010). In 1993, the Ministry of Energy was dissolved and replaced by the State Economic and Trade Commission (SETC). The SETC managed short-term production planning and supervised the production of energy over the energy sectors. In 1994, in order to strengthen controls over investment, the central government restructured the investment corporations, unifying all of them into a national development bank under the authority of the State Planning Commission. The central government expanded government ministries and energy corporations. The expansion strengthened government control in the energy sector but increased inefficiencies (Xu, 2010; Zhou *et al.*, 2010).

In 1998 the government embarked on a radical reorganisation and streamlining of government agencies, and restructured the state-owned corporations (Zhou *et al.*, 2010). Since then, with the objective of separation of commercial operators from policy makers and regulators, two types of organisations govern the energy sector: government commissions and ministries as policy makers and regulators, and national corporations as commercial operators. National energy corporations have emerged with less government control and more market-oriented management (Xu, 2010).

In order to build more effective and coordinated administrative institutions, the Ministry of Coal and the Ministry of Electric Power were restructured once again in 1998. The responsibility of management of energy sectors was shifted to the SETC. In 2003, the State Development Planning Commission (SDPC, formerly State Planning Commissions) and SETC were combined to form the National Development and Reform Commission (NDRC), as a macroeconomic management agency under the state council. One of its principal purposes is to make plans for the development of the energy sector and the management of natural resources. The Energy Bureau was set up within the NDRC. In 2007, in order to enhance energy conservation and reduce pollutant emissions, a leadership group was established by the State Council, with Premier Wen Jiabao serving as the nominated head of the group. The formation of this group moved the topic to a level above even the NDRC, involving all relevant ministries (Xu, 2010; Zhou *et al.*, 2010).

The National Energy Administration (NEA) and the National Energy Commission (NEC) were established under the NDRC in 2008. This was the latest effort to reform China’s highly dispersed energy management and to create an effective energy institution at the national level (Zhou *et al.*, 2010). Currently, there are a number of government agencies involved in the policy making and regulation of the energy sector (see Appendix Table A4.2).

The State-owned enterprises (SOEs) still dominate the energy industries such as oil, electricity and coal, while the participation of private and joint-venture enterprises is limited and mainly concentrates on the coal and renewable energy industries.

In the last 30 years, the development of energy institutions has reflected the changing role of government in the energy sector. The central government has shifted its focus to energy policy formulation and regulatory oversight, while the SOEs have been given more authority over business decisions.

4.2.2 Energy Policies

Due to the heavy reliance on coal and oil after industrialisation, the problems of energy shortages, increasing dependence on foreign energy and a deteriorating natural environment have arisen. Therefore, China's energy policies have been focused on four areas: pricing reform, energy conservation, environmental protection and renewable energy (Yu, 2010; Fang and Deng, 2011). Table 4.1 summarises the key policies since the 1980s.

Table 4.1: Key Energy and Relevant Policies

Issue / revise year	Key Policies
1982	The regulation of international cooperation for mining offshore oil resources
1983	The environmental protection regulation of offshore oil exploration and production
1986/1996	The mineral resource law
1986	The regulation for supervision and management of civil nuclear facilities
1987	The regulation on control of nuclear materials
1987	The regulation of electric power facility protection
1987/1995,2000	The air law
1988	The water law
1989	The environmental protection law
1991	The regulation on land use compensation and migrant settlement for construction of large and medium hydro conservancy and power engineering
1991	The regulation on safety management of reservoir dams
1992	The mineral mine safety law
1993	The regulation for management of electricity network dispatching
1993	The regulation of international cooperation for mining land oil resources

1993	The regulation on control of nuclear power plant accident emergencies
1994	The regulation of village and town coal mine management
1994	The means of coal mining licence management
1995	The electric power law
1995/2004	The law on protection of solid waste pollution
1996	The law on coal industry
1996	The regulation of electric power supply and usage
1996/2007	The energy technology policy
1997	The regulation on control of nuclear-related exports
1997/2007	The energy conservation law
2000	The regulation of coal mine safety supervision
2001	The regulation on protection of oil and natural gas pipelines
2002	The environmental impact assessment law
2002	The law of cleaner production promotion
2003	The law on protection against radiation pollution
2005	The regulation of electric power supervision and management
2005	The regulation on safety and protection of radio isotopes and radioactive devices
2005	The renewable energy law
2005	Medium and long-term plan for energy conservation
2005	11th Five Year Plan (2006-2010)
2007	National climate change programme
2007	Medium- and Long-Term Program for Renewable Energy Development
2007	China's scientific and technological actions on climate change
2008	The circular economy law*
2008	The ordinance on civil-building energy-saving
2008	The energy efficiency regulations on the public sector
2008	White paper: China's policies and actions for addressing climate change
2009	Implementation of the Bali Roadmap: China's position at the Copenhagen climate change conference

Note: *The term "circular economy" refers to the reducing (reducing the consumption of resources and the production of wastes), reusing (using wastes as products directly, using wastes after repair, renewal or reproduction or using part or all wastes as components of other products) and recycling (using wastes as raw materials directly or after regeneration) activities conducted in the process of production, circulation and consumption (CCICED, 2005).
Source: Yu (2010); Fang and Deng (2011).

Pricing Reform

Before the 1980s, all energy prices were set by the central government at very low levels. This had several negative impacts on the energy sector: heavy subsidizing of energy producers; lack of incentive to improve productivity, efficiency and quality, and discouragement of energy conservation. In the early of 1980s, a two-tiered pricing structure – planned price and floating price – was introduced to the coal, oil and natural gas industry[45]. This allowed the SOEs to produce more than production quotas and sell surpluses at higher prices. In the mid-1990s, the two-tiered pricing system was abolished. The price of coal was liberalised either by allowing it to free-float or by converging market and planned prices; the price of oil was more or less aligned with the international market price; and the power plants were allowed to set their own prices based on a formula for return on investment (Peng, 2009). In 2004, the NRDC set up a policy on differential electricity pricing for high energy-consuming industries. This allowed electricity prices determined on the energy intensity level of each enterprise. In 2007, the policy was adjusted, giving authority to local provincial offices to retain revenue obtained through the differential electricity pricing system, which provided incentives for provincial offices to impose the policy (Moskovitz, 2008).

By 2006, subsidies for energy had been significantly decreased and China's energy prices increasingly reflected actual costs (IEA, 2007). Currently, China's energy prices have largely converged with world prices, and the prices of crude oil and coal are largely determined by the market. However, several key final product prices, such as diesel, gasoline and electricity are still controlled by government.

Energy Conservation Policy

Government-led investment programs and regulatory activities were recognised as the major drivers of improvement in energy efficiency, which was believed to have accounted for one third to one half of the drop in energy intensity (Sinton *et al.*, 1998). The Chinese government began to promote energy conservation in the early 1980s.

[45] The two-tiered pricing system was applied as an incentive to increase production. Above-quota output that the state mines produced could be sold to the state at 50% (later changed to 70%) above the plan price, or on the open market at a floating price (Peng, 2009).

During this period, administrative and regulatory structures were established to manage energy use, to develop standards for processing and equipment efficiency, to provide direct support for energy-efficient projects, to formulate energy codes, and to create financial incentives. A nationwide network of technical centres was set up for consulting, training and public education; the most energy-intensive industrial subsectors were targeted, such as steel and iron, chemicals, building materials and power generation (Sinton *et al.*, 1998).

Since the 1990s, the government has shifted from direct investment and project implementation to regulatory control. The most important energy conservation policy was the Energy Conservation Law (ECL), which was approved in 1997 and came into force in 1998. The ECL states that "*government should encourage energy efficiency, as well as the development and use of new and renewable energy; formulate energy conservation policy, compile energy conservation plans, and incorporate them into the economic and social development plans of the nation; develop policies and plans that ensure rational energy utilisation, and coordinate those plans with environmental protection and economic growth; stimulate and support technology R&D and scientific research in energy conservation as well as application and dissemination; and, strengthen educational activities and propaganda in energy conservation to disseminate scientific knowledge and increase public awareness of energy conservation*" (Zhao, 2001, p.22). Other relevant regulations, such as the Coal Industry Law and the Electric Power Law, were implemented in the late 1990s. These laws reinforce the convictions of energy conservation and efficiency promotion; reinforce the importance of developing renewable and clean energy for long-term energy development strategies; and shut down small mines, refineries, power plants, as well as small, highly polluting manufacturing facilities.

In 2004, the NDRC released the Medium- and Long-Term Plan for Energy Conservation. This plan set out specific targets for the industrial, transportation and building sectors, and provided the “top ten priorities” and “ten key projects” (see Appendix Table A4.1). Some priorities, such as the implementation of the Top-1000 enterprises conservation action, increased financial incentives for energy efficiency, and the strengthening of energy conservation laws has been realised since the issuance of this plan. The ten key projects were focused on reducing energy use in industry and buildings.

In 2006, the 11th Five Year Plan (2006-2010) set the targets of reducing energy intensity by 20% and pollution by 10%. This plan established specific efficiency targets for electricity generation, selected industrial processes, appliances and transport. Later, the State Council approved and distributed a scheme disaggregating the national targets into each province, and further required local governments to disaggregate provincial targets to cities and counties (Zhou, 2006).

In 2007 the revised ECL was adopted. It clarified the legal basis for the measures identified in the 11th Five Year Plan (2006-2010); identified the organisations of government responsible for implementing the plan; prohibited many highly energy-consuming products; authorised provinces to penalise companies deemed to be using energy wastefully; and provided the basis for the creation of special fund and incentive policies for energy efficiency. The Medium- and Long-Term Energy Conservation Plan, the General Work Plan for Energy Conservation and the Pollutant Discharge Reduction Plan set up targets for reducing energy consumption and major pollutant discharge for the 11th Five Year Plan (2006-2010).

Environmental Protection Policy

China's policy and international setting for environmental protection has undergone several transformations over the past decades. After taking part in the 1972 United Nations Conference on the Human Environment (UNCHE) in Stockholm, China started to concern itself with environmental issues. In 1973, the Chinese government held the first National Congress of Environmental Protection, set up a national environmental protection organisation (the Environmental Protection Office under the State Council) and stipulated a "three synchronisations" system[46]. Pollution control during the1970s was only concerned with three forms of industrial wastes (wastewater, waste gas and solid waste) and made no effort to prevent and abate other forms of pollution (Sinkule and Ortolano, 1995).

In 1978, the Chinese Constitution adopted Article 9, which says that the State shall protect the environment and natural resources, and shall also prevent and eliminate pollution and other public nuisances (Shaw *et al*., 2010). In accordance with this new article "the PRC Environment Protection Law for Trial Implementation" was promulgated by the National People's Congress in 1979, which adopted the Environmental Impact Assessment system and the Polluter Pays Principle. In 1982 a pollution levy system based on the Polluter Pays Principle was implemented nationally. Furthermore, in 1983 environmental protection was declared to be one of the two fundamental national policies. Observers seem to agree that the real improvements in environmental protection only started to come after the promulgation of the Environmental Protection Law (Shaw *et al*., 2010). In the 1980s, more environmental laws and ambient standards were gradually established. An important one was the

[46] This "three synchronisations" system entailed (1) designing antipollution measures simultaneously, (2) constructing antipollution equipment simultaneously with the construction of industrial plants, and (3) operating antipollution equipment simultaneously with the operation of industrial plants (Shaw *et al.*, 2010).

"Environmental Responsibility System", in which governors and mayors would be responsible for overall environmental quality in their jurisdictions. In 1988, the environmental agency took a more independent position from other ministries[47].

Since the 1990s, due to rapid industrial development, China's environment has been degraded. The energy sector is regarded as a major source of air and water pollution. It is believed that about 85% of CO_2, 90% of SO_2, 60% of NO_X and 70% of suspended particulates are from coal burning (UNEP, 2000). Recognising the seriousness, the government began to develop environmental protection policies which focused on the energy sector from the end of 1980s. China passed the first Environmental Protection Law in 1989. Following the UN Conference on Environment and Development in 1992, China's Agenda 21st Century was developed. This agenda set up a strategic goal of sustainable development by encouraging energy efficiency, using renewable energy and clean coal technology, and combining cycle power plants and nuclear power (Yu, 2010). In 1994, State Council approved the Sustainable Energy Programs under Agenda 21st Century. In the 9th Five Year Plan (1996-2000), China initiated several national programs including the Brightness Program, Integrated and Comprehensive Rural Electrification, Energy Efficient Lighting and the Riding Wind Program. In the late 1990s, a cleaner production program and a discharge permit system were applied. Under this system pollution sources were required to register with local Environmental Protection Bureaus and apply for a discharge permit (Fang and Deng, 2011).

In 2000, the Air Pollution Control Law was revised and energy efficiency was directly addressed in it. Several environmental laws were promulgated subsequently, including

[47] The National Environmental Protection Agency (NEPA) was upgraded to the Vice-ministry level from the National Environmental Protection Bureau established in 1984. The NEPA was further upgraded to ministerial status and renamed the State Environmental Protection Agency (SEPA) in 1998. Finally, in 2008 the SEPA was renamed Ministry of Environmental Protection (MEP) which has a seat in the State Council and remains the as powerful as some other key ministries.

the Environmental Impact Assessment Law (issued in 2002)[48] and the Law on protection from Solid Waste Pollution (issued in 1995, revised in 2004). The core aspect of the 11th Five-Year Plan (2006-2010) approved in 2005 was building a harmonious society. Achieving a better balance between economic, social and environmental development by narrowing the gap between rich and poor and by curbing widespread environmental degradation was the main task during this period. In 2008 the Circular Economy Law was approved to promote a more sustainable economy by improving energy use and protecting the environment. At the end of 2008, State Council promulgated the White Paper: China's Policies and Actions for Addressing Climate Change. In 2009, the government proposed Implementation of the Bali Roadmap: China's Position at the Copenhagen Climate Change Conference, which introduced the major actions: to strengthen energy-saving, to enhance energy efficiency, to develop renewable energy, to increase forest carbon sink capacity, to develop low-carbon and a circular economy, and to promote climate-friendly technology. At the executive meeting of the State Council in Nov, 2009, China adopted a "binding" goal to reduce CO_2 emissions per unit GDP by 40% to 45% of 2005 levels by 2020.

Renewable Energy Policy

In order to diversify energy sources and protect the environment, the government began to encourage the development of renewable energy in the 1990s. During this period, most energy laws supported renewable energy. For example, the Electric Power Law (issued in 1995) emphasised government support for small hydropower systems, solar energy, wind, geothermal, biomass and other renewable energy sources for rural electrification; the 9th Five Year Plan "2010 Long-Term Objective on Economic and

[48] The new law does not attempt to modify the existing Environmental Impact Assessment system in any radical way, which suggests that the government considers that the current practices are satisfactory (Wang *et al.*, 2003).

Social Development in China", and the Energy Conservation Law (issued in 1998) stressed the importance of renewable energy and proposed strategies for using renewable energy to reduce emissions (Zhao, 2001).

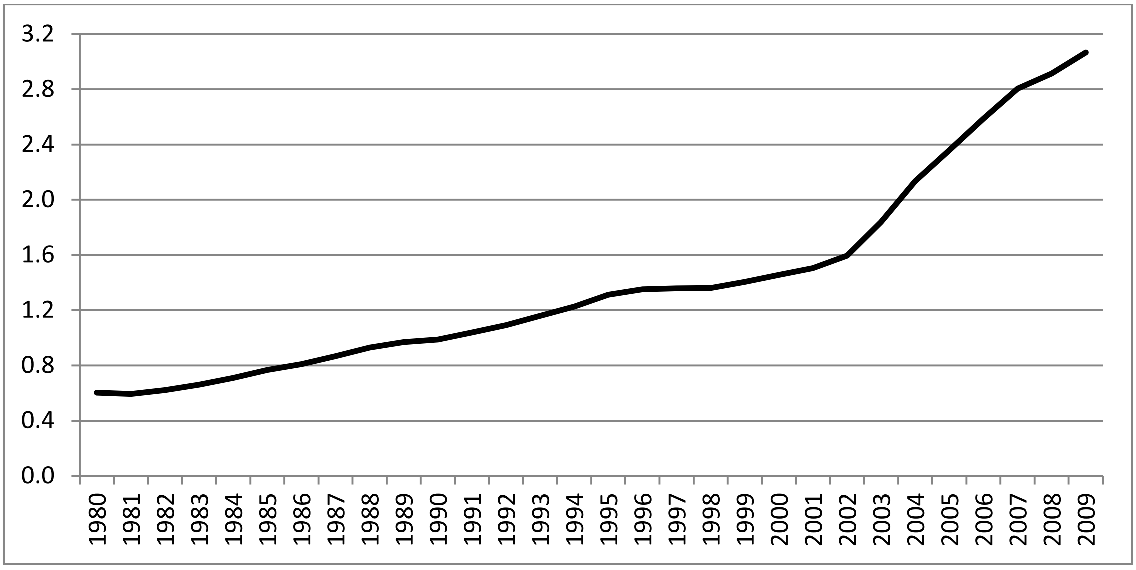
In the 2000s, a series of renewable energy policies were announced and implemented, which marked the increasing importance of renewable energy in the national energy development strategy. In 2005, the Renewable Energy Law was enacted, which set the stage for the widespread development of renewable energy, particularly of commercial scale renewable generating facilities. In 2007, the Medium- and Long-Term Program for Renewable Energy Development established energy conservation targets for local governments and key central departments, and required an increase in renewable energy consumption to 10% of total energy consumption by 2010 and 15% by 2020. In 2009, two national solar energy subsidy programs were introduced, providing up to 50% of the investment cost for grid-connected solar power systems.

At the different stages of economic reforms, China's energy policy has had different focuses: in the 1980s, energy policy encouraged energy conservation and efficiency improvement through direct government technical support and program/project implementation and administration; in the 1990s, several important energy laws were announced to set up the legal framework to promote energy efficiency, reduce emissions and utilise renewable energy; and in the 2000s, energy policy has been multifaceted so as to restructure the industrial sector to move the national economy away from highly energy-demanding, highly polluting industries, to promote clean and renewable energy through policy support and subsidy programs and to incorporate energy and environmental targets into assessment mechanisms.

4.3 Energy Consumption

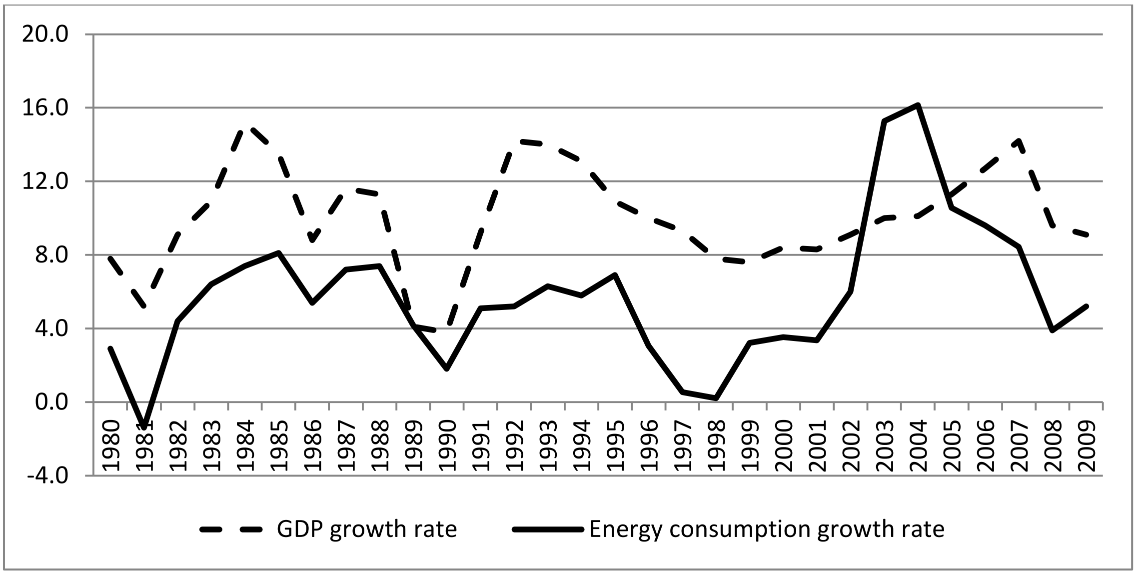
In the last 30 years, energy consumption in China has more than quintupled. Total primary energy consumption (coal, oil, natural gas and hydroelectricity) in China increased from 0.6 billion tce (ton of coal equivalent) in 1980 to 3.07 billion tce in 2009. From 1980 to 2001, the average annual growth rate of energy consumption was 3.8%, which was less than the average GDP growth rate (9.5%). Since 2002, energy consumption has increased significantly, especially during 2003-2005 where it grew faster than GDP (see Figure 4.1 and 4.2). Since 1980, China's energy consumption has had several distinct characteristics, such as an unbalanced composition of energy consumption, a reduced energy intensity, and a falling per capita energy consumption.

Figure 4.1: Total Energy Consumption in China: 1980-2009 (Billion tce)



Source: *China Energy Statistical Yearbook* (2010).

Figure 4.2: Annual Growth Rates of GDP and Energy Consumption: 1980-2009 (%)

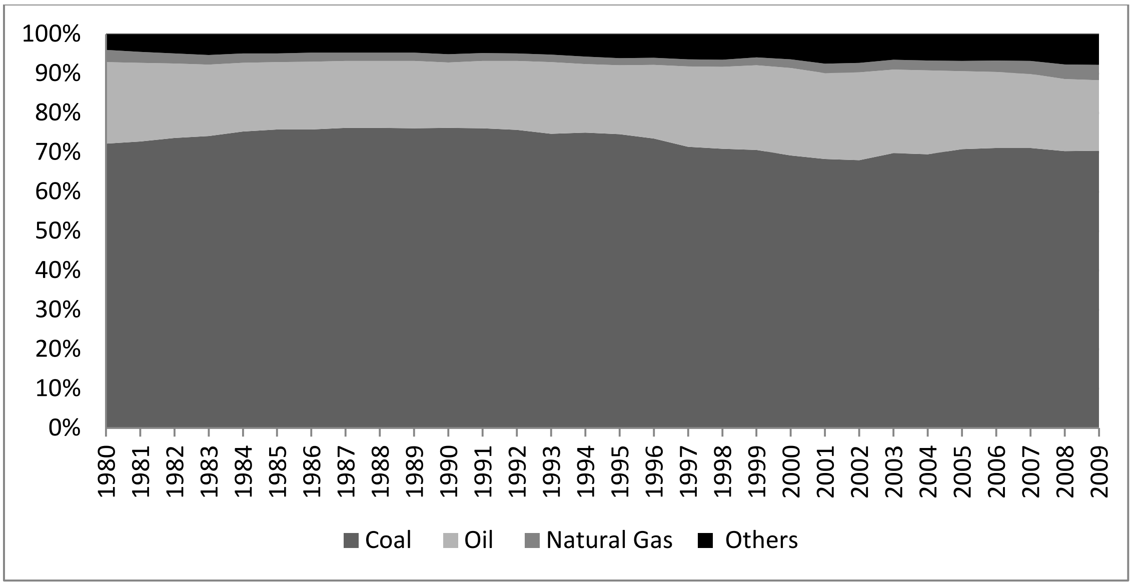


Source: *China Energy Statistical Yearbook* (2010).

4.3.1 Composition of Energy Consumption

The composition of energy consumption in China is unbalanced compared with other countries. Table 4.2 shows the composition of energy consumption in selected countries in 2009. And Figure 4.3 shows China's energy consumption composition from 1980 to 2009. This is highlighted by the large share of coal-sourced energy (around 70%), while the share of natural gas-sourced energy is trivial (less than 4%). Energy consumption in the industrial sector accounted for 70% of overall energy consumption in 2009 (see Table 4.3).

Figure 4.3: Composition of Energy Consumption by Energy Type in China: 1980-2009



Source: *China Energy Statistical Yearbook* (2010).

Table 4.2: Total and Composition of Energy Consumption by Energy Type in Selected Countries in 2009

Country	Total (million tonnes oil equivalent)	Composition (%)				
		Coal	Oil	Natural Gas	Nuclear Energy	Hydroelectric
US	2182.0	22.82	38.63	26.98	8.72	2.85
China	2177.0	70.62	18.58	3.66	0.73	6.40
Russia	635.3	13.05	19.66	55.20	5.82	6.26
India	468.9	52.42	31.67	9.96	0.81	5.12
Japan	463.9	23.45	42.60	16.96	13.39	3.60

Note: the selected countries were the top five energy consumers in 2009.
Source: BP, 2010.

Table 4.3: Composition of Energy Consumption by Sector in China: 1980-2009 (%)

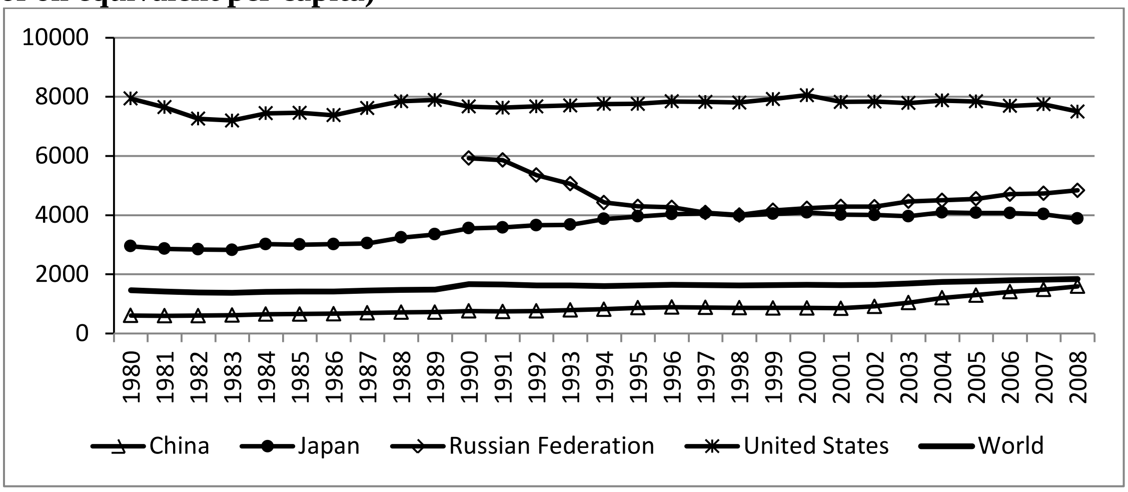
Year	Primary	Secondary		Tertiary	Others	Residential Consumption
		Industry	Construction			
1980	5.76	68.04	1.59	5.84	3.54	15.23
1985	5.28	66.60	1.70	5.84	3.56	17.02
1990	4.90	63.63	1.20	5.91	3.52	13.51
1995	4.20	73.33	1.01	6.00	3.45	12.00
2000	2.69	71.31	1.50	9.82	3.96	10.73
2005	2.57	71.49	1.44	9.85	3.92	10.72
2009	2.04	71.48	1.49	9.82	4.14	11.04

Source: *China Energy Statistical Yearbook* (various issues).

4.2.2 Energy Consumption Per Capita

Although China's energy consumption is large in absolute terms, energy consumption per capita is very low relative to developed countries. Figure 4.4 shows energy consumption per capita in selected countries from 1980 to 2008. Although per capita energy consumption in China has increased during the period (it reached 1,598 kg of oil equivalent per capita in 2008), it is still much lower than in developed countries, such as the US (7,503 kg of oil equivalent per capita) and Japan (3,883kg of oil equivalent per capita), and it is also lower than the world average (1,840 kg of oil equivalent per capita).

Figure 4.4: Energy Consumption Per Capita in Selected Countries: 1980-2008 (kg of oil equivalent per capita)

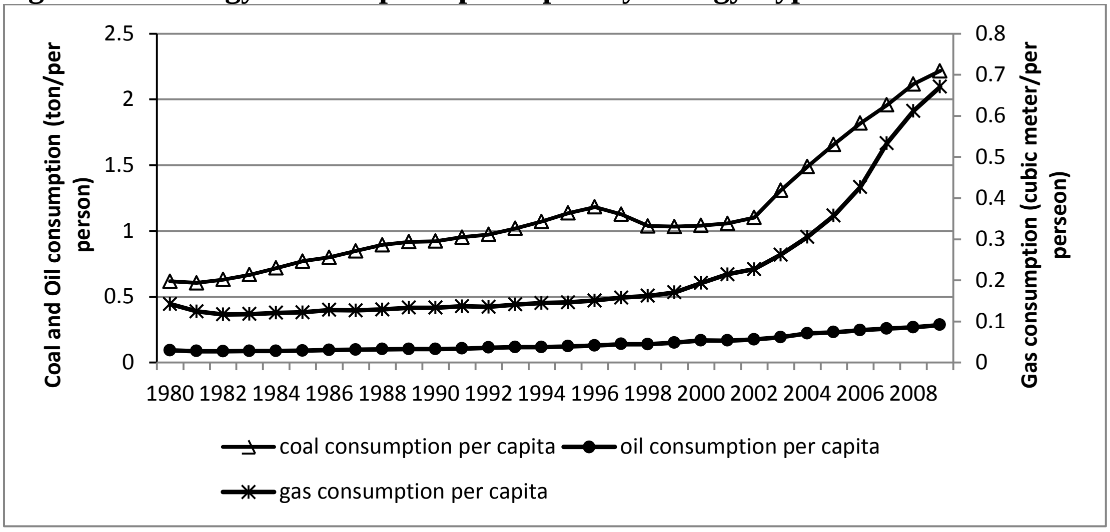


Source: World Bank, 2011.

Figure 4.5 shows per capita energy consumption by energy source in China from 1980 to 2009. As a coal-dominated country, coal-sourced energy consumption increased rapidly from the early 1980s, although there was a small decrease in the period of 1996-2002. From 2002-2009, it doubled from 1.1 ton per capita to 2.2 ton per capita. During the 1980s and 1990s, gas sourced energy consumption per capita was between 0.1-0.2

cubic metres per person, but this increased significantly to 0.7 cubic metres by 2009. Oil-sourced energy consumption per capita has been more stable during the last three decades, increasing from 0.1 ton in 1980 to 0.3 ton in 2009.

Figure 4.5: Energy Consumption per capita by Energy Type in China: 1980-2009

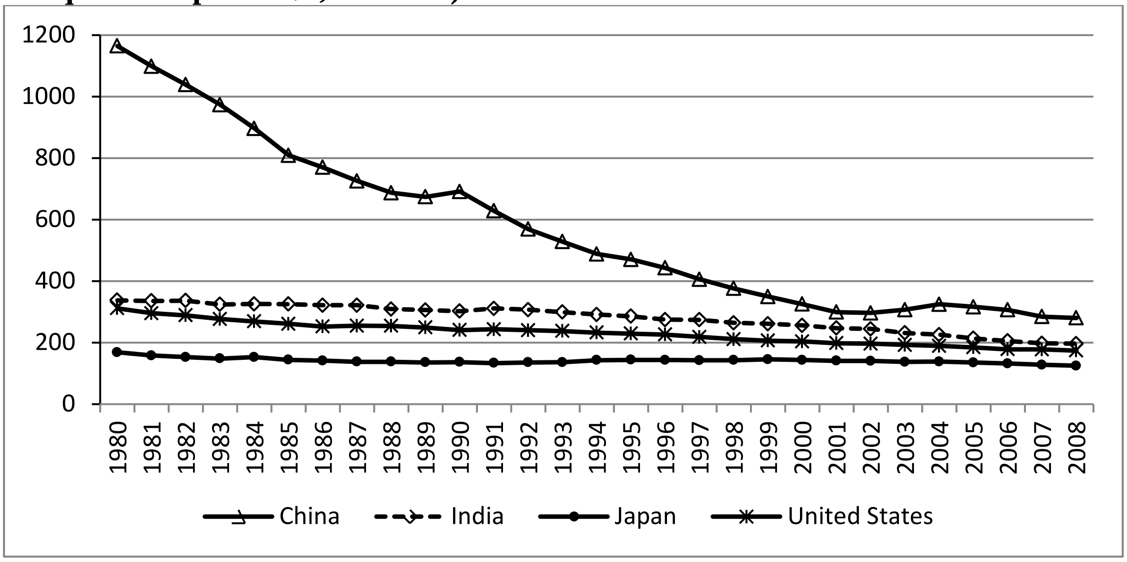


Source: Author's calculation based on *China Energy Statistical Yearbook* (various issues).

4.3.3 Energy Intensity

Over the last 30 years, growth in energy consumption has been accompanied by a dramatic decline in energy intensity (energy consumption per $US1,000 of GDP) in China (see Figure 4.6). When China began its economic reforms, its energy intensity was 1,164 kg of oil equivalent, which was four times that of the US (311 kg of oil equivalent) and nearly seven times that of Japan (168 kg of oil equivalent). By 2008, China's energy intensity (280 kg of oil equivalent) had fallen to levels more comparable to those of the US and Japan, despite two short periods of trend reversal: 1988-1990 and 2001-2004. Technical and structural factors intervened (Kambara, 1992; Garbaccio *et al.*, 1999; and Fisher-Vanden *et al.*, 2004). Galli (1998) and Sinton and Fridley (2000) have argued that the improvements in energy efficiency and the development of new materials partially caused the decline in energy intensity.

Figure 4.6: Energy Consumption Intensity in Selected Countries: 1980-2008 (kg of oil equivalent per US$1,000 GDP)



Source: World Bank, 2011.

4.3.4 Regional Energy Consumption

Total and per capita energy consumption are highly unbalanced across the Chinese provinces, as illustrated in Figure 4.7 and in Table 4.4. For example, the coastal region, which is richer than the others, consumed 51% of total energy in 2009, while the poorest western region only consumed 18% of the total. With the highest per capita income level, Shanghai consumed between three and six times more energy per capita than was the case in China's developing provinces.

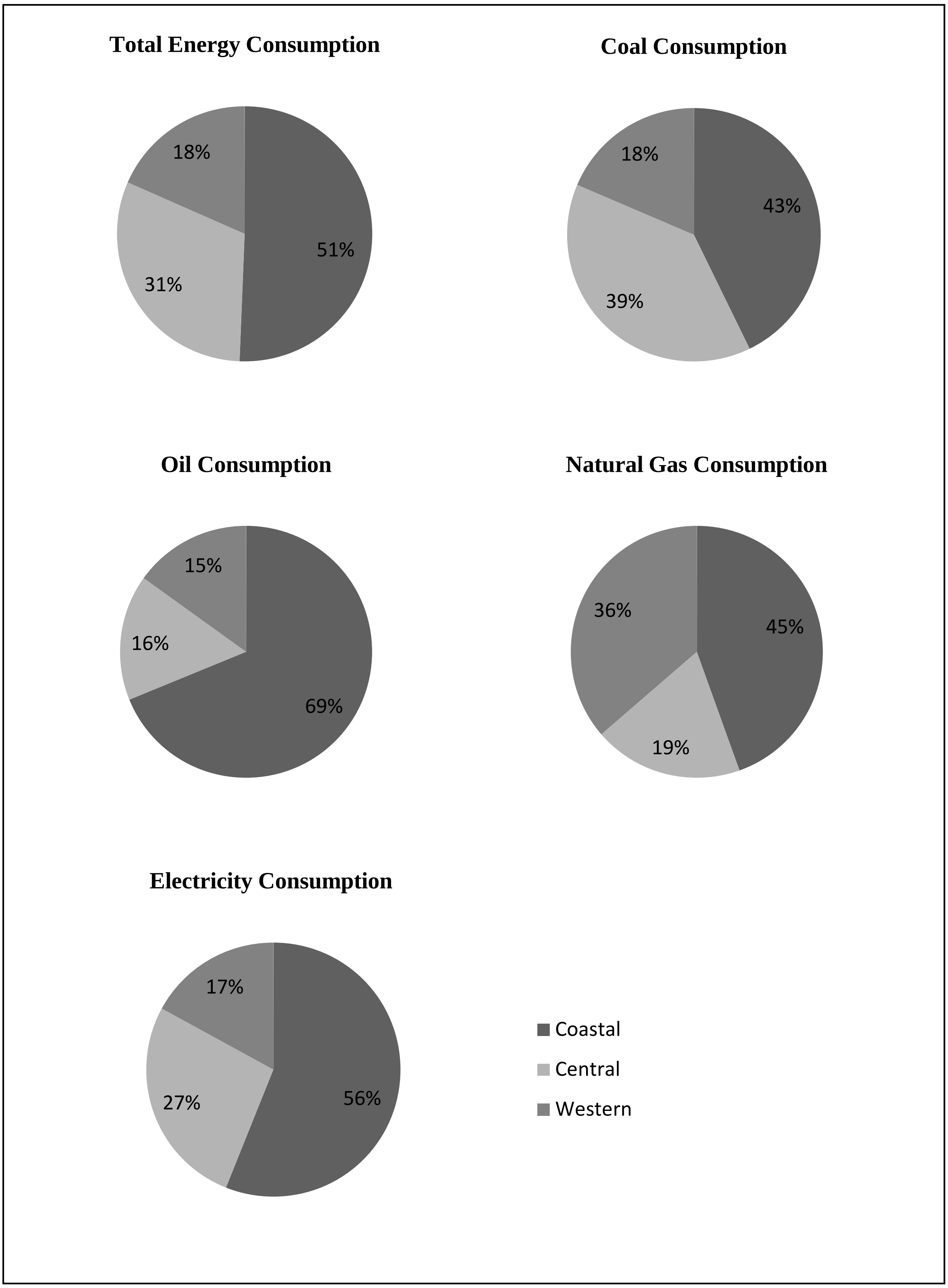
Table 4.4: Energy Consumption per capita in Selected Provinces in 2009

	Income (yuan)	Total (kgce)	Coal (kg)	Oil (kg)	Natural Gas (cu.m)	Electricity (kwh)
Developed Provinces						
Shanghai	78,326	5397	2762	1008	175	6004
Beijing	69,248	3743	1518	663	395	4324
Tianjin	61,244	4783	3354	688	148	4697
Jiangsu	44,604	3069	2719	345	82	4290
Zhejiang	44,382	3005	2563	484	37	4771
Guangdong	40,965	2558	1416	385	117	3745
Developing Provinces						
Anhui	16,413	1451	2066	74	15	1553
Guangxi	15,978	1457	1071	34	2	1763
Yunnan	13,497	1757	1944	0.01	10	1950
Gansu	12,853	2080	1699	547	47	2677
Guizhou	10,301	1992	2873	NA	11	1976

Note: 1) Developed provinces are located in the coastal region, while developing provinces are in the central and western regions; 2) kgce=kilograms of coal equivalent, kg=kilograms, cu.m=cubic meters, kwh=kilowatt hours.

Source: Author's calculation based on data from *China Statistical Yearbook* (2010) and *China Energy Statistical Yearbook* (2010).

Figure 4.7: Regional Energy Consumption in 2009



Source: Author's calculation based on data from *China Energy Statistical Yearbook* (2010).

4.4 Environmental Performance

The economic activities of production and consumption require the use of energy, and so inevitably result in some environmental damage. In particular, air pollution occurs via SO_2 emissions and greenhouse gas emissions (mainly CO_2 emissions) that cause global warming. Most of these effects are produced by the burning of coal. These effects and China's policy responses are discussed below.

4.4.1 Changing Environmental Issues

As already noted, between 1978 and 1984 China initiated agricultural and industrial reforms, while both industrial and agricultural production doubled over this period. Agricultural pollution was not a severe problem due to backward production methods and limited supply of pesticides and fertilisers (Xia *et al.*, 2007). However, due to the large number of randomly scattered township enterprises with irrational product structure, obsolete technical equipment, poor management control, and a lack of pollution prevention measures, environmental damage quickly became more severe. Pollution hot spots quickly spread throughout whole regions, typically from urban to rural areas. During this period, environmental protection work was ignored.

From 1985 to 1992, China's light and textile industries expanded rapidly to meet people's demand for food, clothing, and other consumables. By 1988, the push for economic development was so great that many projects with high energy consumption, low efficiency, waste of resources and heavy pollution were undertaken, such as small-scale paper mills, electroplating, coking and smelting plants. Moreover, deforestation and overexploitation of natural resources were common effects, which accelerated environmental deterioration. Urban air pollution became a more severe problem. The average value of annual total suspended particulates exceeded 800mcg/m^3 in northern urban areas and 1,000mcg/m^3 in some cities in winter. Water quality suffered even worse effects. The Ministry of Environmental Protection (MEP) reported that 436 of China's 532 rivers had been polluted to varying degrees, and that 13 of the 15 major urban reaches of the seven large rivers had been severely polluted. In addition, 6.6 billion tons of untreated industrial residues and urban domestic waste occupied a land area of 536 km^2, and became the second largest pollution source. The area of land with soil and water loss increased from 1.16 million km^2 in the early 1980s to 1.50 million km^2 by the late 1980s (Qu, 1989).

Between 1993 and 2000, China experienced accelerated industrialisation and urbanisation, especially with the 9th Five-Year Plan (1996-2000). Heavy industry was the major contributor to GDP. The energy, infrastructure and electrical manufacturing sectors were growing fast. In 1999, China's urbanisation rate was 30.9%, 1.7 times that of 1978 (Ren and Chen, 2006). Because economic growth was heavily reliant on energy consumption associated with backward technologies and poor management levels, China's environmental quality continued to degrade. From 1993 to 2000, industrial wastewater discharge totalled 144.9 billion tons, industrial waste gas aggregated to 77 trillion m^3, and the total industrial SO_2 emission amounted to 98.18 million tons. As a consequence, severe environmental pollution and ecological damage had resulted in health problems and impeded the development of the economy in some regions (Li, 1996).

During the 2000s, the heavy chemical industries were growing fast in China, and became the major drivers of economic growth due to the high demand for housing and travelling. These industries included electricity, steel, mechanical equipment, cars, shipbuilding, chemicals, electronics and building materials. Since 2003, China has undergone even more rapid economic growth at a rate exceeding 10% for five consecutive years, and according to the World Bank, China's GDP (nominal) per capita exceeded US$3,748 in 2009, compared with US$1,135 in 2002. This phase witnessed the fastest and most long-lasting economic growth and accelerating urbanisation. In 2009, the rate of urbanisation reached 46.6%, and an average annual increase of 1.3%. At the same time, the consumption of resources and energy increased significantly. Coal consumption rose from 1.41 billion tons in 2000 to 2.96 billion tons in 2009.

4.4.2 Air Pollution

Atmospheric environment problems related to energy utilisation are complicated. Energy consumption can cause not only regional environmental problems, such as air pollution, acid rain, and deforestation, but also global environmental problems, such as climate change and ozone depletion. China's major air pollutants – CO_2 emissions, SO_2 emissions and waste gas emissions – are discussed below.

Greenhouse Gas Emissions (CO_2 Emissions)

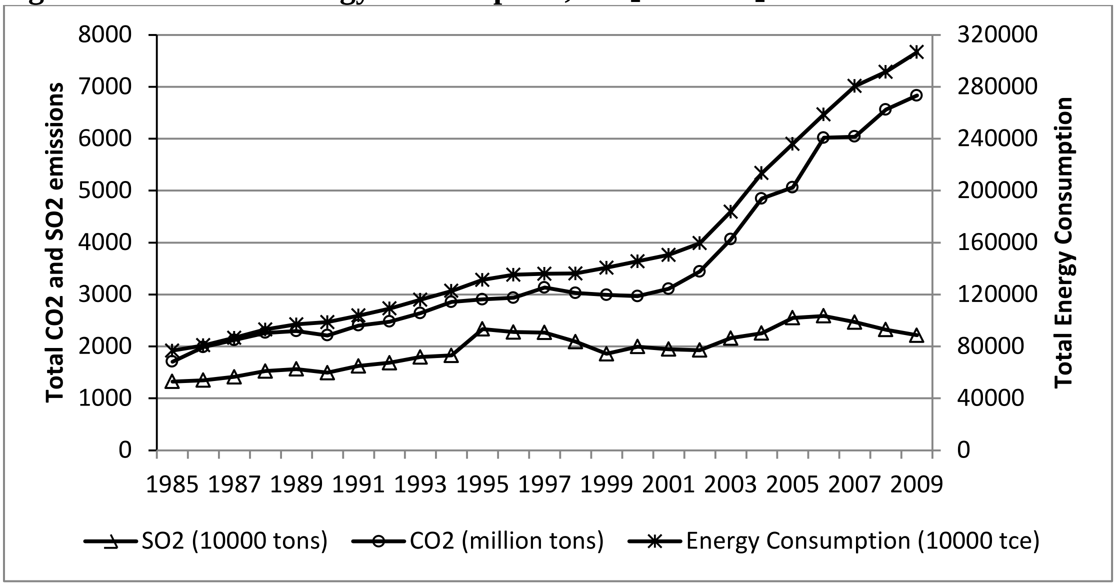
The IPCC (2007, p2) concluded that "*most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations*". The use of energy represents by far the largest source of greenhouse gases. According to IEA (2011), energy accounts for 83% of the greenhouse gases in Annex I countries[49], with CO_2 emissions comprising 92% of total greenhouse gases (CH_4 7%, and N_2O 1%). In 2009, the CO_2 emissions of

[49] The Annex I countries to the 1992 UN Framework Convention on Climate Change (UNFCCC) are: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, the Czech Republic, Denmark, Estonia, European Economic Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lichtenstein, Lithuania, Luxembourg, Malta, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, UK and US (IEA, 2010).

developed countries (Annex I) fell sharply by 6.5%, while the emissions of developing countries (non- Annex I) continued to grow by 3.3%. The IEA (2011) points out that the increase in emissions for developing countries was mainly due to an increase in energy consumption, especially coal. In 2009, 43% of the global CO_2 emissions from fuel combustion were produced from coal, 37% form oil and 20% from natural gas.

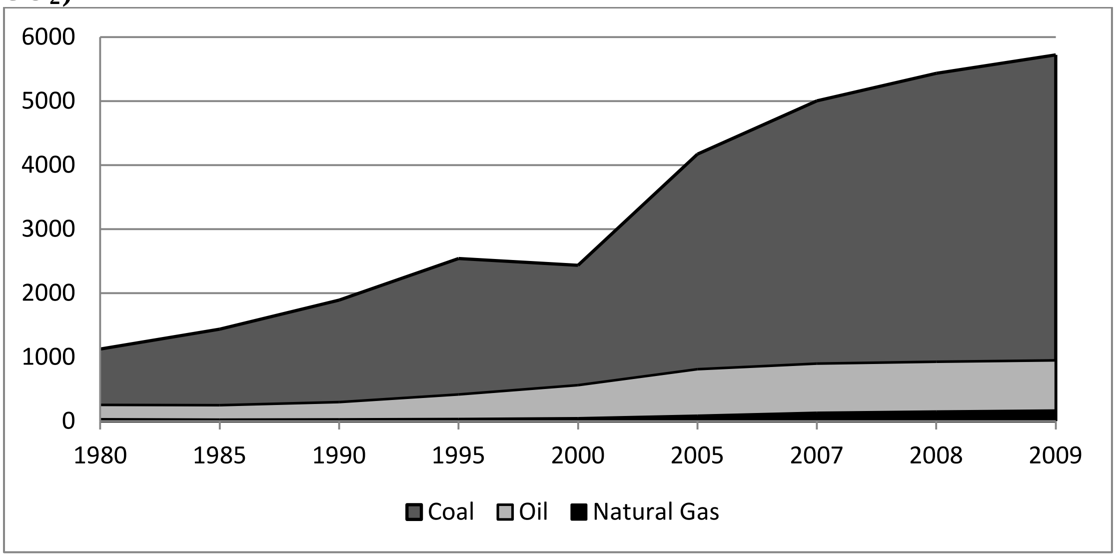
China is a large energy consumer in the world (see Table 4.2), and also takes coal as the main energy source (see Figure 4.3). In the past three decades, China experienced a rapid decoupling of energy consumption and CO_2 emissions from economic growth. As shown in Figure 4.8, accompanied with the rapid growth of energy consumption, China's CO_2 emissions increased rapidly from 1.41 billion tons in 1980 to 6.84 billion tons in 2009, accounting for 24% of global emissions. The increases were especially large in recent years: 16% in 2003, 19% in 2004, 11% in both 2005 and 2006, 8% in 2007 and 2008. However, the growth rate slowed to 5% in 2009. Figure 4.9 shows China's CO_2 emissions from using different fuels. Since 1980, as the main energy source, CO_2 emissions from utilisation of coal have grown the most, representing 84% of total national emissions in 2009. The emissions from using natural gas have also grown rapidly since 1990, by 534%, although it only accounted for 2% of the total in 2009, from a much smaller base.

Figure 4.8: China's Energy Consumption, CO_2 and SO_2 Emissions: 1985-2009



Source: *China Energy Statistical Yearbook* (2010), *China Statistical Yearbook* (various issues), and EAI (2011).

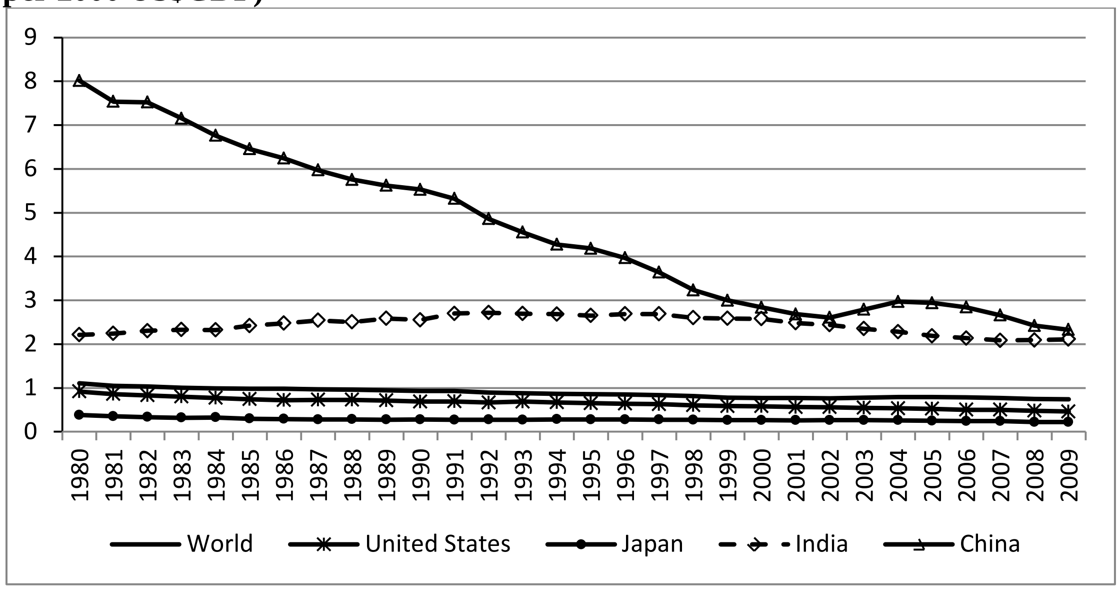
Figure 4.9: China's CO_2 Emissions by Energy Type: 1980-2009 (million tons of CO_2)



Source: IEA (2011).

Figure 4.10 presents the CO_2 intensity (CO_2 emissions per unit of GDP) for the top emitting countries. At the beginning of the reforms, China's CO_2 intensity, as measured by GDP, was more than 8 kg per unit of GDP, which was eight times that of the US. During the 1980s and 1990s, China's intensity fell rapidly, because the industrial energy intensity was reduced. The central government established standards and quotas to each firm for the energy supplied and had the authority to shut off the power supply if firms exceeded their quotas (Lin, 2005). However, because the Chinese economy has moved towards an open-market operation, the share of investment in energy conservation compared to total energy investment gradually decreased (IEA, 2006). And since 2003, the heavy industrial sectors have expanded rapidly to serve huge infrastructure investments and burgeoning demand for China's products from domestic and overseas consumers, pushed up demand for fossil fuels (IEA, 2011). Hence, from 2002 to 2004 CO_2 intensity in China actually rose. After 2005, China's intensity continuously declined, and the 2009 CO_2/GDP was 71% less than in 1980.

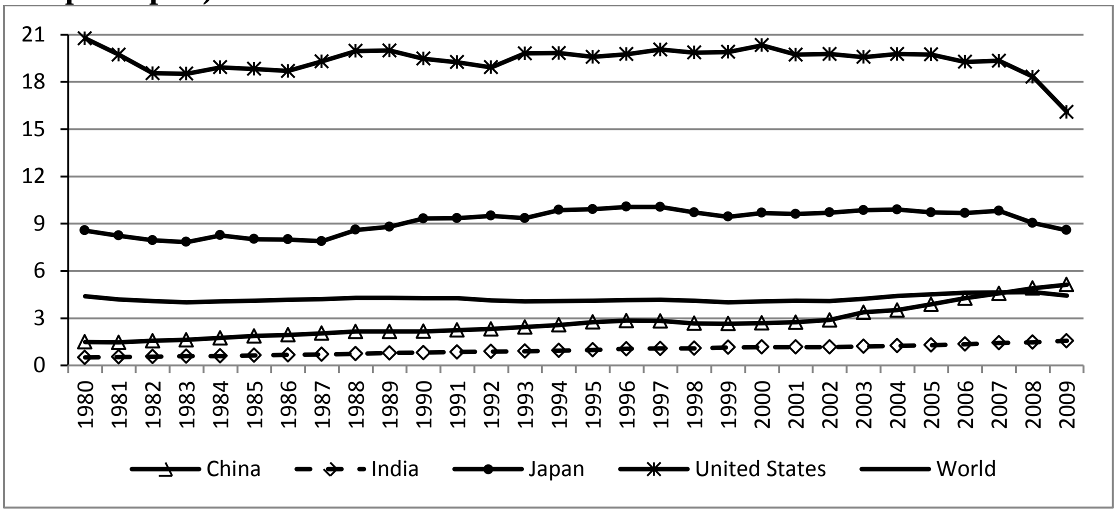
Figure 4.10: CO_2 Emissions Per Unit of GDP in Selected Countries: 1980-2009 (kg per 2000 US$GDP)



Source: World Bank (2011) and IEA (2011).

Although per capita CO_2 emissions in China were much lower than in developed countries, such as the US and Japan, they have increased gradually during the past 30 years, with the largest increases occurring in the last seven years, 2002-2009 (see Figure 4.11). Since 2007, the world average per capita CO_2 emissions, as well as those of the US and Japan, have reduced, and China's per capita emissions exceeded the world level.

Figure 4.11: CO_2 Emissions Per Capita in Selected Countries: 1980-2009 (metric tons per capita)



Source: World Bank (2011) and IEA (2011).

In order to limit growth in CO_2 emissions in the future, the 12th Five Year Plan set the target of lowering CO_2 emissions per unit of GDP by 17% in 2015 compared to 2010. The Chinese government announced in 2009 under the Copenhagen Accord that they would reduce CO_2 emissions per unit of GDP by 40-45% in 2020 compared to 2005 (IEA, 2011).

SO_2 Emissions

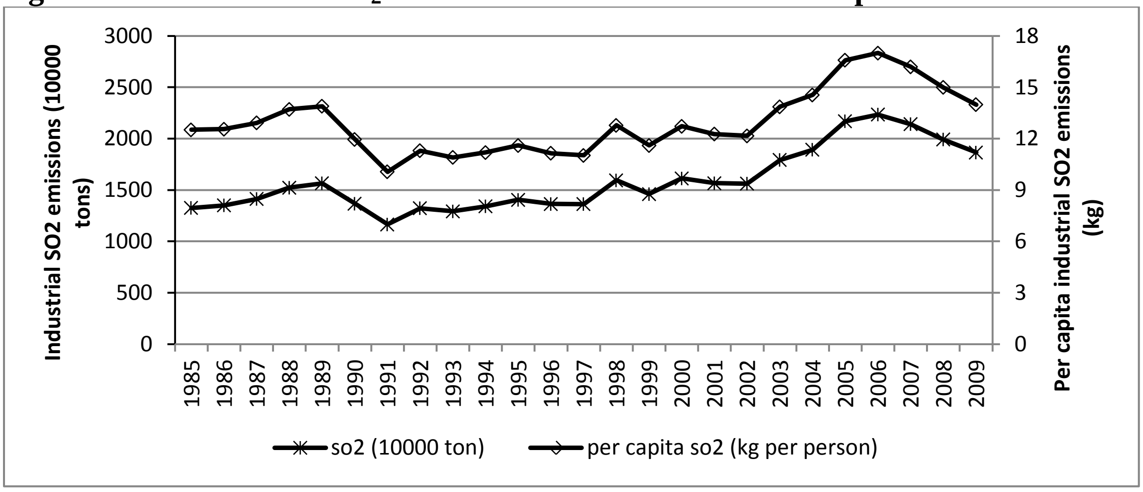
Besides CO_2, China is also the world's largest emitter of sulphur dioxide (SO_2)[50], which is the most important air pollution problem in China. Today over one third of China's big cities have SO_2 concentration levels which are at least double the standard of 60 $\mu g/m^3$ fixed by the WHO for developing countries. Total SO_2 emissions in China increased between 1980 and 1995 to 23.4 million tons. Since a series of SO_2 control policies, such as a nationwide SO_2 emission levy and requirements for SO_2-abatement technology in power plants, were implemented in 1995, as well as government-

[50] SO_2 in the atmosphere is emitted from both anthropogenic and natural sources. In addition to adverse effects on human health, SO_2 and its atmospheric products (e.g., sulphate, sulphuric acid) can affect the atmospheric environment from local to regional and global scales. It is estimated that anthropogenic sources account for more than 70% of SO_2 global emissions, half of which are from fossil fuel combustion (Lu *et al*., 2010).

designated control zones for SO_2 and acid rain in late 1990s, SO_2 emissions have declined each year, with a small increase in 2000 (see Figure 4.8). From 2002, SO_2 emissions again increased. The government is now paying more attention to reducing SO_2 emissions. As approved by the 11th Five-Year Plan (2006-2010), the macro-level goal is to reduce SO_2 emissions to 22.5 million tons by the end of 2010. Fortunately, this goal was achieved in 2009. According to MEP (2010), SO_2 emissions were reduced from 23.2 million tons in 2008 to 22.1 million tons in 2009 (see Figure 4.8).

Industrial production activity has been the largest source of SO_2 emissions in China,[51] emitting about 75% of total national emissions. SO_2 emissions variations have also principally been caused by variations in the emissions from industrial sectors. Industrial SO_2 emissions in absolute terms and in per capita terms increased dramatically from 2002 and peaked in 2006. From 2007 emissions fell significantly (See Figure 4.12). This decline in industrial emissions was confirmed to the 10-year environmental review issued by MEP (2010), and also noted by the OECD (2007).

Figure 4.12: Industrial SO_2 Emissions in Absolute and Per Capita Terms



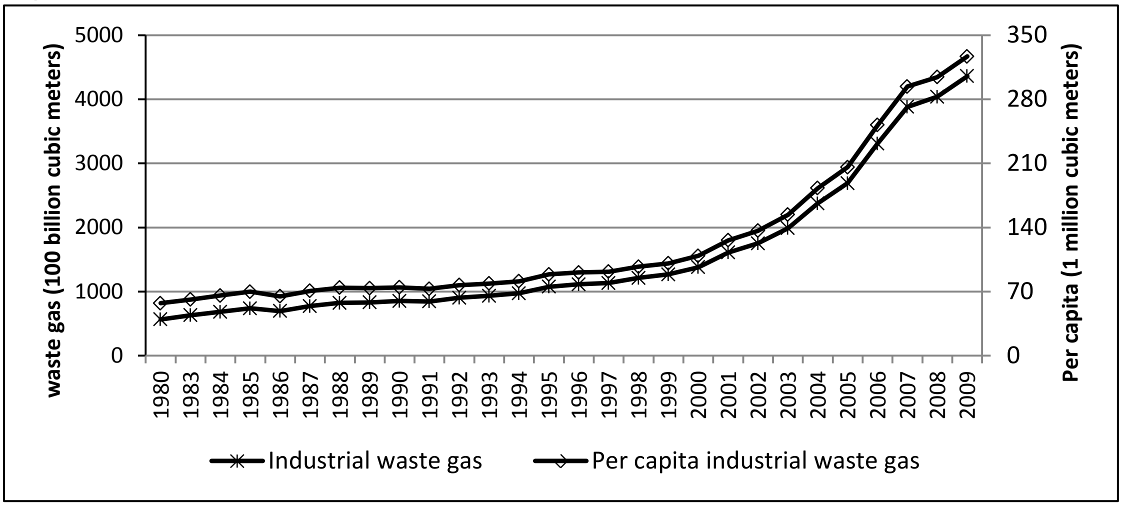
Source: *China Statistical Yearbook* and *China Environmental Statistical Yearbook*, (various issues).

[51] Industrial SO_2 emissions are mainly from three sectors: production and distribution of electric power and heat power, smelting and pressing of ferrous metals, manufacture of non-metallic mineral products.

Industrial Waste Gas Emissions

Industrial waste gas, an important cause of air pollution in China, mainly originates from three sectors: production and supply of electric power, gas and water, smelting and pressing of non-ferrous metals, and non-metal mineral products. During the 1980s and 1990s, total industrial waste gas emissions increased at an annual rate of 4.6%, while after 2001, the annual rate of increase jumped to 13.3% (See Figure 4.13). Recently, industrial waste gas has been highly concentrated on six provinces (Hebei, Sichuan, Shandong, Shanxi, Guangdong and Inner Mongolia)[52].

Figure 4.13: Industrial Waste Gas in Absolute and Per Capita Terms



Source: *China Statistical Yearbook* and *China Environmental Statistical Yearbook*, (various issues).

4.4.3 Water Pollution (Wastewater and Chemical Oxygen Demand)

As rivers may run through several provinces, the water quality of China's rivers reflects a regional environmental problem. According to MEP (2010), the share of surface water in China's seven major river basins[53] which is at or better than Grade III[54], which means

[52] These provinces are responsible for 43% of waste gas emissions and 39% of SO_2 emissions in 2009.
[53] The seven major rivers are the Yangtze River, Yellow River, Pearl River, Songhua River, Huaihe River, Haihe River and Liaohe River.

it can be used as a drinking water source, is now over 57%. In 2001, this share was only 30%. Most of the increase has occurred in the southwest of China, 88.2% met Grade I-III standard, while the rivers in northwest and east were under slightly polluted. The main reason for the improvement is that more industrial wastewater[55] is being treated and is meeting discharge standards (See Figure 4.14). The share of treated industrial wastewater that has met the standards reached 94% in 2009. Urban sewage treatment is also increasing steadily and reached 46% in 2004 (World Bank, 2007). Since 2007, industrial wastewater discharge has declined continuously. MEP (2009) reported that it was 3% less in 2009 than in 2008.

As the most prevalent measure of water pollution in China, the level of chemical oxygen demand[56] (COD) also fell from 1990 to 2009 (See Figure 4.15). In 2009 the amount of industrial COD was 4.4 million tons, which was only 40% of the amount in 1990. According to MEP (2009), the COD level across China was about 4% lower in 2009 than in 2008. Four sectors – paper industry, food processing from agricultural products, raw chemical materials and chemical products and textiles – contributed more than 60% of the total. From 1980 to 2009, industrial wastewater and COD decreased in most provinces, while increasing in some provinces. In 2009, six provinces (Guangdong, Jiangsu, Shandong, Zhejiang, Henan and Guangxi), in which wastewater was higher than 3 billion tons, caused 44% of the total; and 57% of total COD was from

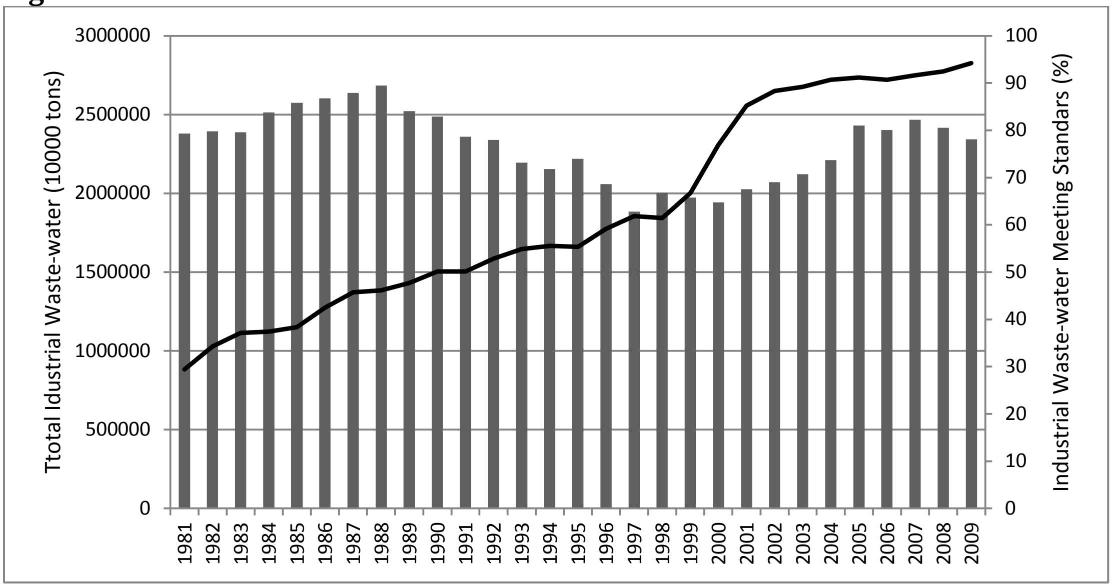
[54] The grades of Chinese water quality standard (Cann *et al.*, 2004):
Grade I: water that flows through national nature reserves;
Grade II: sources of municipal drinking water (first-grade conservation area), conservation areas for rare aquatic species, and areas for fish spawning;
Grade III: sources of municipal drinking water supplies with treatment required (second-grade conservation area), conservation areas for common aquatic species, and areas for swimming;
Grade IV: sources of industrial water supply and recreational use other than swimming (boating, fishing); and
Grade V: sources of industrial cooling water, irrigation water, and ordinary landscape.

[55] Industrial wastewater was mainly produced by four sectors: textiles, electric power production and supply, raw chemical materials and chemical products, and the paper industry. About 52% of total industrial wastewater was from these four sectors in 2009.

[56] COD refers to the amount of oxygen required when chemical oxidants are used to oxidise organic pollutants in water; high organic content can lead to algal blooms and often indicates the presence of water-borne pathogens (Hu, 2010).

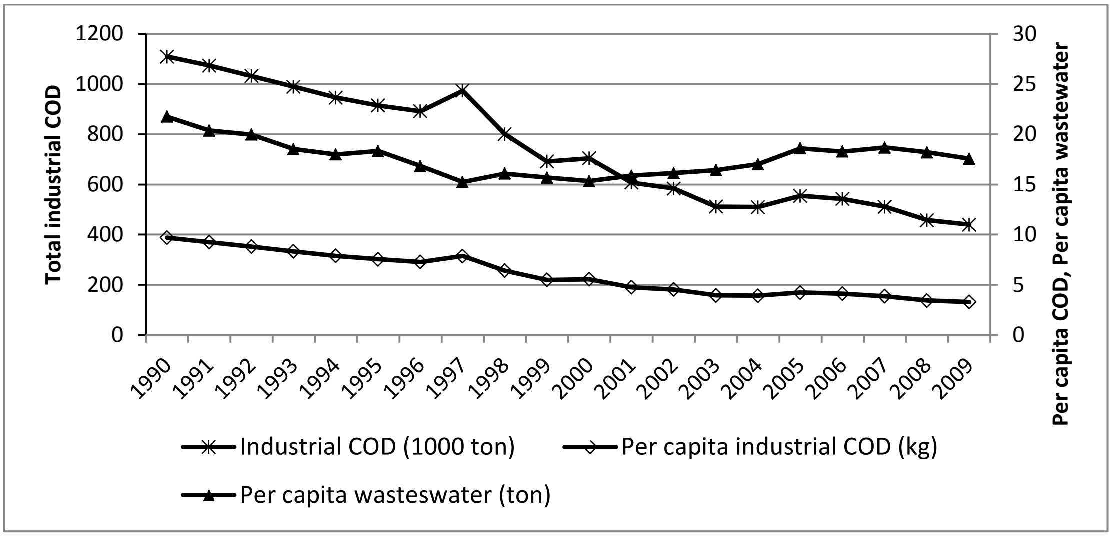
10 provinces (Guangxi, Guangdong, Hunan, Sichuan, Shandong, Henan, Hubei, Hebei and Liaoning). Figure 4.15 also shows that per capita industrial COD decreased dramatically from 1990 to 2009; while per capita industrial wastewater first fell significantly, increased from 1997 to 2005, and then declined again.

Figure 4.14: Industrial Wastewater in China: 1981-2009



Source: *China Statistical Yearbook* and *China Environmental Statistical Yearbook*, (various issues).

Figure 4.15: Total Industrial COD, Per Capita Industrial COD, and Per Capita Industrial Wastewater



Source: *China Statistical Yearbook* and *China Environmental Statistical Yearbook*, (various issues).

4.4.4 Industrial Solid Waste

As a consequence of industrialisation, the amount of industrial solid waste[57] generated in China has increased rapidly, from 487 million tons in 1980 to 2,039 million tons in 2009. According to MEP (2009), there are four disposal methods for solid waste: recycling, physical or chemical treatment and final disposal, temporary storage, and direct discharge into the environment. The rate of recycling increased from 20% in 1982, to 68% in 2009 (Wei *et al.*, 1997; Huang *et al.*, 2006; MEP, 2009), while the amount of treated and stored industrial solid waste has also increased recently. Therefore the direct discharge of industrial solid waste has fallen to a low level (See Table 4.5). Figure 4.16 shows the amount of generated and discharged industrial solid waste per capita. Although per capita generated industrial solid waste has increased, the per capita direct discharge of solid waste dropped significantly from 42 kg in 1990 to 5 kg in 2009.

Unlike other wastes and pollution, industrial solid waste was mainly produced in the central and western regions. For example, in 2009 three provinces (Sichuan, Shanxi and Xinjiang) produced 56% of total industrial solid waste. And of all industrial solid waste, 61% originated from two industrial sectors: mining and quarrying, and smelting and pressing of non-ferrous metals (MEP, 2009).

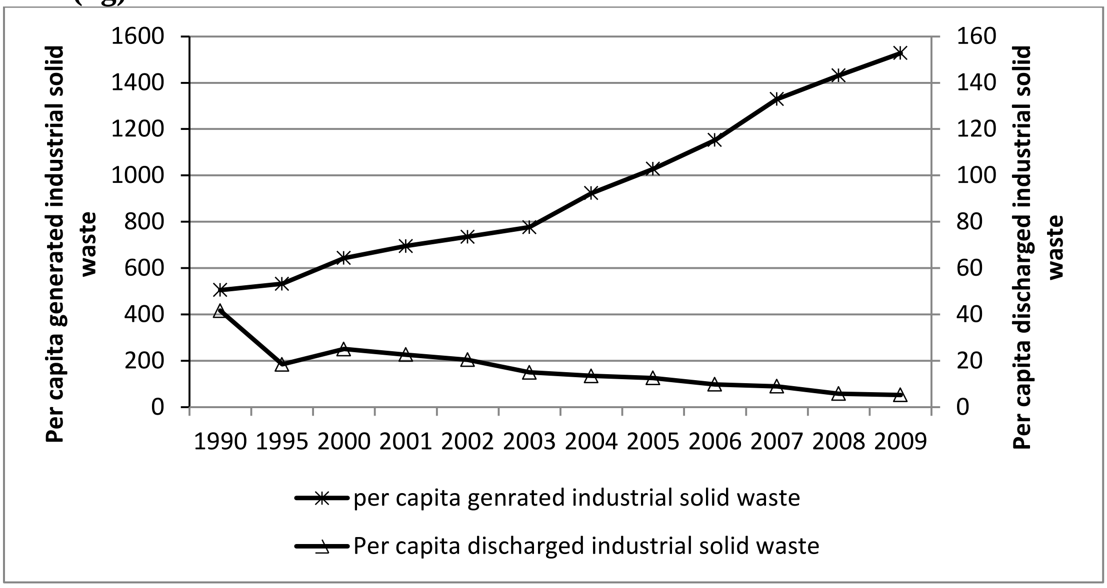
[57] Industrial solid waste refers to solid waste generated in production activities such as industry, traffic and resource development, which include solid and semi-solid wastes and liquid and gaseous wastes in vessels that are not permitted to discharge into the environment (Wei et al., 1997).

Table 4.5: Variation of Amount of Industrial Solid Waste: 1980-2009 (100 million tons)

Year	Generated	Recycled	Treated	Stored	Discharged
1980	4.9	--	--	--	--
1985	4.8	--	--	--	--
1987	5.3	1.4	0.6	2.6	--
1990	5.8	1.7	3.2	--	0.48
1995	6.4	2.9	1.4	2.5	0.22
2000	8.2	3.5	0.9	2.9	0.32
2001	8.9	4.7	1.4	3.0	0.29
2002	9.5	5.0	1.7	3.0	0.26
2003	10.0	5.6	1.8	2.8	0.19
2004	12.0	6.8	2.7	2.6	0.18
2005	13.4	7.7	3.1	2.8	0.17
2006	15.2	9.3	4.3	2.2	0.13
2007	17.6	11.0	4.1	2.4	0.12
2008	19.0	12.3	4.8	2.2	0.08
2009	20.4	13.8	4.7	2.1	0.07

Source: *China Statistical Yearbook* and *China Environmental Statistical Yearbook*, (various issues).

Figure 4.16: Per Capita Generated and Discharged Industrial Solid Waste: 1990-2009 (kg)



Source: *China Statistical Yearbook* and *China Environmental Statistical Yearbook*, (various issues).

4.5 Conclusion

China is a developing country which is seeking to improve the living standard of its people through economic development. Naturally, this has resulted in increasing energy consumption and the emission of more pollutants, especially carbon dioxide. Due to the pace of Chinese economic growth, absolute energy consumption has increased rapidly, especially in recent years. In 2009, China was the second-largest energy consumer in the world, with a heavy reliance on coal and oil. However, energy intensity is declining and per capita energy consumption is still much lower than in many other countries.

Nevertheless, China's environmental problems are receiving attention from all over the world. Although the amounts of most pollutants in both absolute and per capita terms (such as SO_2, industrial wastewater, industrial COD and discharge of industrial solid waste) have declined in recent years, China is still the largest emitter of CO_2 and SO_2. Therefore, reducing overall pollution and saving energy, while implementing rapid economic growth, are challenges that China is confronting. The following chapters will analyse the relationship between economic growth, energy consumption and measures of environmental quality, and identify key factors causing changes in China's output of greenhouse gases.

Chapter Five

Economic Growth, Energy Consumption and CO_2 Emissions in China: A Factor Decomposition Analysis

5.1 Introduction

Economic growth, energy consumption and population growth all contribute to the growth of CO_2 emissions. The production-based accounting approach, a traditional method, is widely used to investigate changes in CO_2 emissions. The common method is to estimate the fixed- or random-effects models, which has its own merits and demerits (discussed in Chapter Two). Another popular method is decomposition analysis, which is widely used in energy-related environmental studies. Generally, decomposition analysis uses sectoral time data to explain which factors contributed how much to the total change in CO_2 emissions. For example, increased energy intensity (emission per unit of energy generated), growth of the economy (increases in per capita income) and structural change (changes in the composition of the produced goods and services) may all contribute to increases in the emissions of CO_2. Such a method is superior since it shows each element separately, which is helpful in setting up goals for reducing CO_2 emissions.

In 2007, China exceeded the US as the world's largest annual emitter of energy-related CO_2, with six billion tons of emissions. With almost seven billion tons of CO_2 in 2009 (24% of the world emissions), China's CO_2 emissions far surpassed those of other countries (IEA, 2011). So, the first objective of this chapter is to identify the factors influencing the rapid growth in CO_2 emissions in China at the aggregate level from

1980 to 2009. Additionally, we are interested in this at a sectoral disaggregate level. For China, there exist obvious differences in economic growth, population, energy use and CO_2 emissions across provinces (Appendix Table A5.3 shows some indicators for each province). Therefore, the second objective of this chapter is to provide a comparative analysis of the changes in CO_2 emissions across Chinese provinces between 1990 and 2009, which will provide the characteristics for each sector/province and help in drawing up specific policies to reduce CO_2 emissions.

The rest of chapter is organised as follows: section 5.2 briefly reviews the literature on decomposition analysis; section 5.3 provides the decomposition method used in this chapter; section 5.4 describes and analyses the data; section 5.5 reports the results of the decomposition analysis; finally, the conclusion is reported in section 5.6.

5.2 Literature Review

5.2.1 Decomposition Analysis

Decomposition analysis is a popular and widely used method for identifying the factors influencing a system's emission changes or energy consumption. There are two main types of decomposition method: structural decomposition analysis (SDA) and index decomposition analysis (IDA) (Hoekstra and Van der Bergh, 2003). The fundamental difference is that the SDA approach is based on an input-output model, while IDA uses more aggregated data. Therefore, as Hoekstra and Van der Bergh (2003) point out, IDA is capable of more detailed time and country studies because of the availability of data, which is easy to apply. Ang and Zhang (2000) and Ang *et al.* (2003) survey more than 100 studies on energy and environmental decomposition, and find that most of them use IDA.

During the last two decades, the Laspeyres index and Divisia index have been the most commonly applied methods in the IDA literature[58]. These methods decompose an object into a multiplicative product of several components to explore the principal factors affecting its variation (e.g. Howart *et al.*, 1991; Scholl *et al.*, 1996; Lin and Chang, 1996; Shrestha and Timilsina, 1996; Greening *et al.*, 1998; Zhang, 2000a; Paul and Bhattacharya, 2004; Steenhof, 2006; Steenhof, 2007)[59].

There are two imperfections in the conventional decomposition methods: the existence of a decomposition residual[60], which leaves a significant part of the examined changes unexplained, and a calculation difficulty because of zero values (Chen, 2011). In order to achieve perfect decomposition, handle the zero values in the data set and study the decomposition of a differential change, Ang *et al.* (1998) introduce the modified Divisia decomposition approach in multiplicative and additive forms, namely the logarithmic mean Divisia index (LMDI) decomposition method. Ang and Liu (2001) improve the LMDI and then put forward the new method, log-mean Divisia Method I (LMDI I), which has the desirable characteristics of perfect decomposition and consistency in aggregation. Ang (2004) compares the decomposition methodologies and concludes that the LMDI is the best method for theoretical foundation, adaptability, ease of operation and result interpretation[61]. He recommends the LMDI as the most preferred method for empirical studies. Ang (2005) proposes a practical guide for the general formulation of the LMDI method and uses industrial energy consumption and

[58] The details of the Laspeyres index and Divisia index can be found in Ang and Zhang (2000) and Sun (1998), respectively.

[59] See details in Chapter Two.

[60] The Laspeyres-based method yields a larger residual term, while the adaptive weighting and simple average Divisia index methods tend to yield smaller residuals in decomposition (Ang and Lee, 1994).

[61] The Fisher index requires that an ideal index should pass three tests (time-reversal, circular and factor reversal tests). According to Ang (2004), only the modified Laspeyres method and LMDI method pass these tests. The reason is that "*the modified Laspeyres method is normally used in additive decomposition to undertake incremental decomposition while the LMDI can take both the additive and multiplicative decomposition forms, and the latter is more extensively used in application*" (Chen, 2011, p.1152).

CO_2 emissions as an example for realising the applications and advantages of the LMDI approach. Ang (2006) examines and illustrates how the technique of IDA is able to provide a bottom-up framework for an economy-wide composite energy efficiency index and national energy efficiency trend monitoring.

Recently, the LMDI method has been widely used to decompose energy-related CO_2 emissions. Most studies focus on CO_2 emission changes or emission intensity changes for the whole economy. In addition to structural and energy intensity changes, sectoral fuel shares and emission coefficients are relevant factors for changes in emissions or emission intensity on a national level. Examples are Bhattacharyya and Ussanarassemee (2004), Lee and Oh (2006), Akbostanci *et al.* (2008), Vinuya *et al.* (2010)[62].

5.2.2 Empirical Evidence in China

As the greatest source of CO_2 emissions in the world, China has been paid more attention. Many studies analyse China's carbon emissions and emission intensity changes by using LMDI methods[63]. Based on aggregate data from the provinces, Wu *et al.* (2005) decompose China's energy-related CO_2 emissions from 1996 to 1999. They argue that rapid reduction of energy intensity and slowdown in the growth of average labour productivity in the industrial sector are the main factors in the sudden changes in the CO_2 emissions.

[62] Details are in Chapter Two.

[63] Other methods are also adopted by researchers. For example, Guan *et al* (2008) combine structural decomposition and input-output analysis to investigate the driving forces of China's CO_2 emissions from 1980 to 2030. They find that household consumption and capital investment are largely responsible for the increase in CO_2 emissions and efficiency gains can only partially offset this trend. Using the complete decomposition method, Zhang *et al.* (2009) identify the factors influencing the changes in energy-related CO_2 emissions and emission intensity during the period 1991-2006. Their results confirm that energy intensity is the dominant contributor to the decline in China's CO_2 emissions and emission intensity. Zhang (2010) uses structural decomposition to find that the structural variables in the supply side, measured by sectoral value-added share are important influential factors.

Wang *et al.* (2005) investigate the change of aggregated CO_2 emissions in China during 1957-2000. Their results show that the total theoretical decrease of CO_2 emissions is 2466 Mt during the research period (energy intensity decline contributes about 95% of the total decrease, and fossil fuel mix and renewable energy penetration only contribute 1.6% and 3.2%, respectively).

Using the same methodology, Wu *et al.* (2006) decompose China's CO_2 emissions in the period 1980-2002. They conclude that before 1996 the economic scale, fuel mix and energy intensity on the energy demand side are the main causes affecting changes in emissions; while the structural and efficiency changes on the energy supply side play only a minor role. After 1996, the speed decrease in energy intensity in end-use and transformation sectors accounts for the decline in China's CO_2 emissions related to the total primary energy supply.

Liu *et al.* (2007) analyse changes in industrial CO_2 emissions from 36 industrial sectors in China from 1998 to 2005, and find the overwhelming contributors are industrial activity and energy intensity. Chen (2011) identifies the factors affecting changes in CO_2 emission intensity for 38 industrial sectors in the period 1980-2008. He concludes that energy intensity is the most important driving force for the reduction in China's CO_2 emission intensity.

The existing China studies show that economic growth and energy intensity are two major factors affecting the changes in China's CO_2 emissions and/or emission intensity, while other factors (carbon coefficient, economic structure, fuel mix and population) are relatively less important but cannot be ignored. Those studies focused on the Chinese industrial sectoral level, while this chapter will provide the provincial analysis as well, due to the significant divergence across China.

5.3 Methodology

5.3.1 IPAT Framework and Kaya-type Identity

There are few aspects of environmental change that are universally agreed upon, due to the complexity of the factors that drive environmental change. However, human activities are recognised as the major driver of environmental change. Because human societies enjoy and utilise the environment for the fulfilment of their basic needs (food, clothing, shelter, etc.) and wants (luxury items, social prestige based, for example, on economic status etc.), human beings have a vested interest in a healthy and productive environment (Shi, 2003; Karakaya and Ozcag, 2005).

The Intergovernmental Panel on Climate Change (IPCC, 2001) states that because of energy consumption and industrialisation, fossil fuel use is the major contributor to human-induced CO_2 emissions. And it is confirmed that CO_2 emissions have been increasing significantly since the industrial revolution. In order to analyse human induced driving forces of environmental change, studies take the approach of either Ehrlich’s IPAT framework or its extended version (Kaya Identity), which demonstrate that demographics, economics, resources and technology as well as environmental policies are the main driving variables.

The theoretical IPAT framework proposed by Ehrlich and Holdren (1974) formulates the factors driving environmental changes:

$$I = PAT \tag{5.1}$$

where I represents the impact of human activities on environment, P indicates population, A is the output per capita, and T denotes the impact of unit output on the environment, which depends on the technology.

On the basis of the IPAT equation, Kaya (1990) proposes the Kaya-type Identity, which breaks CO_2 emissions into several contributing factors:

$$CO_2 = \frac{CO_2}{TE} \times \frac{TE}{GDP} \times \frac{GDP}{P} \times P \qquad (5.2)$$

where TE is the total primary energy consumption; $\frac{CO_2}{TE}$ describes the CO_2 emissions intensity of energy used; $\frac{TE}{GDP}$ denotes the energy intensity of GDP; P represents population; and $\frac{GDP}{P}$ indicates per capita of GDP.

The Kaya-type Identity provides an intuitive approach to the interpretation of historical trends and future projections of energy-related CO_2 emissions. It is widely applied in empirical studies. Recently, the Kaya-type Identity has been further developed to include other factors which influence changes in CO_2 directly, such as economic structural change, energy intensity and energy structure (Ang and Choi, 1997; Schipper *et al.*, 2001).

Both formulas suggest that economic growth, population size and technology (energy intensity and CO_2 intensity) are important in the emissions. Therefore, in order to understand their impacts on CO_2 emissions, we decompose the influencing factors of CO_2 emissions into five parts in our study, which is expressed as follows:

$$CO_2{}^t = \sum_i CO_{2i}^t = \sum_i \left(\frac{CO_{2i}^t}{E_i^t} \times \frac{E_i^t}{Y_i^t} \times \frac{Y_i^t}{GDP^t} \times \frac{GDP^t}{P^t} \times P^t \right)$$

$$= \sum_i (F_i^t \times I_i^t \times S_i^t \times G^t \times P^t) \tag{5.3}$$

where the variables are defined in Table 5.1.

Table 5.1: Definition of Variables in Equation (5.3)

$i = 1, 2, 3, 4, 5$	Primary sector: farming, forestry, animal husbandry, fishery and water conservancy; Industry sector: mining, manufacturing, utility supply; Construction sector; Transport sector; Other Services sector: post and telecommunications, and wholesale, retail trade and catering services[64]
$CO_2{}^t$	Total energy-related CO_2 emissions at time t
CO_{2i}^t	The amount of CO_2 emissions from fossil fuels in the i^{th} sector at time t
E_i^t	The primary energy (or fossil fuel) consumption of the i^{th} sector at time t, including coal, oil and natural gas[65]
Y_i^t	The value added of the i^{th} sector at time t
P^t	The population at time t
$F_i^t = \frac{CO_{2i}^t}{E_i^t}$	The CO_2 emission coefficient of fossil fuels of the i^{th} sector at time t
$I_i^t = \frac{E_i^t}{Y_i^t}$	The energy intensity of the i^{th} sector at time t
$S_i^t = \frac{Y_i^t}{GDP^t}$	The share of value added of the i^{th} sector to GDP at time t
$G^t = \frac{GDP^t}{P^t}$	The GDP per capita at time t

[64] According to *China Statistical Yearbook* (2009), China's material production sectors are primary sector, secondary sector and tertiary sector. The primary sector includes farming, forestry, animal husbandry, fishery and water conservancy; the secondary sector includes industry and construction; the tertiary sector refers to transport, post and telecommunications, and wholesale, retail trade and catering services. In our analysis, the other services sector refers to the tertiary sector excluding transport.

[65] Primary energies are coal, oil, natural gas and hydropower. The share of hydropower is relatively small. And there is no CO_2 emission for the use of hydropower. Therefore, we do not consider hydropower, and analyse coal, oil and natural gas in this chapter.

From equation (5.3), the CO_2 emission is broken down into five factors, carbon emission coefficient (F), energy intensity (I), economic structure (S), economic growth (G) and population (P).

Population size and its growth have been one of the main factors in increasing CO_2 emissions. First, in order to support an additional person, economic activity must be expanded, which requires more resources, and more emissions are generated. Second, a large population will cause a large demand for energy use, and then increase the fossil fuel emissions. Third, due to an increase in population, timber consumption will increase, resulting in greater deforestation and land use changes, and then increasing CO_2 emissions (Birdsall, 1992). Shi (2003) argues that one percent of population growth can lead to an increase in emissions by 1.28 percent. And the impact of population on emissions has been recognised as being more pronounced in developing countries than developed countries.

Economic growth (increases in GDP per capita) can represent the level of affluence of a country, which is the crucial determinant of environmental degradation. Rapid economic growth is associated with rapid resource use and waste production. Many studies show that economic growth is the most important factor affecting the growth of CO_2 emissions (see Section 5.2 and Section 2.3.3). However, regarding decreasing affluence, the main issue is that there would be no single country that accepts reducing their economic growth.

Besides population and affluence, technology is an important factor influencing the environment. Generally, there are two ways in which technology can lower emissions: reducing the materials and energy used per unit of output (energy intensity), and shifting from highly polluting fossil fuels (coal) to less polluting fossil fuels or nonfossil fuels, which is termed fuel mix (the share of fossil fuels in total energy consumption) or the carbon coefficient (emission intensity of fuels) (Roca and Alcantara, 2001). Empirical studies show that improving the efficiency of energy use (lowering energy intensity) is the most important factor for offsetting the effect of economic growth and population growth in CO_2 emissions, while fuel mix and the carbon coefficient also contribute to lower emissions, but relatively less (see Section 5.2 and Section 2.3.3).

The effect of structural change is inconclusive. It is believed that industrialisation will lead to more emissions, and then an expanding service sector may cause emissions reduction again. Moreover, Syrquin (1988), Panayotou (1995) and Dinda *et al.* (2000) point out that the structure within the industrial sector changes as well, from light to heavy industry and then high-tech industry expansion, associated with fewer emissions. However, many studies find that the effect of structural change is small and even increases emissions (see Section 5.2 and Section 2.3.3).

All these factors influencing environmental impact and change are interrelated and future emissions will depend on the complex interactions among economic growth, population growth, structural change and technological innovation.

5.3.2 LMDI Decomposition Method

According to Ang *et al.* (1998), Ang and Liu (2001), and Ang (2004), the logarithmic mean Divisia index (LMDI) method is better than other decomposition methods because of its advantages of path independency, ability to handle zero values and consistency in aggregation. Therefore, the LMDI method is adopted in this chapter. Following Ang (2004) and manipulating equation (5.3), the change in CO_2 emissions from the base year (year 0) to the current year (year t), $\Delta CO_2 = CO_{2t} - CO_{20}$, can be decomposed as follows:

$$\Delta CO_2 = \Delta CO_{2,F-effect} + \Delta CO_{2,I-effect} + \Delta CO_{2,S-effect} + \Delta CO_{2,G-effect} + \Delta CO_{2,P-effect} \tag{5.4}$$

where Δ denotes the change over the period, $\Delta CO_{2,F-effect}$ denotes the change in CO_2 caused by the emission coefficient, which is called the effect of carbon emission coefficient, and similarly $\Delta CO_{2,I-effect}$, $\Delta CO_{2,S-effect}$, $\Delta CO_{2,G-effect}$, and $\Delta CO_{2,P-effect}$ denote the effect of energy intensity, the effect of industry structure, the effect of economic growth, the effect of population change, respectively.

These changes can be precisely linked in an additive form of LMDI decomposition analysis. More specifically, the effects can be calculated as follows:

$$\Delta CO_{2,F-effect} = \sum_i \frac{CO_{2i}^t - CO_{2i}^o}{\ln CO_{2i}^t - \ln CO_{2i}^0} \ln(\frac{F_i^t}{F_i^0}) \tag{5.4a}$$

$$\Delta CO_{2,I-effect} = \sum_i \frac{CO_{2i}^t - CO_{2i}^o}{\ln CO_{2i}^t - \ln CO_{2i}^0} \ln(\frac{I_i^t}{I_i^0}) \tag{5.4b}$$

$$\Delta CO_{2,S-effect} = \sum_i \frac{CO_{2i}^t - CO_{2i}^o}{\ln CO_{2i}^t - \ln CO_{2i}^0} \ln(\frac{S_i^t}{S_i^0}) \tag{5.4c}$$

$$\Delta CO_{2,G-effect} = \sum_i \frac{CO_{2i}^t - CO_{2i}^o}{\ln CO_{2i}^t - \ln CO_{2i}^0} \ln(\frac{G^t}{G^0}) \tag{5.4d}$$

$$\Delta CO_{2,P-effect} = \sum_i \frac{CO_{2i}^t - CO_{2i}^o}{\ln CO_{2i}^t - \ln CO_{2i}^0} \ln(\frac{P^t}{P^0}) \tag{5.4e}$$

The additive form of decomposition used allows the effects to be added so as to equal the total change in CO_2 emissions. Kojima and Bacon (2009) argue that in the absence of an additive decomposition, the relative importance of the different changes that contribute to the total change in emissions would be difficult to evaluate.

5.3.3 Provincial Decomposition

This chapter also applies decomposition analysis to provincial data. Decomposition is carried out similarly to equation (5.3), but excluding S_i^t due to lack of the detailed data of sectors in each province.

$$CO_2{}^t = \sum_i CO_{2i}^t = \sum_i \left(\frac{CO_{2i}^t}{E_i^t} \times \frac{E_i^t}{Y_i^t} \times \frac{GRP_i^t}{P_i^t} \times P_i^t\right)$$

$$= \sum_i (F_i^t \times I_i^t \times G_i^t \times P_i^t) \qquad (5.5)$$

where i is one of China's 29 provinces, CO_{2i}^t is the CO_2 emissions of province i, E_i^t is the primary energy (or fossil fuel) consumption of province i, GRP_i^t is the gross regional product of province i; P_i^t is the population of province i; $F_i^t = \frac{CO_{2i}^t}{E_i^t}$ is the CO_2 emission coefficient in province i (and similarly for I_i^t, G_i^t and P_i^t). The calculation of the province-specific terms is given by $\Delta CO_{2,F-effect,i} = \frac{CO_{2i}^t - CO_{2i}^o}{\ln CO_{2i}^t - \ln CO_{2i}^0} \ln\left(\frac{F_i^t}{F_i^0}\right)$, and so on.

5.4 Data Description and Analysis

In this chapter the national sectoral data used span from 1980 to 2010, and the provincial data from 1990 to 2009. All energy data are collected from the *China Energy Statistical Yearbook* (various issues). Other economic information is collected from

China Statistical Yearbook (various issues) and the *Comprehensive Statistical Data and Materials on 60 Years of New China* (2009). However, the sectoral and provincial CO_2 emissions data are not available at all. The only way to estimate them is by using the IPCC manual. Therefore, we first deal with it.

5.4.1 Carbon Dioxide Emissions

The CO_2 emissions cannot be obtained directly and need to be estimated. According to the World Bank, CO_2 emissions are defined as those stemming from the burning of fossil fuels and the manufacture of cement, with the former accounting for at least 70 percent of the total CO_2 emissions. Accurate estimated emissions from fuel combustion depend on knowledge of several interrelated factors, such as fuel types, combustion technology, as well as abatement efficiency. Therefore, the CO_2 emissions used in this chapter are computed from the consumption of fossil energy, namely coal, oil and natural gas, which are at a highly aggregated level. Following the IPCC manual (Houghton *et al.*, 1996), the sectoral/provincial CO_2 emissions can be calculated by multiplying consumption of each fuel with its coefficient as follows:

$$CO_{2i} = \sum_{j=1}^{3} CO_{2j} = \sum_{j} E_{ij} \times CEF_j \times COF_j \times (44/12) \tag{5.6}$$

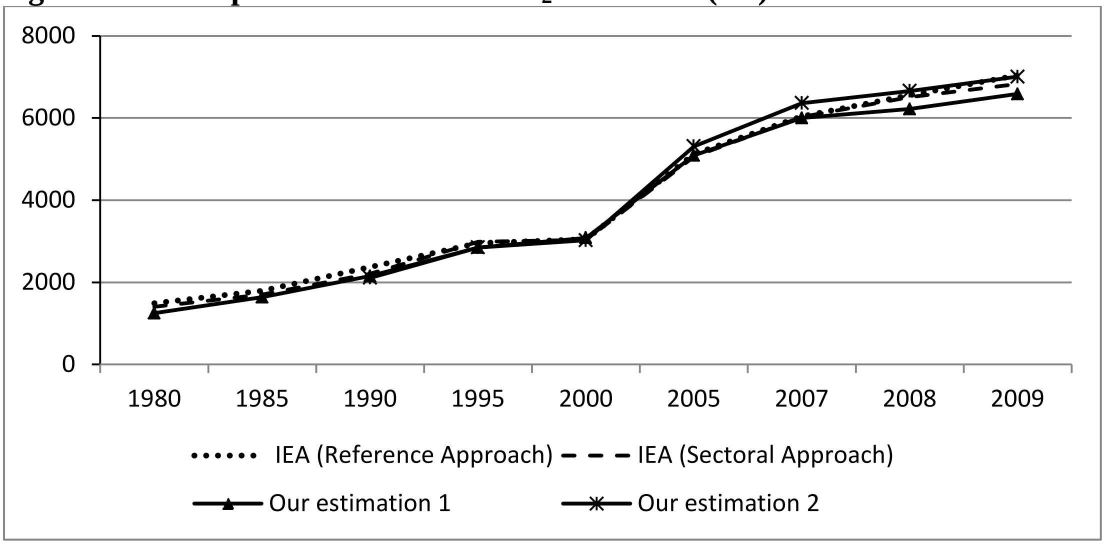
where CO_{2i} is the total CO_2 emissions of the i^th^ sector/province; CO_{2j} is CO_2 emissions from energy j; E_{ij} is the consumption of the j^{th} energy in the i^{th} sector/province, converted into tce[66]; CEF is the carbon emission factor and COF is the carbon oxidisation factor. Detailed calculation of the emission factors can be found in the

[66] The data of different types of energy usually are converted into standard coal equivalent (TCE, ton of coal equivalent) or standard oil equivalent (TOE, ton of oil equivalent). Due to coal being the major energy source in China, all energies are converted into TCE. Consumption of coal and oil is measured in tons, and natural gas in cubic metres in the *China Energy Statistical Yearbook*. Coal: 1 ton = 0.7143 tce; oil: 1 ton = 1.4286 tce; natural gas: 1 cubic metre = 0.00133 tce.

Appendix. Therefore, the calculated CO_2 emission coefficients for coal, oil and natural gas are 2.611, 2.028 and 1.541 tons of CO_2 per ton coal equivalent, respectively.

Sorting through the energy consumption data, the CO_2 emissions data from various Chinese sectors and provinces are estimated as shown in Appendix Tables A5.4 and A5.5. As shown by Figure 5.1, our estimated national CO_2 emissions are much in accordance with IEA data, which provides some supports for the method we used. The small difference may result from using various data sources and different emission factors.

Figure 5. 1: Comparison of China's CO_2 Emissions (Mt)



Note: Our estimation 1 is the sum of sectoral emissions (Appendix Table A5.4), including primary, industry, construction, transport & post & telecommunications, wholesale & retail trade &catering service, other services, and residential sectors.

Our estimation 2 is the sum of provincial emissions (Appendix Table A5.5), including 29 Chinese provinces.

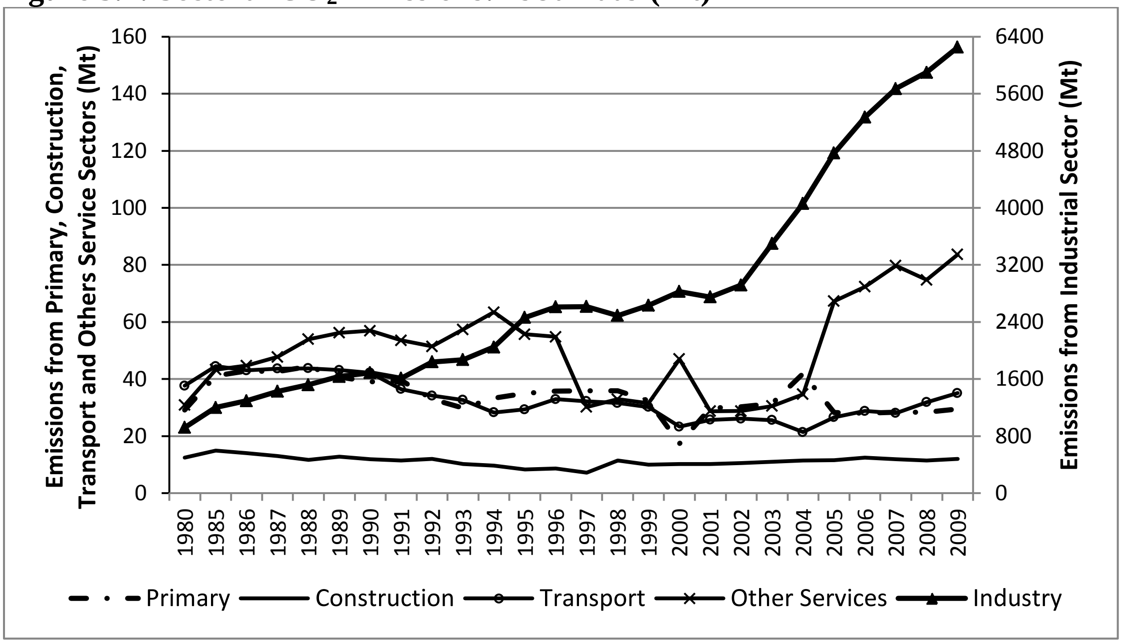
The IEA Reference Approach is a top-down approach using a country's energy supply data and has no detailed information on how the individual fuels are used in each sector (IEA, 2011).

Source: IEA (2011) and author's calculation.

***Estimated Sectoral CO2 Emissions from 1980 to 2009*[67]**

China's estimated sectoral CO_2 emissions (excluding the residential sector, See Appendix Table A5.4 and Figure 5.2) show several characteristics as follows: 1) during the past 30 years, the total CO_2 emissions have had three major phases. From 1980 to 1996, CO_2 emissions grew rapidly. From 1996 to 2001 CO_2 emissions entered a stable phase, while from 2002 to 2009 it increased rapidly again. 2) Industry sector CO_2 emissions show obvious variety. Among the total emissions, emissions from the industry sector account for the majority, 73% - 94%, and show a rising trend, while emissions from other sectors are small and declining. This indicates that rapid industrialisation has promoted CO_2 emissions in China.

Figure 5.2: Sectoral CO_2 Emissions: 1980-2009 (Mt)



Source: Author's calculation, using equation (5.6).

Although the total CO_2 emissions were growing rapidly in China, except for the period 1997-2001, the sectoral CO_2 emission intensity (sectoral CO_2 emissions / sectoral value added) declined continuously over the last 30 years (see Figure 5.3), which is consistent

[67] In our decomposition analysis, the CO_2 emissions exclude the emissions from the Residential Sector.

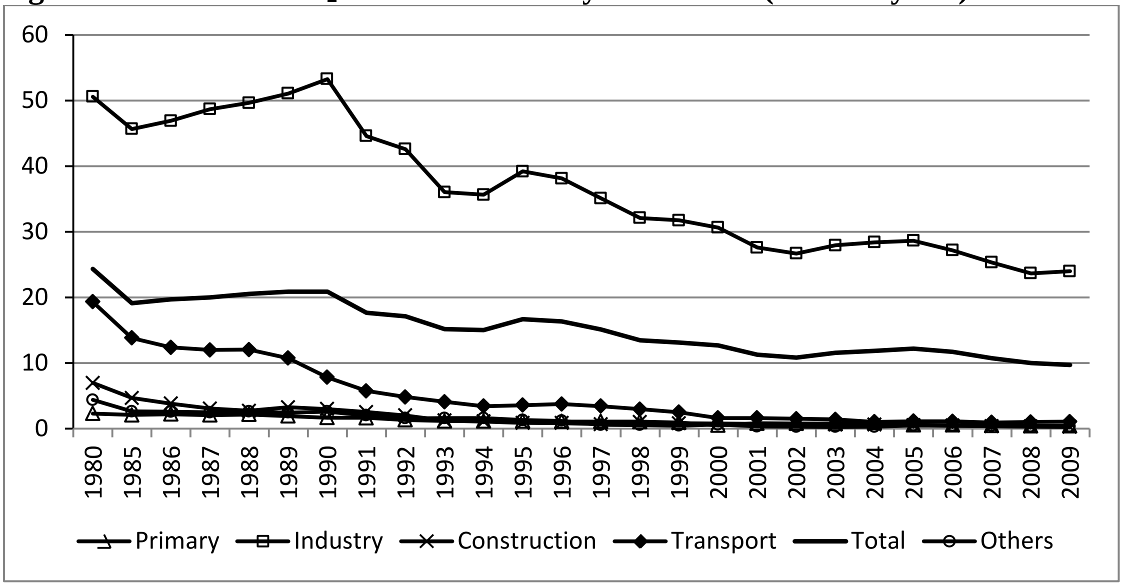
with many studies (e.g. Fan *et al.*, 2007; Leggett *et al.*, 2008; Chen 2011). The early decline in CO_2 intensity was in the early 1980s, because the central government formulated an energy-saving policy in 1980 and light industry grew rapidly (Chen, 2011). In the late 1980s, in order to encourage energy production, energy- and emission-intensive enterprises were set up, such as small coal mines[68], which cause serious coal resources waste and environmental pollution. Therefore, the CO_2 intensity began to increase. In 1992, the concept of sustainable development arose from the United Nations Conference on Environment and Development. China's serious environmental problem received more attention. The government again emphasised the energy policy and restricted the development of energy enterprises. This led to the decline of CO_2 intensity in the late of 1990s. Due to heavy industry re-emerging in the early 2000s, the CO_2 intensity increased from 2002 to 2005, but continued to fall after that time. The reason could be the implementation of several energy saving and environmental protection regulations[69], such as the medium and long term plan for energy conservation enacted in 2005, the targets of reducing energy intensity by 20% and pollution by 10% in the 11^{th} Five Year Plan proposed in 2006, the Circular Economy Law approved to improve energy use, protect the environment and achieve sustainable development in 2008 and so on.

[68] In the 1980s, the central government issued a series of economic policies to improve small coal mines, such as subsidies for losses, partial waiver of taxation, added equity, and maintenance fees for small coal mines. However, due to lack of effective regulations, the government could not control and supervise these small coal mines. Consequently, different kinds of small coal mines (including a large number of illegal coal mines) were developed with a rapid speed.

Recognising the serious environmental impact, the government enacted the policy of rectification in the early 1990s and the closure policy in late 1990s. More than 30,000 illegal and irrational small coal mines were closed (Shen and Andrews-Speed, 2001).

[69] More details are in Chapter Four.

Figure 5.3: Sectoral CO_2 Emission Intensity: 1980-2009 (tons/10^4 yuan)

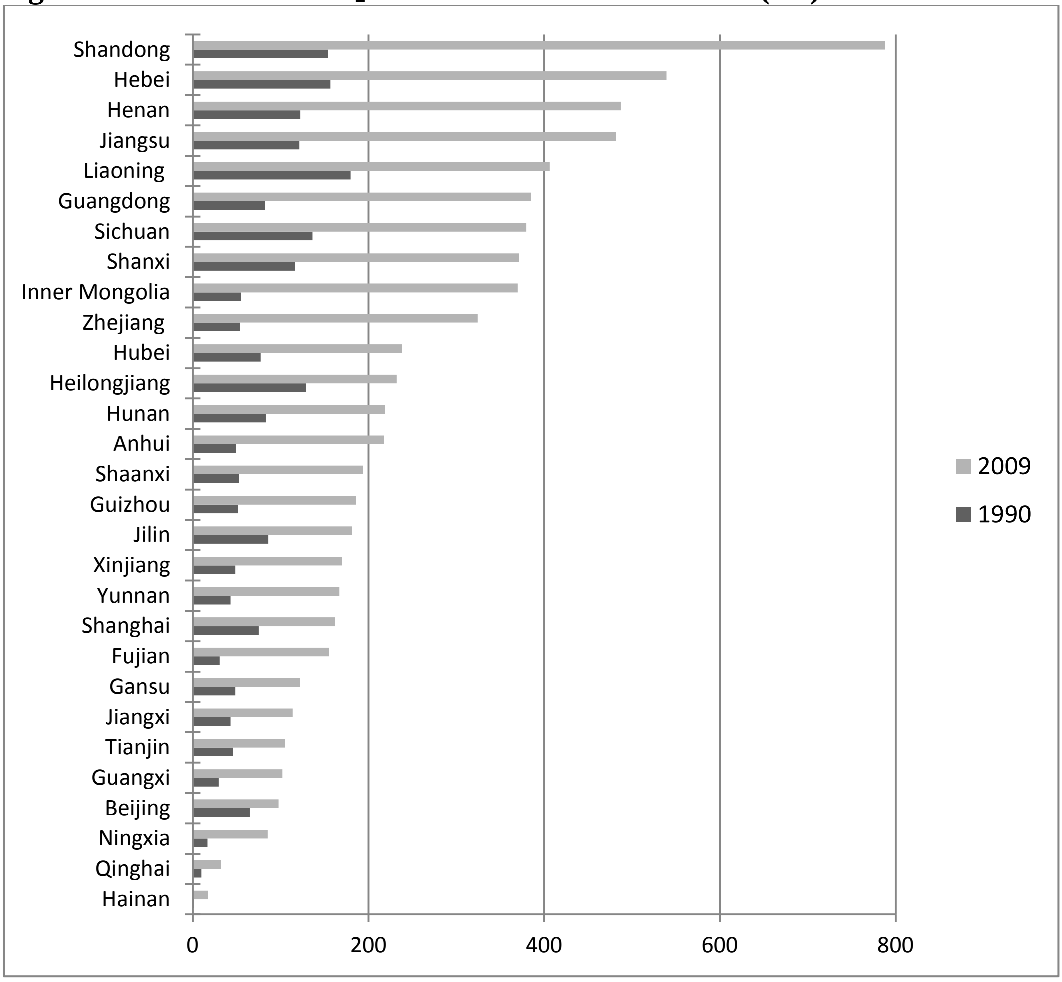


Note: Sectoral value added is converted to 1978 price level.
Source: Author's calculation.

Estimated Provincial CO_2 Emissions from 1990 to 2009

Figure 5.4 shows the provincial CO_2 emissions in 1990 and 2009[70]. In 1990, the top five emitters were Liaoning, Hebei Shandong, Sichuan and Heilongjiang, accounting for 35% of total CO_2 emissions. In 2009, the emissions from Shandong, Hebei, Henan, Jiangsu and Liaoning accounted for 39% of the total.

Figure 5.4: Provincial CO_2 Emissions in 1990 and 2009 (Mt)



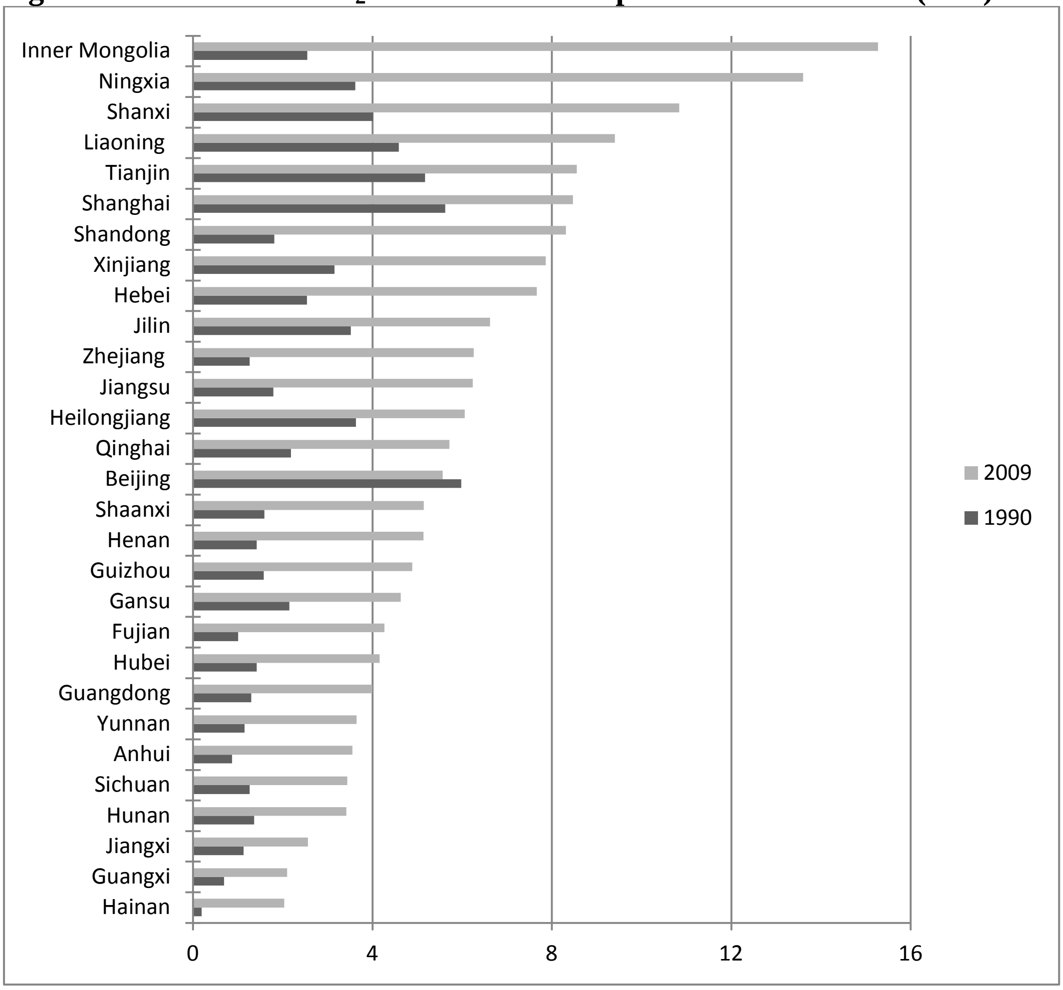
Source: Author's calculation.

The CO_2 emissions per capita across the 29 provinces ranged from the minimum of 1.92 tons in 1990 to the maximum of 5.59 tons in 2009. Compared with 1990, the per

[70] Since the *China Energy Statistical Yearbook* does not contain the energy consumption data of Tibet, Hong Kong, Macau and Taiwan, these four provinces are excluded. Chongqing became a municipality directly under the jurisdiction of the central government in 1996, so the relevant data for Chongqing are added to those for Sichuan province for the sake of consistency.

capita emissions of every province increased, except Beijing (see Figure 5.5). According to EIA (2011), the world average level in 2009 was 4.43 tons/ person. There were 19 out of China's 29 provinces with emissions per capita levels higher than the world average level.

Figure 5.5: Provincial CO_2 Emissions Per Capita in 1990 and 2009 (tons)



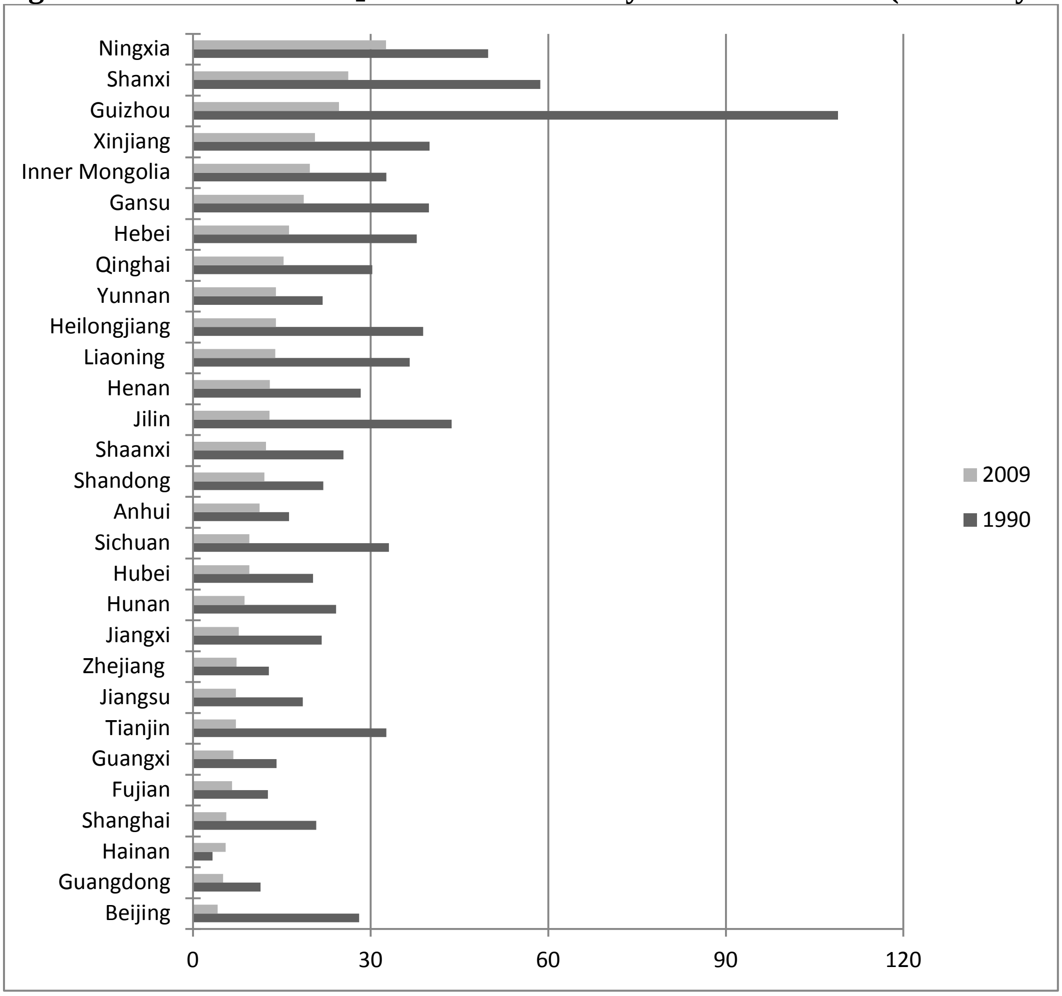
Source: Author's calculation.

Compared with 1990, CO_2 intensity declined in all provinces in 2009, except Hainan (see Figure 5.6). The provincial CO_2 intensity is defined as CO_2 emissions per unit of Gross Regional Product (GRP)[71], the reciprocal of which being carbon productivity. Hence, the decline of CO_2 intensity means an improvement in carbon productivity,

[71] The GRP is constant at the 1978 price level.

indicating that CO_2 abatement is substantial and efficient in most provinces. The significant drops of above 60% took place in Beijing, Tianjin, Guizhou, Shanghai, Sichuan, Jilin, Jiangxi, Hunan, Heilongjiang, Liaoning and Jiangsu provinces. Beijing had the greatest reduction of 85%.

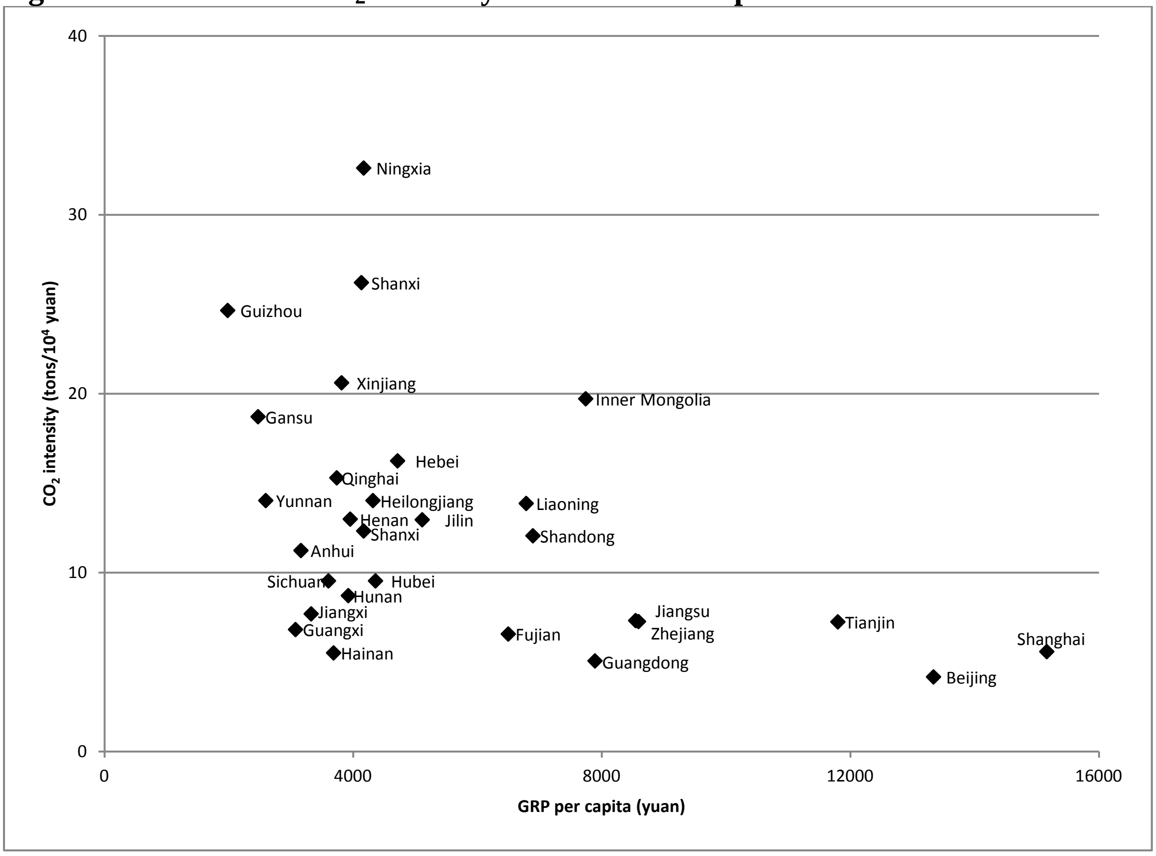
Figure 5.6: Provincial CO_2 Emissions Intensity in 1990 and 2009 (tons/10^4 yuan)



Source: Author's calculation.

The CO_2 intensity was high in Ningxia, Shanxi, Guizhou, Xinjiang, Inner Mongolia and Gansu, being even more than 18 tons/10^4 yuan in 2009; while the CO_2 intensity of Beijing, Guangdong and Shanghai provinces was on the low side, below 5 tons/10^4 yuan. As shown in Figure 5.7, the difference in CO_2 emissions intensity is closely related to the income level. The regions with a high level of income and low carbon intensity include three municipalities and most coastal provinces (Jiangsu, Zhejiang, Fujian and Guangdong); the areas with a low level of income and high carbon intensity include seven western provinces (Ningxia, Shanxi, Guizhou, Xinjiang, Gansu, Qinghai and Yunnan).

Figure 5.7: Provincial CO_2 Intensity and GRP Per Capita in 2009



Source: Author's calculation.

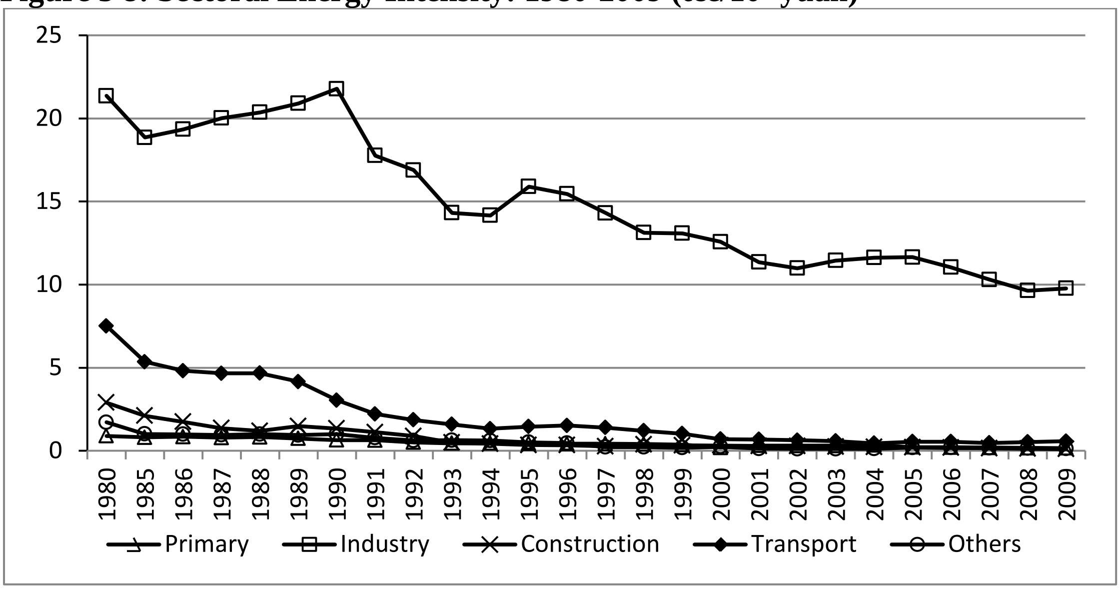
China's main coal-producing provinces are Shanxi, Guizhou, Ningxia, Inner Mongolia and Xinjiang, with CO_2 intensities higher than other provinces. They supply coal to other provinces, for example, Ningxia exported 45% of its coal to others in 2008 (Geng *et al.*, 2011). According to *China Statistical Yearbook* (2010), in the period 2000-2009, the coal reserves of Shanxi and Inner Mongolia comprised 31.9% and 21.4% of China's entire coal resource reserves, respectively; however, their GRP was only 1.75% and 1.74% of China's national GDP. Moreover, energy-intensive industries developed rapidly in these provinces, for example, energy production and processing dominated by coal mining and processing, and using the low-technology equipment with high energy consumption, which generates higher CO_2 emissions and lower GRP (Yu *et al.*, 2012). The share of industry of Shanxi, Ningxia and Inner Mongolia was 56.2%, 48.6% and 47%, respectively, higher than the national average of 46.4% during 2000-2009.

The three municipalities, Shanghai, Beijing and Tianjin, located in the eastern coastal area, have a high level of income and lower CO_2 intensity. Changes in economic structure have played an important role in these cities. Shanghai began to change its economic structure very early and is becoming the national centre of overseas trade, finance and R&D. Its share of industry declined from 60% in 1990 to 36% in 2009. As the capital city, the share of industry of Beijing was only 19% in 2009, down from 44% in 1990. Another reason for low carbon intensity is the 'Green Olympics', which provided a powerful motivation for environmental improvement in Beijing. Although the share of industry of Tianjin has remained at around 50% from 1990 to 2009, its GRP has increased rapidly. Yu *et al.* (2012) argue that due to lack of fossil fuel energy in these cities, most of their electric power is provided by other provinces. For example, from 2000 to 2009 the annual transferred proportion of the electricity consumed in Shanghai increased from 21% to 34%. And in China electricity is mainly generated by thermal power, which located in Shanxi, Ningxia and Inner Mongolia.

5.4.2 Energy Intensity

Figure 5.8 shows the energy intensities for five sectors: primary, industry, construction, transport and other services. It is evident that industry has the highest energy intensity followed by transport, throughout the period. It is also observed that the energy intensities for all sectors decreased from 1980 to 2009, although there were numerous fluctuations. The main reason for the falling sectoral intensity is that the technological level of Chinese enterprises increased rapidly after 1980 as new plants embodied technologies closer to international best practice than those inherited before, which is demonstrated by NDRC (2004). Sinton *et al.* (1998) point out that in China improving technology reduced the energy required to make a given physical product, and also improved the quality of the physical product which enhances the value (at constant price level).

Figure 5 8: Sectoral Energy Intensity: 1980-2009 (tce/10^4 yuan)



Source: Author's calculation.

5.4.3 Economic Growth

China's real GDP (constant at the 1978 price level) has increased from 4,151 million yuan in 1980 to 65,608 million yuan in 2009, representing an average annual growth rate of 9.99%. During the past 30 years, there have been four periods of especially rapid growth, surpassing 10% per year. The peaks are in 1985, 1987-1988, 1992-1994 and 2003-2007 (See details in Chapter Three).

China has experienced significant structural changes. From 1980 to 1990, the shares of primary sector and industry sector declined slowly, while the Other Services sector grew rapidly. Since 1991, the share of industry sector has increased and levelled off around 40% of GDP, and the share of other services sector has maintained a rising trend, while the share of primary sector declined rapidly, sliding from 27% of GDP in 1990 to 10% in 2009. The share of transport and construction sectors has remained at around 5-6% during the last 30 years.

5.5 Factor Decomposition Results

5.5.1 Results for Aggregated Analysis

According to China's economic reforms and economic growth process, the calculated results are tentatively presented over three periods: 1980-1992, 1992-2002 and 2002-2009[72].

Changes in CO_2 emissions for all the sectors in aggregate are shown in Table 5.2. Economic growth ($\Delta CO_{2,G-effect}$) and population growth ($\Delta CO_{2,P-effect}$) are the main influence factors for CO_2 emission growth in China. The energy intensity effect ($\Delta CO_{2,I-effect}$) plays an important role in reducing CO_2 emissions in every period, which offsets 30.6% of CO_2 emissions caused by both economic and population effects during 1980-2009. The carbon emission coefficient effect ($\Delta CO_{2,F-effect}$) is negative in the period 1992-2000, while it is positive in 1980-1992, 2000-2009 and 1980-2009, which indicates the present energy structure is not effective for reducing CO_2 emissions. In the sub-periods 1980-1992 and 2000-2009 and entire period 1980-2009, a

[72] Details can be found in Chapter Three and Four.

negative structure effect ($\Delta CO_{2,S-effect}$) is found, due to the significant reduction for industry sector and primary sector shares of GDP. However, the GDP share of industry sector increases in the period 1992-2000, which causes a positive structure effect, although the shares of primary sector and transport sector decline in the same period. During the entire period 1980-2009, the negative energy intensity effect, together with the structure effect, offset 32.9% of emissions caused by other effects.

Table 5.2: Decomposition of CO_2 emissions change in All Sectors (Mt)

Period	Decomposition of changes in CO_2 emissions					Total change ΔCO_2
	$\Delta CO_{2,F-effect}$	$\Delta CO_{2,I-effect}$	$\Delta CO_{2,S-effect}$	$\Delta CO_{2,G-effect}$	$\Delta CO_{2,P-effect}$	
1980-92	88.85	-480.79	-122.83	1201.11	251.33	937.68
1992-02	-89.92	-1185.37	25.45	2061.87	232.98	1045.00
2002-09	27.71	-780.02	-93.49	4056.29	187.00	3397.49
1980-09	26.64	-2446.18	-190.87	7319.27	671.31	5380.17

Note: $\Delta CO_{2,F-effect}$=carbon emission coefficient effect, $\Delta CO_{2,I-effect}$=energy intensity effect, $\Delta CO_{2,S-effect}$ =economic structural effect, $\Delta CO_{2,G-effect}$=economic growth effect, $\Delta CO_{2,P-effect}$=population growth effect.
Source: Author's calculation.

Change in CO_2 emissions in China varies across sectors and provinces. In the next section, we present the factors driving the change in sectoral and provincial CO_2 emissions over the period 1980-2009.

5.5.2 Sectoral Analysis

The contribution of each factor to the change in sectoral CO_2 emissions for all the sub-period and the entire period 1980-2009 are discussed below.

Primary Sector

Table 5.3 indicates that economic growth ($\Delta CO_{2,G-effect}$) is the biggest factor influencing CO_2 emissions in the primary sector. The share of the primary sector in GDP has declined significantly since 1980. This is reflected in a negative structural effect ($\Delta CO_{2,S-effect}$, CO_2 emissions decline) in all sub-periods and in the entire period. The positive carbon emission coefficient ($\Delta CO_{2,F-effect}$) is seen in all the periods, suggesting fuel substitution and abatement technology for reducing CO_2 emissions in the primary sector remained absent. Negative energy intensity ($\Delta CO_{2,I-effect}$) can be found in all periods, due to the increase in integrated energy efficiency. The contributions of energy intensity and structural change are stronger than that of the economic growth component in the sub-periods 1992-2000 and 2002-2009, which led to total CO_2 emissions declining. In the entire period (1980-2009), total CO_2 emissions only increased 0.36 Mt in the primary sector, due to the large contribution of both the negative intensity effect and structural effect.

Table 5.3: Decomposition of CO_2 Emissions Change in the Primary Sector (Mt)

Period	Decomposition of changes in CO_2 emissions					Total change ΔCO_2
	$\Delta CO_{2,F-effect}$	$\Delta CO_{2,I-effect}$	$\Delta CO_{2,S-effect}$	$\Delta CO_{2,G-effect}$	$\Delta CO_{2,P-effect}$	
1980-92	0.08	-21.06	-12.55	30.74	6.61	3.83
1992-02	0.01	-16.60	-14.10	25.04	2.94	-2.71
2002-09	0.001	-18.74	-8.49	25.28	1.19	-0.76
1980-09	0.09	-56.40	-35.14	81.06	10.75	0.36

Note: $\Delta CO_{2,F-effect}$=carbon emission coefficient effect, $\Delta CO_{2,I-effect}$=energy intensity effect, $\Delta CO_{2,S-effect}$ =economic structural effect, $\Delta CO_{2,G-effect}$=economic growth effect, $\Delta CO_{2,P-effect}$=population growth effect.
Source: Author's calculation.

Industry Sector

Table 5.4 shows that economic growth ($\Delta CO_{2,G-effect}$) is still the most important factor to affect CO_2 emissions from the industry sector. The GDP share of the industry sector has decreased slightly from 1980 to 2009, but during the 1990s it increased slightly. Therefore, we can see the negative structure effect ($\Delta CO_{2,S-effect}$) in the sub-periods 1980-1992 and 2000-2009, and the entire period, while a positive effect in the sub-period 1992-2000 led to increasing CO_2 emissions. The energy intensity factor ($\Delta CO_{2,I-effect}$) is an important factor reducing CO_2 emissions in all sub-periods and hence in the entire period. The negative energy intensity effect is due to industrial structural change (a shift from energy-intensive to non-energy-intensive industry) and energy conservation. During the second sub-period (1992-2000), the carbon emission coefficient ($\Delta CO_{2,F-effect}$) is negative. In the first and third sub-periods as well as the entire period, the carbon emission coefficients are positive and lead to an increase in CO_2 emissions, which reflects that it is necessary to adjust the energy supply structure to strengthen clean energy utilisation in the industry sector. From 1980 to 2009, the energy intensity and structural effects jointly reduce by 30.6% CO_2 emissions caused by other effects.

Table 5.4: Decomposition of CO_2 Emissions Change in the Industry Sector (Mt)

Period	**Decomposition of changes in CO_2 emissions**					**Total change**
	$\Delta CO_{2,F-effect}$	$\Delta CO_{2,I-effect}$	$\Delta CO_{2,S-effect}$	$\Delta CO_{2,G-effect}$	$\Delta CO_{2,P-effect}$	$\Delta \boldsymbol{CO_2}$
1980-92	88.48	-341.29	-147.18	1089.56	227.57	917.15
1992-02	-87.79	-1056.72	32.70	1969.45	222.18	1079.82
2002-09	36.80	-747.82	-88.30	3950.22	182.11	3333.00
1980-09	37.50	-2145.83	-202.79	7009.23	631.86	5329.97

Note: $\Delta CO_{2,F-effect}$ = emission coefficient effect, $\Delta CO_{2,I-effect}$=energy intensity effect, $\Delta CO_{2,S-effect}$ =economic structural effect, $\Delta CO_{2,G-effect}$=economic growth effect, $\Delta CO_{2,P-effect}$=population growth effect.
Source: Author's calculation.

Construction Sector

As shown in Table 5.5 the change of total CO_2 emissions in the construction sector is negative in the sub-periods 1980-1992 and 1992-2000 as well as in the entire period 1980-2009. The main reason for this is the negative energy intensity effect ($\Delta CO_{2,I-effect}$) in all periods, and it outweighs the economic growth effect. The negative energy intensity is due to increased compliance with building energy standards and codes, strengthening the capacity of local governments to implement and enforce building codes, and promoting renewable energy use (solar heating and heat pump). Economic growth ($\Delta CO_{2,G-effect}$) and population ($\Delta CO_{2,P-effect}$) are two important contributors to escalating CO_2 emissions in the construction sector. The GDP share of the construction sector increased from 4% to 6% in the period 1980-2009, so the positive structure effect ($\Delta CO_{2,S-effect}$) is found in all periods. The positive carbon emission coefficient ($\Delta CO_{2,F-effect}$) is found in all periods and leads to increased CO_2 emissions, which demonstrates that the advancement of fuel quality is necessary in the construction sector.

Table 5.5: Decomposition of CO_2 Emissions Change in the Construction Sector (Mt)

Period	Decomposition of changes in CO_2 emissions					Total change ΔCO_2
	$\Delta CO_{2,F-effect}$	$\Delta CO_{2,I-effect}$	$\Delta CO_{2,S-effect}$	$\Delta CO_{2,G-effect}$	$\Delta CO_{2,P-effect}$	
1980-92	-0.67	-15.58	2.81	10.79	2.25	-0.40
1992-02	1.24	-12.04	0.51	7.96	0.89	-1.45
2002-09	0.01	-10.93	2.36	9.57	0.44	1.46
1980-09	0.59	-38.55	5.68	28.32	3.58	-0.38

Note: $\Delta CO_{2,F-effect}$=carbon emission coefficient effect, $\Delta CO_{2,I-effect}$=energy intensity effect, $\Delta CO_{2,S-effect}$ =economic structural effect, $\Delta CO_{2,G-effect}$=economic growth effect, $\Delta CO_{2,P-effect}$=population growth effect.
Source: Author's calculation.

Transport Sector

The results of the transport sector are given in Table 5.6. Negative energy intensity ($\Delta CO_{2,I-effect}$) can be seen in all periods, and is stronger in sub-periods 1980-1992 and 1992-2000, as well as in the entire period 1980-2009, which is the major contributor for reducing total CO_2 emissions in the transport sector. A decline in energy intensity is due to the implementation of stringent vehicle fuel economic standards[73]; the increase in overall energy efficiency in the railways, waterways and aviation; tax incentives for the production of vehicles with small engines, which causes a shift to the manufacture of

[73] Vehicle fuel economy standards have been applied in many developed countries, where they are regarded as successful tools to reduce fuel demand and CO_2 emissions from the transport sector (An and Sauer, 2004). China began regulating fuel economy standards in 2005, and followed that with even more stringent standards in 2008. An *et al.* (2007) find that the standards improved overall vehicle fuel efficiency from 26 mpg in 2002 to 28.4 mpg in 2006.

smaller and less energy-intensive vehicles. Although the GDP share of the transport sector remained constant at about 5% throughout the entire period 1980-2009, it led to a decrease in CO_2 emissions in the last two sub-periods 1992-2000 and 2000-2009 ($\Delta CO_{2,S-effect}$). The carbon emission coefficient effects ($\Delta CO_{2,F-effect}$) are negative in the last two sub-periods and the entire period, which indicates that fuel quality is extremely advanced in the transport sector. Economic growth ($\Delta CO_{2,G-effect}$) and population growth ($\Delta CO_{2,P-effect}$) are the major factors in the growth of emissions in the transport sector.

Table 5.6: Decomposition of CO_2 Emissions Change in the Transport Sector (Mt)

Period	Decomposition of changes in CO_2 emissions					Total change ΔCO_2
	$\Delta CO_{2,F-effect}$	$\Delta CO_{2,I-effect}$	$\Delta CO_{2,S-effect}$	$\Delta CO_{2,G-effect}$	$\Delta CO_{2,P-effect}$	
1980-92	0.34	-56.91	12.54	33.43	7.13	-3.46
1992-02	-2.47	-31.81	-0.39	23.84	2.76	-8.07
2002-09	-6.81	-1.52	-6.23	22.42	1.05	8.92
1980-09	-8.93	-90.23	5.92	79.70	10.94	-2.61

Note: $\Delta CO_{2,F-effect}$=carbon emission coefficient effect, $\Delta CO_{2,I-effect}$=energy intensity effect, $\Delta CO_{2,S-effect}$ =economic structural effect, $\Delta CO_{2,G-effect}$=economic growth effect, $\Delta CO_{2,P-effect}$=population growth effect.
Source: Author's calculation.

Other Services Sector

Table 5.7 illustrated that economic growth is the most important factor affecting CO_2 emissions in the other services sector. The GDP share of the other services sector has increased since 1980, which causes an increase in CO_2 emissions in all sub-periods and the entire period. Energy intensity ($\Delta CO_{2,I-effect}$) is an important factor in reducing CO_2 emissions in all periods. The reduction of energy intensity is mainly due to the high electrification in other services sector. The carbon emission coefficient is found to be negative in the sub-periods 1992-2000 and 2000-2009, as well as the entire period 1980-2009.

Table 5.7: Decomposition of CO_2 Emissions Change in Other Services Sector (Mt)

Period	Decomposition of changes in CO_2 emissions					Total change ΔCO_2
	$\Delta CO_{2,F-effect}$	$\Delta CO_{2,I-effect}$	$\Delta CO_{2,S-effect}$	$\Delta CO_{2,G-effect}$	$\Delta CO_{2,P-effect}$	
1980-92	0.662	-45.96	21.54	36.59	7.77	20.56
1992-02	-0.92	-68.19	6.74	35.57	4.20	-22.60
2002-09	-2.29	-1.02	7.17	48.79	2.21	54.86
1980-09	-2.59	-115.17	35.45	120.95	14.19	52.83

Note: $\Delta CO_{2,F-effect}$=carbon emission coefficient effect, $\Delta CO_{2,I-effect}$=energy intensity effect, $\Delta CO_{2,S-effect}$ =economic structural effect, $\Delta CO_{2,G-effect}$=economic growth effect, $\Delta CO_{2,P-effect}$=population growth effect.
Source: Author's calculation.

At the sectoral level, the total changes in China's CO_2 emissions from 1980 to 2009 are driven entirely by the industry sector, which is consistent with Zhang *et al.*, (2009)'s finding; the contributions of other sectors are very small, especially, the construction and transport sectors. The main reason for this is that China's industry sector is extremely energy-intensive and accounts for more than 70% of the country's total energy use during the last 30 years (see Chapter Four). In particular, the proportion of the three main primary energy sources consumption (coal, oil and gas) in the industry sector is increasing and more than 90%. The industry sector can be divided into light and heavy industry, reflecting the relative energy-intensity of the manufacturing processes. In China, heavy industry consumes about 80% of the primary energy used in the industry sector, for example, chemicals, ferrous metals and building materials (Sinton *et al.*, 1996). However, the primary energy use in the other sectors, such as construction and transport sectors, is small, and even decreases.

5.5.3 Provincial Analysis

Due to lack of historical data, the time period of provincial analysis is from 1990 to 2009. Because China has implemented the "Great Western Development" strategy[74] since 2000, we decomposed the changes in provincial CO_2 emissions for two sub-periods, 1990-2000 and 2000-2009, as well as the entire period 1990-2009.

Period: 1990-2009

The decomposition of the change in CO_2 emissions of 29 provinces between 1990 and 2009 is reported in Table 5.8. In the period 1990-2009, economic growth was the main factor driving the growth of CO_2 emissions in 29 provinces. As a result of economic growth, CO_2 emissions increased by 8170.9 Mt, of which 47% was from the coastal region. Meanwhile, the increase in the population also resulted in the growth of CO_2 emissions by 640.2 Mt. However, the decline in energy intensity helped decrease CO_2 emissions by 3594.3 Mt, and a decrease in the carbon emission coefficient also resulted in a decline of CO_2 emissions by 49.6 Mt. Therefore, China's CO_2 emissions from 29 provinces increased by 5167.2 Mt between 1990 and 2009.

[74] In order to help the western region catch up with the eastern region, a leadership Group for Western China Development was created by State Council in 2000. The central government offered preferential policies to the western region in terms of capital input, investment environment, international and external opening-up, development of science and education, and human resources, thus making western China a land of great development. The policy covers Gansu, Guizhou, Qinghai, Shaanxi, Sichuan, Yunnan, Guangxi, Inner Mongolia, Ningxia, Tibet, Xinjiang and Chongqing. They are all in our 'western group', except Tibet due to lack of data, and the data of Chongqing are added to Sichuan.

Table 5.8: Decomposition of CO_2 Emissions Change in 29 Provinces between 1990 and 2009 (Mt)

Provinces	Total change ΔCO_2	Decomposition of changes in CO_2 emissions			
		$\Delta CO_{2,F-effect}$	$\Delta CO_{2,I-effect}$	$\Delta CO_{2,G-effect}$	$\Delta CO_{2,P-effect}$
Coastal	**2497.1**	**-28.0**	**-1679.5**	**3829.6**	**374.9**
Beijing	32.72	-7.79	-144.99	147.03	38.47
Tianjin	59.44	-0.65	-106.59	143.03	23.65
Hebei	382.74	-2.29	-258.96	602.89	41.10
Liaoning	226.65	-6.39	-263.08	468.99	27.13
Shanghai	86.80	-3.80	-144.82	194.98	40.43
Jiangsu	360.47	-1.92	-243.25	571.02	34.62
Zhejiang	270.73	-4.96	-78.75	324.31	30.14
Fujian	124.32	0.85	-50.83	160.73	13.58
Shandong	633.99	5.51	-238.46	824.72	42.22
Guangdong	302.89	-5.22	-154.27	380.44	81.94
Hainan	16.29	-1.34	4.55	11.43	1.64
Central	**1354.6**	**-1.4**	**-1084.1**	**2316.9**	**123.2**
Shanxi	255.07	-0.99	-176.08	395.38	36.77
Jilin	95.65	-1.13	-154.21	236.18	14.80
Heilongjiang	103.32	-3.83	-174.97	268.66	13.46
Anhui	168.81	2.18	-43.87	201.46	9.03
Jiangxi	70.48	-0.45	-74.95	134.90	10.98
Henan	364.78	0.53	-206.75	546.58	24.42
Hubei	160.63	1.75	-109.56	261.25	7.18
Hunan	135.89	0.56	-143.76	272.47	6.61
Western	**1315.5**	**-20.2**	**-830.7**	**2024.4**	**142.0**
Sichuan	243.45	-2.66	-293.01	534.11	5.01
Guizhou	134.22	1.02	-156.58	274.03	15.74
Yunnan	123.85	1.59	-42.18	145.93	18.51
Shaanxi	141.27	-6.68	-71.81	205.80	13.96
Inner Mon.	314.77	-3.48	-79.94	379.46	18.73
Gansu	73.60	-1.24	-58.98	121.40	12.41
Qinghai	22.06	-1.70	-11.06	30.74	4.08
Ningxia	68.15	-1.13	-16.75	73.62	12.39
Xinjiang	121.52	-5.15	-58.76	152.12	33.31
Guangxi	72.63	-0.77	-41.65	107.17	7.88
All Regions	**5167.2**	**-49.6**	**-3594.3**	**8170.9**	**640.2**

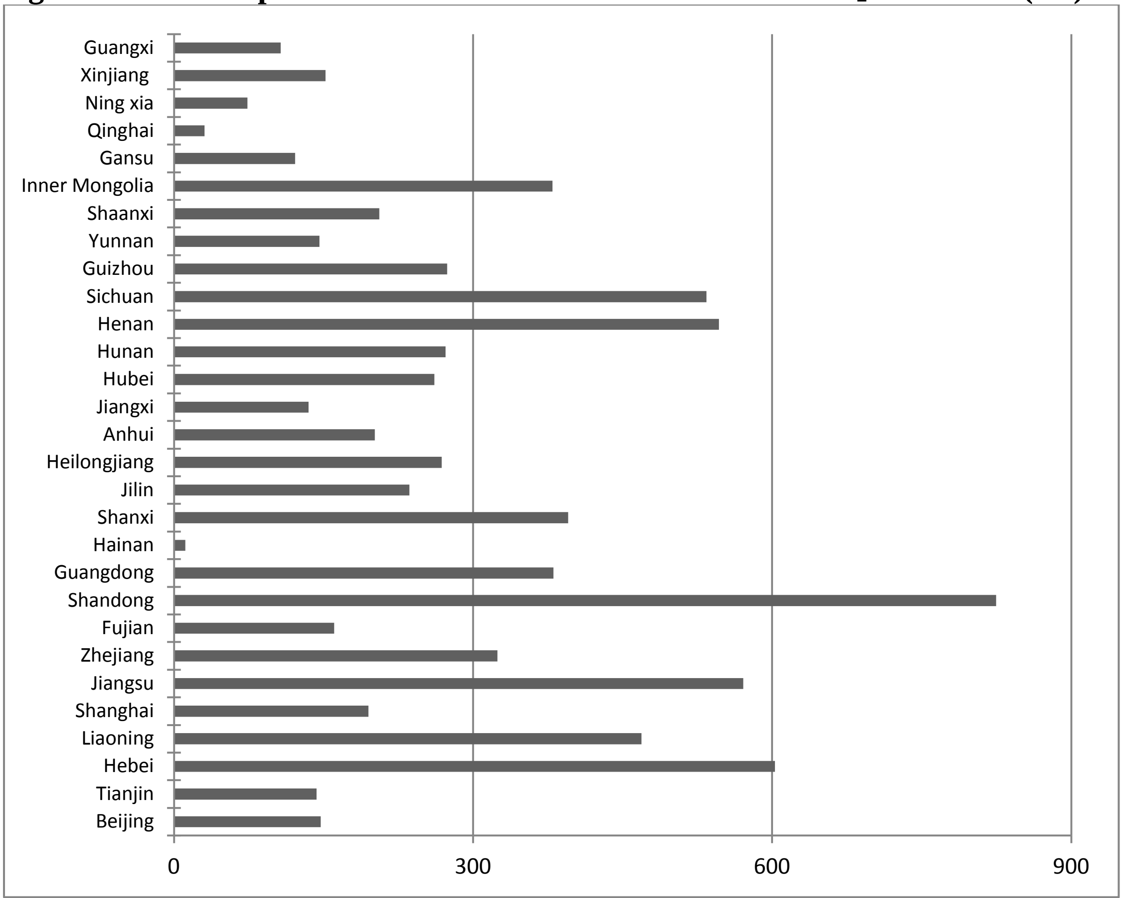
Note: $\Delta CO_{2,F-effect}$ = emission coefficient effect, $\Delta CO_{2,I-effect}$=energy intensity effect, $\Delta CO_{2,G-effect}$=economic growth effect, $\Delta CO_{2,P-effect}$=population growth effect.

Source: Author's calculation.

Economic Growth Effect

The rapid economic growth in each province is the main factor affecting the growth of CO_2 emissions. Figure 5.9 shows the impact of economic growth on CO_2 emissions in 29 provinces between 1990 and 2009. The economic growth in Hebei, Liaoning, Jiangsu, Shandong, Henan and Sichuan resulted in an increase of CO_2 emissions by 602.9, 469.0, 571.0, 824.7, 546.6 and 534.1 Mt, respectively (3548.3 Mt in total, accounting for 43.4% of the overall impact of economic growth on CO_2 emissions). These provinces are not only the major provinces for energy consumption but also for booming economic growth, contributing 38.6% of GDP growth. Therefore, there is a big challenge for the coordination of economic growth and the reduction of CO_2 emissions in these provinces.

Figure 5.9: The Impact of Economic Growth on Provincial CO_2 Emissions (Mt)

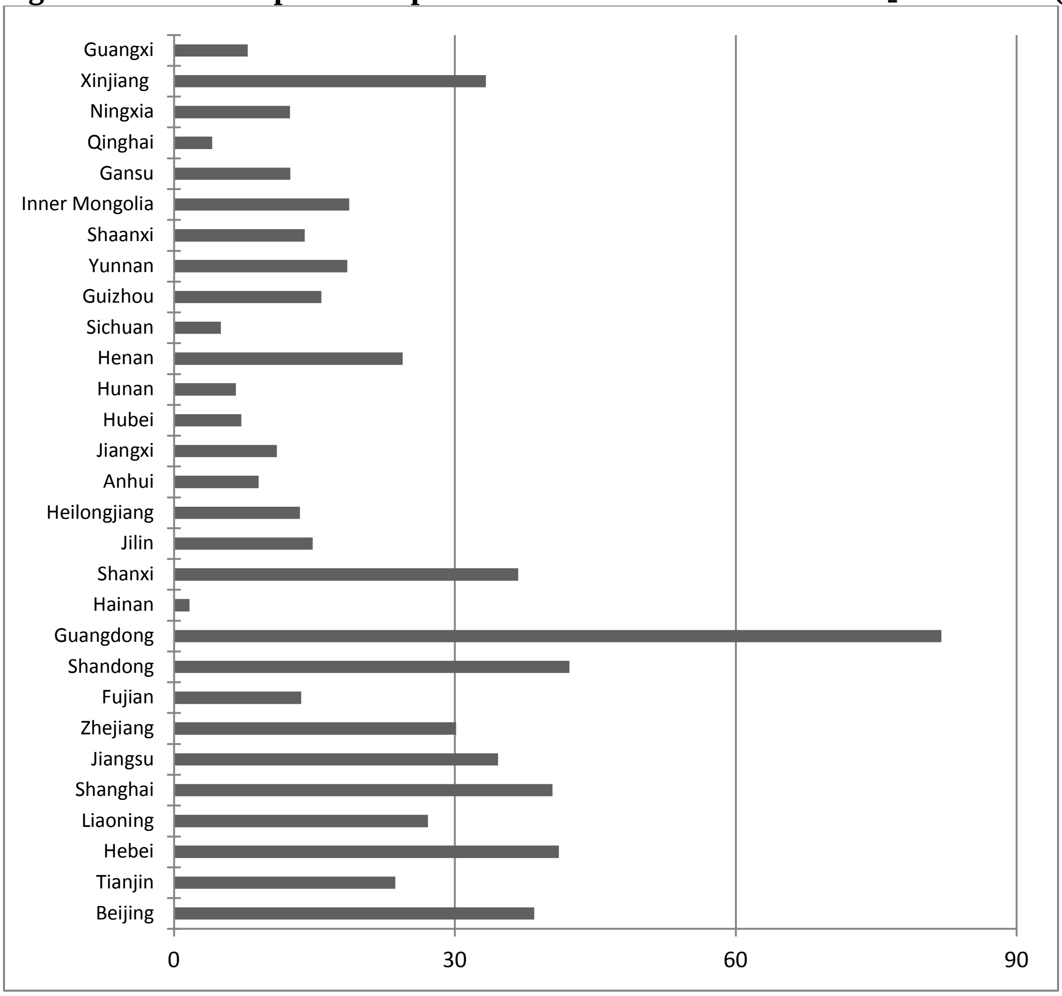


Source: Author's calculation.

Population Growth Effect

Figure 5.10 shows the impact of population growth on CO_2 emissions in 29 provinces. Population growth in the coastal region helped increase CO_2 emissions by 374.9 Mt, accounting for 59% of the total impact of population growth. The main reason for this is that during the last two decades labour flows have been directed from the interior to coastal areas (such as Guangdong, Shandong and Jiangsu provinces), from rural to big cities (such as Shanghai and Beijing).

Figure 5.10: The Impact of Population Growth on Provincial CO_2 Emissions (Mt)

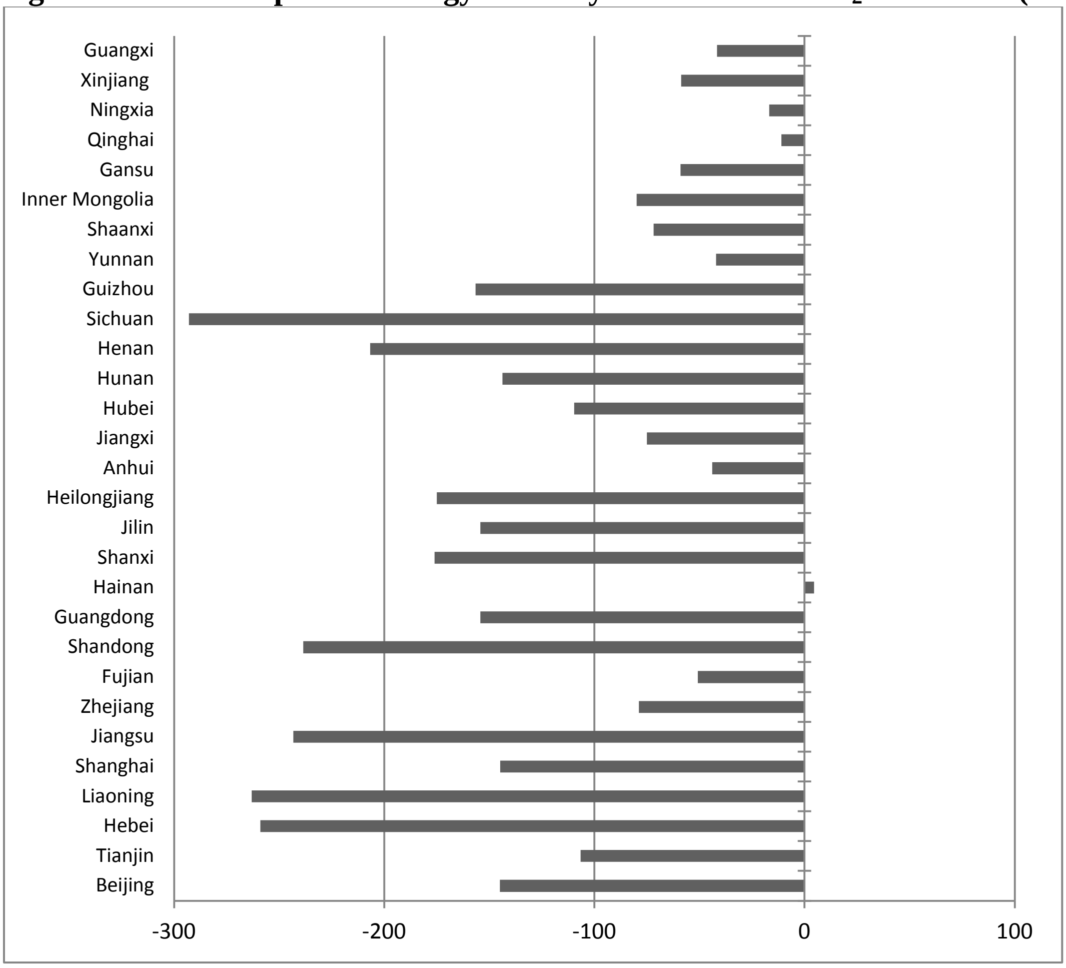


Source: Author's calculation.

Energy Intensity Effect

Energy intensity is the key factor mitigating the growth of CO_2 emissions, as shown in Table 5.8. Figure 5.11 shows the impact of energy intensity change on CO_2 emissions between 1990 and 2009. The change in energy intensity in all provinces, except Hainan, resulted in a decrease in CO_2 emissions by 3594.3 Mt. The highest decrease occurred in Sichuan, Liaoning, Hebei, Jiangsu and Shandong.

Figure 5.11: The Impact of Energy Intensity on Provincial CO_2 Emissions (Mt)

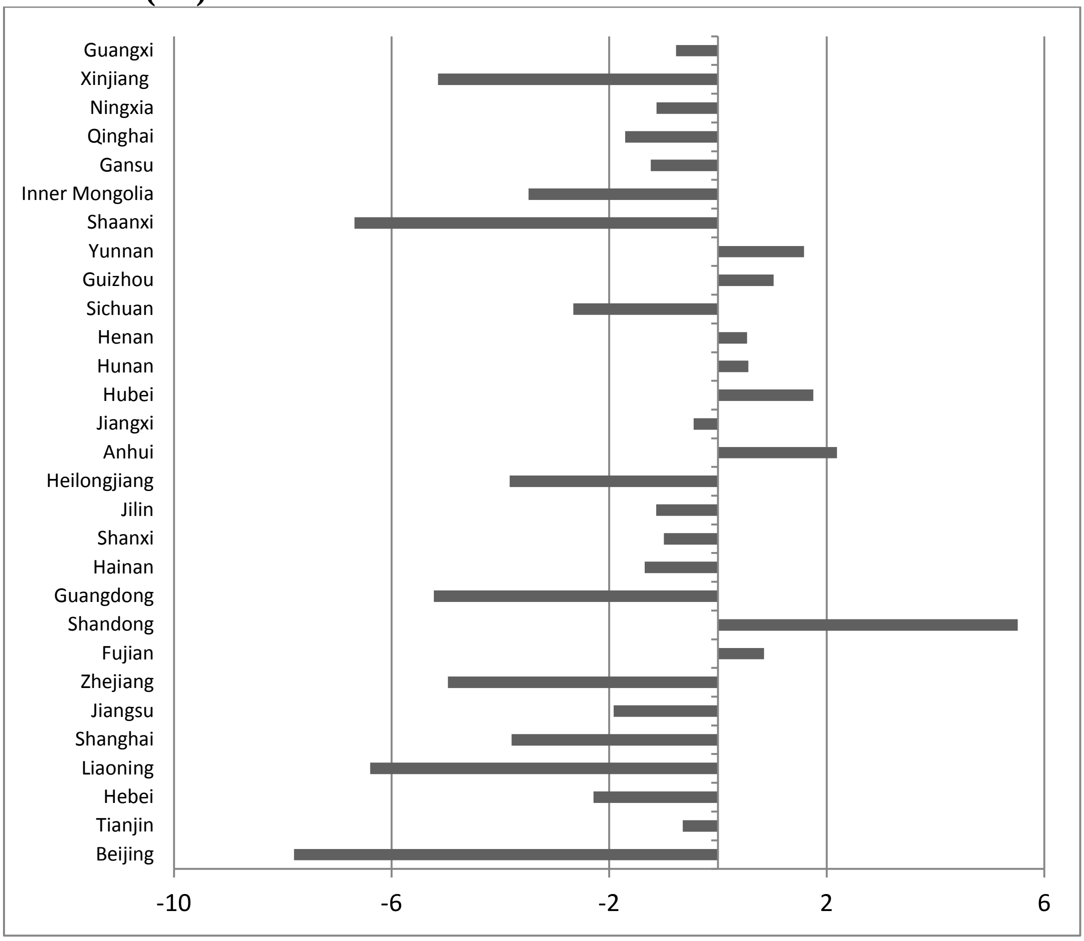


Source: Author's calculation.

Carbon Emission Coefficient Effect

The impact of the carbon emission coefficient on CO_2 emissions not only reflects the impact of the change in the energy consumption structure, but also reflects the change in energy quality and the installation of abatement technologies. From Table 5.8, it is observed that the impact of the carbon emission coefficient is smaller than other factors. Figure 5.12 presents the carbon emission coefficient effect of 29 provinces during 1990-2009. For Fujian, Shandong, Anhui, Jiangxi, Hubei, Hunan, Henan, Yunnan and Guizhou provinces, the carbon emission coefficients indicate the increase in CO_2 emissions, while for others, the carbon emission coefficients result in a reduction in CO_2 emissions due to a decline in coal share and the use of high-quality fuel.

Figure 5.12: The Impact of the Carbon Emission Coefficient on Provincial CO_2 Emissions (Mt)



Source: Author's calculation.

Sub-periods: 1990-2000 and 2000-2009

Table 5.9 shows the decomposition results for two sub-periods: 1990-2000 and 2000-2009. CO_2 emissions grew more quickly during 2000-2009, accounting for 80% of the total growth during 1990-2009. Comparing these two sub-periods, although the CO_2 emissions in all regions grew quickly, the increase in the western region was greater than the others. The total increases in 2000-2009 were 1107 Mt in the western region, which was five times the figure in 1990-2000 (coastal was three times, and central region was four times). Shanghai is the only province whose total increase in 2000-2009 was less than its increase in 1990-2000, mainly due to a large decrease in energy intensity.

During both sub-periods, economic growth was always the most important factor driving increases in CO_2 emissions. The contribution of economic growth to China's total change in CO_2 emissions was highest in the sub-period 1990-2000, being 55.5%. From 2000 to 2009, the contribution of economic growth increased and remained the highest (75.6%). Due to the implementation of the "western development" strategy since 2000, the western region entered a period of rapid growth, with an average annual growth rate of 13.58% during 2000-2009, exceeding the growth of the central region. And since 2006 the western region has surpassed the coastal region (Lu and Deng, 2011). The GRP per capita of the western region also grew much more quickly after 2000. In the sub-period 1990-2000, the average annual growth rate of real GRP per capita was only 8.4%, but then rose to 14.9% from 2000 to 2009, which was higher than other regions. As a result of the rapid economic development in 2000-2009, CO_2 emissions increased by 1407.9 Mt, which was triple the amount in 1990-2000.

Compared with economic growth, the energy intensity effect resulted in reduced emissions in both sub-periods. The contribution of energy intensity to decreasing the CO_2 emissions was 36.6% in 1990-2000; however, it fell to 21% in 2000-2009. The energy intensity effect in all provinces, except Hainan, resulted in decreased emissions in 1990-2000. The strength of the energy intensity factor was 35% in the coastal, 39% in the central and 37% in the western region, respectively. From 2000 to 2009, these percentages declined to 21% in the coastal, 22% in the central and 19% in the western region. Besides Hainan, there were three provinces, Fujian, Shandong and Yunan, in which the energy intensity effect increased emissions in 2000-2009. The main reason was the re-emergence of heavy industry in the early 2000s. This led to an increase in energy intensity from 2000 to 2005, although after that date it declined, albeit slowly. The situation in the western region was worse. Industry in the western region centres on oil, gas, coal, ferrous metals and hydropower, essentially energy and raw materials. Since 2000, heavy industries have been expanding rapidly, while the traditional and more environmentally friendly sectors, such as tourism and culture, were ignored. Recently, the proportion of extractive and resource-intensive industries has been steadily increasing. Resource processing took place and low-end industries were increasing. According to *China Statistical Yearbook* (2011), high-tech industries only accounted for 6% of total output of the western region in 2008, which was 7.8 percentage points lower than in the coastal region.

Although population growth is a factor in increasing CO_2 emissions, its impact is reduced from the first sub-period to the second sub-period, due to the reduction of the average national population growth rate, from 1.1% in 1990-2000 to 0.6% in 2000-2009. As shown in Table 5.9, in 1990-2000, the population growth effect helped to increase emissions by 281 Mt, accounting for 7% of total emissions. However, only 241

Mt of emissions were increased due to population growth effect in 2000-2009, which was only 3% of total. In both central and western regions, the increases in emissions induced by population growth in 2000-2009 were much less than in 1990-2000. The population growth effect even tended to reduce emissions in some central provinces, such as Anhui, Henan, Hubei and Hunan, and a western province, Sichuan. Compared with the central and western regions, the population growth effect helped to increase 187 Mt of emissions in 2000-2009, which was more than in 1990-2009. Labour migration plays an important role. In particular, after China's accession to the WTO in 2001 the demand for migrant labour resumed at a high level, and improvements were made to policies introduced to free the labour market across China in the early 2000s[75]. The coastal region is main labour-receiving area, while the central and western regions are main labour-sending areas, especially Anhui, Henan, Hunan, and Sichuan. The large amount of labour migration from these four provinces had started in the early 1980s and continued to increase. Some western provinces, such as Gansu, Inner Mongolia, Hubei and others, mainly started in the late 1990s and early 2000s. According to *China Population and Employment Statistical Yearbook* (2010), the annual average growth of migrant rural labour was 6.6 million in 2001-2008, compared to an annual average of about 4 million in the 1990s.

As a technology factor, the carbon emission coefficient effect played a relatively small role in China. Its impact of reducing emissions declined significantly from sub-period 1990-2000 to sub-period 2000-2009. During 1990-2009, for 24 out of 29 provinces, the carbon emission coefficient effect resulted in a reduction in CO2 emissions, which

[75] The *hukou* reform of 2001 abolished the limit on the number of rural labourers who can apply for permanent residence in medium-size cities and some provincial capitals; adopted a soft policy of "widening the gate, raising the price" in mega-cities such as Shanghai and Beijing. In the early 2000s, the central government issued several new policies in order to create a unified labour market, ensure fair treatment of migrant workers, and provide social services and insurance for migrant labours (Cai *et al.*, 2009).

reduced CO_2 emissions by 31.8 Mt. However, in the sub-period 2000-2009, only 14 provinces showed the negative impact of the carbon emission coefficient, which resulted in a decrease of emissions by 3 Mt. Even in the central region, the carbon emission coefficient effect resulted in increased emissions.

These results show that the energy intensity effect and carbon emission intensity effect are the factors which reduce CO_2 emissions. Thus, improvements in energy efficiency, adjustment of fuel mix, as well as strengthening clean energy utilisation, can offset part of the increased emissions caused by rapid economic growth. Since the mid-2000s, a series of regulations have been implemented. For example, in 2004, the 'Medium- and Long-Term Plan for Energy Conservation' was released; in 2005, a renewable energy law was enacted; in 2006, the targets for reducing energy intensity were set; and in 2007, a mid- to long-term plan for developing renewable energy was passed (See Chapter Four for more details). In order to examine whether these regulations are effective in reducing the emissions, we further split the period 2000-2009 into two periods: 2000-2005 and 2005-2009. The results are reported in Table 5.10.

In the period 2005-2009, the total increased emissions were 1775.1 Mt, which was much less than the amount for 2000-2005. It is thanks to this that the impacts of both the energy intensity effect and emission coefficient effect were strengthened in the late 2000s. The energy intensity effect, together with the carbon emission coefficient effect, offset 46% of increased emissions caused by economic growth and population growth in 2005-2009. The amount of reduced emissions attributable to the energy intensity effect was significant in all provinces, except Shandong.

Some provinces were facing great pressure and difficulties in the period 2000-2005, such as Fujian, Shandong, Hunan, Henan, Yunnan and Inner Mongolia, in which all four factors increased emissions. However, in 2005-2009, their energy intensity effect and/or emission coefficient effect became negative.

Table 5.9: Decomposition of CO_2 Emissions Change in 29 Provinces in Sub-periods: 1990-2000 and 2000-2009 (Mt)

Period	1990-2000					2000-2009				
Factor / Province	Total change	Decomposition of changes in CO_2 emissions				Total change	Decomposition of changes in CO_2 emissions			
		Coefficient effect	Intensity effect	Growth effect	Population effect		Coefficient effect	Intensity effect	Growth effect	Population effect
Coastal	**554.0**	**-13.5**	**-677.4**	**1099.2**	**145.7**	**1943.0**	**-10.6**	**-712.2**	**2478.8**	**187.0**
Beijing	9.93	-0.99	-52.09	47.13	15.88	22.79	-7.12	-91.04	99.31	21.63
Tianjin	22.21	-0.87	-32.64	48.58	7.15	37.23	0.54	-77.68	96.98	17.38
Hebei	92.70	-1.85	-112.78	191.34	16.00	290.00	0.73	-101.83	371.41	19.73
Liaoning	69.70	-5.66	-91.34	155.19	11.51	156.94	1.16	-166.4	308.18	13.99
Shanghai	47.18	-0.03	-55.98	81.43	21.76	39.62	-4.70	-99.27	124.82	18.77
Jiangsu	82.15	0.07	-91.74	161.18	12.64	278.32	-2.51	-114.03	377.9	17.07
Zhejiang	79.24	-2.63	-22.90	96.13	8.64	191.49	-0.60	-56.07	226.40	21.76
Fujian	20.21	-0.06	-31.88	47.54	4.60	104.11	1.16	12.88	84.32	5.75
Shandong	42.27	-0.28	-137.57	170.10	10.02	591.72	6.74	75.03	488.16	21.78
Guangdong	84.59	-0.70	-49.63	97.90	37.01	218.30	-5.41	-96.91	292.40	28.21
Hainan	3.82	-0.44	1.15	2.62	0.48	12.47	-0.59	3.16	8.97	0.93
Central	**235.4**	**-7.9**	**-440.9**	**611.7**	**72.5**	**1119.2**	**10.07**	**-457.6**	**1555.0**	**11.7**
Shanxi	56.66	-0.03	-35.18	75.64	16.22	198.41	-1.12	-144.13	329.71	13.95
Jilin	4.21	-1.15	-62.91	61.78	6.49	91.43	0.55	-64.13	149.53	5.48
Heilongjiang	12.37	-6.47	-89.59	98.75	9.68	90.95	4.78	-60.90	146.16	0.91
Anhui	48.81	0.98	-11.64	52.17	7.31	119.99	0.82	-33.38	156.11	-3.55
Jiangxi	12.62	-0.92	-27.45	36.82	4.17	57.86	1.03	-38.32	89.79	5.37
Hubei	45.68	3.01	-47.87	81.56	8.98	114.95	-3.19	-48.81	174.10	-7.15
Hunan	-5.24	-1.97	-76.12	67.11	5.73	141.12	3.89	-10.79	151.31	-3.28
Henan	60.31	-1.30	-90.18	137.86	13.94	304.46	3.32	-57.11	358.28	-3.27
Western	**208.6**	**-10.5**	**-332.8**	**489.1**	**62.7**	**1107.0**	**-2.54**	**-342.6**	**1409.7**	**42.4**
Sichuan	29.30	-2.79	-139.92	165.97	6.04	214.16	1.90	-78.25	295.41	-4.91
Guizhou	45.65	0.34	-68.14	103.44	10.01	88.57	0.70	-75.04	161.38	1.53
Yunnan	15.39	0.43	-26.85	35.39	6.42	108.46	0.91	7.51	92.330	7.73
Shaanxi	9.61	-2.69	-22.89	29.78	5.41	131.66	-1.72	-30.53	159.90	4.00
Inner Mon.	33.93	-0.69	-10.77	38.84	6.55	280.85	-2.21	-65.32	344.30	4.08
Gansu	20.62	-0.73	-14.99	29.03	7.31	52.98	-0.27	-44.91	95.36	2.80
Qinghai	2.56	-0.57	-3.37	4.92	1.57	19.50	-0.82	-5.87	24.64	1.55
Ningxia	5.29	-0.56	-5.62	8.09	3.38	62.86	0.09	-5.02	62.18	5.61
Xinjiang	32.21	-2.88	-25.13	48.25	11.97	89.32	-0.90	-25.03	96.74	18.51
Guangxi	14.03	-0.36	-15.11	25.44	4.06	58.60	-0.22	-20.11	77.43	1.50
All regions	**998.0**	**-31.8**	**-1451.1**	**2200.0**	**281.0**	**4169.2**	**-3.05**	**-1512.3**	**5443.4**	**241.1**

Source: Author's calculation.

Table 5.10: Decomposition of CO_2 Emissions Change in 29 Provinces in Sub-periods: 2000-2005 and 2005-2009 (Mt)

Period	2000-2005					2005-2009				
Factor / Province	Total change	Decomposition of changes in CO_2 emissions				Total change	Decomposition of changes in CO_2 emissions			
		Coefficient effect	Intensity effect	Growth effect	Population effect		Coefficient effect	Intensity effect	Growth effect	Population effect
Coast	**1119.2**	**10.6**	**-230.0**	**1263.5**	**75.0**	**823.9**	**-30.8**	**-591.0**	**1319.9**	**125.8**
Beijing	12.14	-1.75	-63.21	67.39	9.82	10.65	-5.65	-25.74	29.87	12.17
Tianjin	30.13	0.90	-31.94	57.80	3.37	7.11	-0.46	-53.09	44.10	16.56
Hebei	164.87	1.92	-37.77	192.23	8.50	125.17	-1.89	-73.31	187.87	12.49
Liaoning	69.66	-0.42	-63.59	127.85	5.82	87.29	1.84	-105.65	182.81	8.28
Shanghai	37.47	-3.43	-47.72	80.16	8.45	2.15	-1.41	-58.35	50.23	11.69
Jiangsu	184.93	0.80	-16.79	195.22	5.69	93.39	-4.58	-127.63	211.32	14.29
Zhejiang	109.57	-0.70	-23.09	125.07	8.29	81.92	0.29	-37.88	103.77	15.74
Fujian	47.50	1.96	12.78	30.17	2.59	56.61	-1.86	-4.98	60.22	3.19
Shandong	370.61	8.45	115.56	237.01	9.60	221.10	-5.60	-103.80	314.59	15.92
Guangdong	86.64	3.62	-76.98	147.38	12.63	131.65	-12.02	0.07	128.76	14.84
Hainan	5.62	-0.71	2.70	3.26	0.37	6.85	0.50	-0.61	6.38	0.59
Central	**676.7**	**8.4**	**-81.4**	**727.3**	**22.4**	**442.5**	**0.6**	**-474.7**	**935.6**	**-18.9**
Shanxi	142.36	-0.12	-59.37	194.14	7.71	56.06	-1.30	-104.35	154.46	7.25
Jilin	41.64	-0.12	-26.19	66.21	1.74	49.79	0.82	-39.20	84.12	4.05
Heilongjiang	51.37	4.02	-30.97	77.76	0.56	39.58	0.40	-30.89	69.74	0.33
Anhui	47.20	0.55	-13.61	63.32	-3.06	72.78	0.16	-19.54	91.85	0.32
Jiangxi	34.18	1.05	-13.30	43.69	2.75	23.69	-0.20	-28.91	50.00	2.80
Hubei	68.70	-2.98	12.27	57.57	1.83	46.24	0.20	-76.93	134.31	-11.32
Hunan	105.25	2.83	40.81	58.47	3.15	25.87	1.10	-82.33	127.06	-9.96
Henan	185.96	3.17	8.95	166.13	7.70	118.51	0.54	-92.57	224.03	-12.41
Western	**598.3**	**-0.2**	**-43.0**	**627.8**	**13.7**	**508.7**	**-3.7**	**-402.7**	**880.8**	**34.3**
Sichuan	101.28	1.94	-20.23	124.26	-4.69	112.88	-0.57	-66.53	178.99	0.99
Guizhou	46.02	0.40	-28.22	74.66	-0.82	42.55	0.30	-50.89	90.19	2.95
Yunnan	67.68	0.51	22.63	40.31	4.23	40.78	0.44	-26.89	63.34	3.89
Shaanxi	54.35	-0.86	-7.81	61.26	1.79	77.31	-0.75	-26.32	102.28	2.11
Inner Mon.	175.77	0.48	20.11	154.22	0.95	105.08	-4.47	-143.36	248.26	4.66
Gansu	32.70	-0.14	-18.33	49.93	1.23	20.28	-0.15	-29.61	48.31	1.73
Qinghai	10.37	-0.26	-1.22	10.99	0.86	9.13	-0.66	-5.78	14.89	0.68
Ningxia	41.44	-0.04	11.65	26.97	2.86	21.42	0.22	-29.80	47.52	3.48
Xinjiang	41.42	-2.14	-14.23	49.48	8.32	47.90	2.01	-9.62	45.20	10.31
Guangxi	27.22	-0.11	-7.31	35.72	-1.08	31.38	-0.10	-13.87	41.84	3.51
All regions	**2394.1**	**18.8**	**-354.4**	**2618.6**	**111.1**	**1775.1**	**-33.9**	**-1468.4**	**3136.3**	**141.1**

Source: Author's calculation.

5.6 Conclusion

In this chapter, the LMDI method is used to analyse the nature of the factors that influence changes in energy-related CO_2 emissions (both sectoral and provincial levels) in China during the period 1980-2009[76]. The factors include the carbon emission coefficient effect (emissions per unit of fossil fuel), energy intensity effect (energy consumption per unit of GDP/GRP), economic structure effect[77] (sector value-added share of GDP), economic growth effect (per capita of GDP/GRP) and population growth effect.

China's CO_2 emissions originated mainly from the industry sector/major industrial provinces, such as Shandong, Hebei, Henan, Jiangsu and Liaoning. In the period 1980-2009, industrial CO_2 emissions account for about 73-94% of total emissions, while the emissions from Shandong, Hebei, Henan, Jiangsu and Liaoning account for 39% of total. Therefore, efforts should be focused on the industry sector and these industrial provinces during the mitigation of CO_2 emissions. CO_2 emission intensity differs across sectors/provinces. The industry sector has the highest CO_2 emissions intensity. Due to the differences in provincial economic structure and development level, the highest CO_2 emission intensity is found in western and central provinces, such as Ningxia, Shanxi, Guizhou, Xinjiang and Inner Mongolia; while the lowest is in the coastal provinces, such as Shanghai, Beijing and Guangdong.

Consistent with existing studies, the decomposition results revealed that economic growth was the main factor in increasing CO_2 emissions, and the population growth effect was not even a third of the economic growth effect. However, energy intensity

[76] The time period for provincial decomposition is 1990-2009 due to lack of historical data.
[77] The economic structure effect is not included in the decomposition of provincial CO_2 emissions change, due to lack of the detailed data for sectors in each province.

played a big role in lowering CO_2 emissions, which offset about 33-41% of the combined effect of economic growth and population growth. The impacts of the carbon emission coefficient and economic structure varied across sectors/provinces and were relatively small. The economic structure effect is only found to exhibit a positive effect on CO_2 mitigation in the primary and industry sectors. The carbon emission coefficient effect contributes to the decrease in CO_2 emissions in transport and other service sectors, as well as 21 out of 29 provinces.

The whole production-based accounting approach ignores international trade. Given the fact that the major part of China's production is consumed in overseas, it would be worthwhile to study a consumption-based accounting approach. In the next chapter, we will calculate and analyse China's CO_2 emissions from the consumption-based accounting approach.

Chapter Six

International Trade and CO_2 Emissions in China: An Input-Output Analysis

6.1 Introduction

In the previous chapter, we calculated China's CO_2 emissions and identified the factors influencing the growth of emissions based on domestic production activities. Pan *et al*. (2008) and Yan and Yang (2010) point out that China's high level of foreign trade and large trade surplus are the main reasons for its soaring CO_2 emissions, apart from the expansion of domestic consumption and investment. Since the 1990s, China's exports have exceeded imports, and the surplus has grown sharply after entry into WTO. Most products exported to developed countries are labour-intensive and energy-intensive, with embodied CO_2 emissions. This leads to a geographic separation of consumers and the CO_2 emissions emitted during the production of consumable items (Peters and Hertwich, 2008b).

Under current Kyoto Protocol accounting rules, the emissions associated with the exports are fully attributable to China, because they took place within its territory (production-based accounting), which has questioned its effectiveness. The developed countries can bypass the Clean Development Mechanism (CDM)[78] and offload their responsibilities to developing countries by importing or relocating production abroad, which is called 'carbon leakage' (Lin and Sun, 2010). At the same time, facing the rapid

[78] The CDM is one of the Kyoto Protocol's flexible mechanisms, which allows developed countries to offset their greenhouse gas reduction targets by funding projects in developing countries that lead to reduced emissions (UN, 1998).

increases in CO_2 emissions, China and other developing countries are beginning to question why they are criticised for their increasing emissions. At the Bali conference in December 2007, the Director of the National Development and Reform Commission of China first raised whether developed countries should take responsibility for the emissions which are embodied in the products they import and consume from developing exporters like China. Therefore, a fairer measure based on domestic consumption is gaining recognition (Ahmad and Wyckoff, 2003; Peters and Hertwich, 2008a).

With the input-output tables of China, this chapter attempts to improve the data in estimating China's embodied CO_2 emissions associated with both exports and imports, which is expected to give a more complete and impartial picture of responsibility for carbon reduction for China. The literature is reviewed in section 6.2; the methodology is presented in section 6.3; section 6.4 describes the data; section 6.5 discusses the results; and the conclusion is presented in section 6.6.

6.2 Literature Review

6.2.1 Production-based Approach versus Consumption-based Approach

The United Nations Framework Convention on Climate Change (UNFCCC) requires that all parties develop and submit national Greenhouse Gas inventories. These inventories account for only those emissions arising from the domestic production of goods and services, ignoring whether those goods and services are produced for export or domestic consumption (known as the production-based approach). Under the production-based approach, the recent CO_2 emissions abatement, provided by the Kyoto Protocol, has called its effectiveness into question. Because a country's carbon footprint will increasingly transcend its borders to have a worldwide effect due to international trade. Specifically, developed countries can bypass the CDM and avoid relevant responsibility by relocating production abroad to developing countries, or via import substitution, which is called emissions leakage, whereas the Kyoto Protocol adopts a measure of emissions associated with domestic production (Lin and Sun, 2010).

By contrast, the consumption-based approach includes emissions embodied in imports and excludes emissions embodied in exports, which equals production-based inventories – emissions embodied in exports + emissions embodied in imports. Wiedmann (2009, p.211) lists several advantages of the consumption-based approach: "*1) it complements the production-based approach by including all driving forces for emissions associated with consumption; 2) the complementary information can be useful for international policy on climate change, particularly in relation to participation of developing countries, reducing carbon leakage, alleviating competitiveness concerns, and achieving the ultimate goal of the UNFCCC to avoid dangerous anthropogenic climate change; 3) it provides a better understanding of the common but differentiated responsibility between countries; 4) it quantifies the economic and environmental trade linkages between countries, which could help in the design of an international harmonised price for greenhouse gas emissions; 5) it could encourage and facilitate international cooperation and partnerships between developing and developed countries, for example by prioritising technology transfers, estimating financial transfers, and streamlining the CDM; 6) as a communication tool, it can be used to make consumers aware of the greenhouse gas emissions from their life-style and consumption choice; 7) by identifying hot spots and unsustainable consumption patterns and trends, it can help design strategies on sustainable* *consumption and production, as well as climate change mitigating and adaptation policies at the national, regional and local levels."*

Adoption of the consumption-based approach, in addition to the traditional production-based approach, opens up the possibility of extending the range of policy and research applications (Wiedmann, 2009). In particular, using a consumption-based approach can redress the problem of carbon leakage and reveal the extent to which a relocation of production and associated shift of embodied emissions have occurred (Peters, 2008). Peters (2008), Peters and Hertwich (2008b), and Weber and Peters (2009) argue that using a consumption-based approach can present well when discuss the challenges for climate policy posed by international trade.

6.2.2 Empirical Evidence in China

Environmental extended input-output (I-O) analysis (Leontief and Ford, 1970; Victor, 1972; Miller and Blair, 2009) is recognised as a well established approach and a useful top-down technique that allows pollution and resource use to be assigned to final demand in a consistent framework (Wiedmann, 2009).

The embodied CO_2 emissions in China's international trade have attracted considerable attention from several researchers. Most studies focus on both imports and exports, including the products in multilateral trade by China (such as Wang and Watson, 2007; Liu *et al.*, 2007; Weber *et al.*, 2008; Pan *et al.*, 2008; Xu *et al.*, 2011; Yan and Yang, 2010; Lin and Sun, 2010; Ma and Chen, 2011; Zhang, 2012b), while a few studies examine the bilateral trade between China and another country (such as Shui and Harriss, 2006; Li and Hewitt, 2008; Yan *et al.*, 2011). The studies listed above are summarised in Table 6.1. Most studies applied a SRIO model to analyse a single country issue, while a few papers applied the EIO-LCA method by considering different production processes and emissions behind the goods. The studies covered a time period ranging from one year to 18 years (1987-2006).

The results are varied, due to different data sources and methodologies. Most studies confirmed that China was a net exporter of embodied CO_2 emissions during the studied period and the Chinese trade surplus was accompanied by an ecological deficit (Wang and Watson, 2007; Liu *et al.*, 2007; Pan et al., 2008; Yan and Yang, 2010; Lin and Sun, 2010; Ma and Chen, 2011; Zhang, 2012b). The three studies on bilateral trade gave similar results (Shui and Harriss, 2006; Li and Hewitt, 2008; Yan *et al.*, 2011).

Most SRIO models use the EAI assumption to analyse the emissions embodied in imports. This means the studies use the domestic emission intensities to replace the emission intensities of imported goods. Considering that China's emission intensity is relatively high compared with its trading partners, the imported emissions calculated under the EAI assumption should be the upper limit of actual value. Due to considering all trading partners, the MRIO model is able to obtain a more reasonable result. However, the MRIO model requires a global input-output table, which is more difficult to obtain and update (Ma and Chen, 2011). Two studies use national average emission intensity of the trading partner to calculate emissions embodied in China's imports (Wang and Watson, 2007; Pan *et al.*, 2008). Pan *et al.* (2008) point out the limitation of this approach in that bilateral trade is often concentrated in particular sectors which may be more or less intensive than the national average. Specialisation according to comparative advantage would reduce the risks of divergence, but in practice such specialisation is incomplete.

Liu and Sun (2010) and Ma and Chen (2011) consider the re-exported emissions component [79]. Weber *et al.* (2008) argue that without the re-exported emissions component, the embodied emissions within exports could only represent the domestic additional emissions during the process of exports production, which fail to match the figure of the total exports value. Moreover, the processing trade is an important part of China's international trade. Therefore, it is more reasonable to cover the re-exported emissions component.

In summary, studies on CO_2 emissions embodied in China's trade have been carried out by adopting different methodologies and have provided various results. My objective in the remainder of this chapter is to calculate the CO_2 emissions embodied in China's exports and imports based on recent input-output tables. Unlike many other studies, when we consider the difference in emissions intensities between China and its trading partners, a weighted average emissions intensity of trading partners is applied.

[79] *The re-exported emissions represented emissions imported but later exported. For example, the country imports some raw and processed materials to manufacture the final foods for exporting. The emissions embodied in these materials are called the re-exported emissions* (Lin and Sun, 2010, p. 617).

Table 6.1: Results of Studies on Emissions Embodied in China's Trade

Study	Subject/ Year of estimate	Methodology	CO_2 emissions embodied in		
			Exports (EEX)	**Imports (EEI)**	**Net (BEET)**
Shui and Harriss (2006)	China-US trade 1997-2003	US data were from the EIO-LCA web model. China's data were calculated from American data indirectly, using the method of adjustment by exchange rate, emission intensity ratios etc.	Trade reduced 3-6% of US emissions and increased 7-14% of China's emissions, and increased global emissions by 720 Mt.		
Li and Hewitt (2008)	China-UK trade 2004	EIO-LCA Same as Shui and Harriss (2006)	Trade reduced UK CO_2 emissions by 11%, and resulted in an additional 117 Mt of CO_2 to global emissions.		
Wang and Watson (2007)	Trade of China 2004	SRIO Using average emission intensity of exporters	1,490 Mt	381 Mt	1,109 Mt (23%)
Liu *et al.* (2007)	Trade of China 2007	SRIO Under EAI assumption	NA	NA	484 Mt (8.59%)
Weber *et al.* (2008)	Export of China 1987-2005	SRIO	EEX were 12% of total (230 Mt) in 1987, 21% (760 Mt) in 2002, and 1/3 (1700 Mt) in 2005		
Pan *et al.* (2008)	Trade of China 2002	SRIO Using average emission intensity of exporters	880 Mt (24%)	257 Mt	623 Mt (19%)
Yan and Yang (2010)	Trade of China 1997-2007	EIO-LCA Same as Shui and Harriss (2006)	314 --1725 Mt (10-27%)	138 -- 588 Mt (4.4-9%)	1132 Mt in 2007
Lin and Sun (2010)	Trade of China 2005	SRIO, under EAI assumption, including re-exported	3357Mt	2333 Mt	1024 Mt (18.8%)
Xu *et al.* (2011)	Export of China 2002-2008	SRIO	EEX increased from 1700 Mt in 2002 to 3100Mt in 2008.		
Yan *et al.* (2011)	China-EU trade 1995-2006	Extended SRIO by bilateral trade data	EEX in China were 95 Mt (3%) in 1995 and 532 Mt (9%) in 2006; EEX in EU were 6Mt (0.2%) in 1995 and 26 Mt (0.7%) in 2006.		
Ma and Chen (2011)	Trade of China 2000-2009	SRIO, under EAI assumption Re-export was taken into account	EEX were 20-40% higher than EEI; BEET peaked at 1718 Mt in 2008.		
Zhang (2012b)	Trade of China 1987-2007	SRIO, under EAI assumption, including re-exported	243—1751 Mt (14-32%)	382—1020 Mt (22-19%)	730 Mt in 2007

Note: EIO-LCA: Economic Input-Output-Life Cycle Assessment software was developed by Green Design Initiative at Carnegie Mellon University.
EAI assumption: the emission intensities of imported goods are the same as those used domestically.
The % in parenthesis refers to carbon embodied in total production.

Source: Compiled by the author.

6.3 Methodology

The Input-Output (I-O) model, originally theorised without consideration of trade by Leontief (1966), was widely used for the estimation of embodied pollutant emissions induced by the final consumption of goods and services in an economy (Mongelli *et al.*, 2006). Assuming that an economy includes n industries, the basic I-O model can be represented as:

$$X = AX + Y \tag{6.1}$$

where X and Y are column vectors indicating the total output of the entire economy and final use which includes consumption, investment and export; while AX is the intermediate input. A is the direct input requirement coefficient matrix (known as the Leontief Matrix), with each element $a_{ij} = \frac{X_{ij}}{X_j}$ representing the amount of output from industry i required directly to produce one unit of output from industry j. Thus, the total output can be solved as:

$$X = (I - A)^{-1} \times Y \tag{6.2}$$

where I is the identity matrix, and $(I – A)^{-1}$ is the Leontief inverse matrix. Its element β_{ij} represents the amount of output from industry i required directly and indirectly to produce one unit final use from industry j.

To incorporate CO_2 emissions into I-O model, two row vectors (S and S') are required. S represents the direct CO_2 emissions per unit of industrial output, while for each industry j $S_j = \frac{CO_{2j}}{X_j}$. By using the Leontief inverse matrix, we can construct the domestic embodied CO_2 emissions per unit final use, $S' = S \times (I - A)^{-1}$. Its element, S_j', represents the direct and indirect CO_2 emissions per unit final use in industry j.

Therefore, an economy's CO_2 emissions embodied in domestic production (**EDP**) can be measured as:

$$EDP = SX = S \times (I - A)^{-1} \times Y = S' \times Y \tag{6.3}$$

EDP (production-based CO_2 emissions) includes CO_2 emissions from production for export but excludes emissions embodied in imports. Therefore, in order to know the impact of trade, we need to extend the model to the consumption accounting basis by estimating CO_2 emissions embodied in exports and imports.

CO_2 emissions embodied in exports (EEX)

The gross CO_2 emissions embodied in exports can be given by multiplying the domestic embodied CO_2 emissions per unit final use by export, $S' \times Ex \; or \; S \times (I - A)^{-1} \times Ex$. However, a portion of China's exports are imported from other countries before they are reprocessed for final export. So, to account for the exported emissions from domestic production, this part of the imports should be excluded. According to the United Nations (1999), the direct input requirement coefficient matrix A can be decomposed into two components, the inter-industry requirements of domestically produced products (A^d) and the inter-industry requirements of imported products (A^{im}). Therefore, the CO_2 emissions embodied in exports can be shown as:

$$EEX = S \times (I - A^d)^{-1} \times Ex \tag{6.4}$$

where $A^d = A - A^{im}$, and $A^{im} = MA$. M is a diagonal matrix, with the element $m_{jj} = \frac{Im_j}{X_j + Im_j - Ex_j}, (j = 1,2, \dots, n; \; when \; i \neq j, m_{ij} = 0)$. Assuming that the proportion of the imported intermediate inputs from each sector to all others is the same (Weber *et* *al.*, 2008; Lin and Sun, 2010; and Ma and Chen, 2011), equation (6.4) can be rewritten as:

$$EEX = S \times [I - (I - M)A]^{-1} \times Ex \qquad (6.5)$$

CO_2 emissions embodied in imports (EEI)

Since imports are from various trading partners with different emissions intensities of production, theoretically, the CO_2 emissions embodied in imports should be estimated as: $\sum_1^g \sum_1^j (S_{jg}^* \times Im_{jg})$, S_{jg}^* indicates the emission intensity of industry *j* in country g, and Im_{jg} is the imports from industry *j* of country g. However, the industry-level emission intensity data for every trading partner are not available. Because China imports from more than one hundred countries, whose I-O tables are not readily available; furthermore, there are differences in industrial classification from country to country. As a result, some studies assume that the emission intensity of imported production is the same as the domestic production, $S_{jg}^* = S_j'$. Under this assumption, the results usually overestimate the embodied emissions in imports, because the emission intensity of China is relatively high compared to its trading partners. Thus, in this chapter we assume that the average emission intensity for China's top 20 import trading partners is representative of those of China's imported production[80]. And the CO_2 emissions embodied in imports can be estimated as:

$$EEI = \hat{S} \times Im \qquad (6.6)$$

where $\hat{S}$ presents the average emission intensity for China's top 20 import trading partners, and Im is the total imports whether for domestic consumption or the processing trade.

[80] In order to understand how much emissions would have been saved, we also calculate the embodied CO_2 emissions in imports by using China's domestic emission intensity in place of the import trading partners' average intensity.

To sum up, we can calculate CO_2 emissions on a domestic consumption basis (**EDC**), which is given as:

$$EDC = EDP - EEX + EEI \tag{6.7}$$

The balance of CO_2 emissions embodied in international trade (**BEET**) is the difference between emissions embodied in exports and imports, or the difference between production and consumption estimates:

$$BEET = EEX - EEI = EDP - EDC \tag{6.8}$$

If BEET is positive, a country exports more CO_2 emissions than it imports from other countries (an emissions surplus), which indicates that domestically produced goods with embodied emissions are not consumed completely domestically. If BEET is negative, a country imports more CO_2 emissions than it exports (an emissions deficit).

6.4 Data Description

The data required in this chapter are primary energy consumption (coal, oil and natural gas) data at industrial sector level from *China Energy Statistical Yearbook* (various issues); the input-output (I-O) data from China's Input-Output Tables (*China Statistical Yearbook*, various issues); and the national carbon intensity data of China's major trading partners from World Bank (2011).

6.4.1 Input-Output (I-O) Table

The Chinese government has compiled the I-O table every five years since 1987. Up to now, the tables for the years 1987, 1992, 1997, 2002 and 2007 have been compiled.

This chapter uses the Chinese I-O tables for 2002 and 2007. The former is the year China entered in WTO, while the latter is the most recently available data.

The I-O table covers 17 sectors in total. In order to match the classification of energy data, we merge some sectors with a small impact on emissions in the service industry, such as the real estate and financial sectors. This chapter takes 15 sectors for analysis (see Table 6.2).

Table 6.2: Classification of China's Industrial Sectors in the Input-Output Table

Industrial Sector	**Abbreviation**
Agriculture, Forestry, Animal Husbandry & Fishery	ARG
Mining	MNI
Manufacture of Foods, Beverages & Tobacco	FBT
Manufacture of Textile, Wearing Apparel & Leather Products	TWL
Other Manufacture	OMI
Production and Supply of Electric Power, Heat Power and Water	EHW
Coking, Gas and Petroleum Processing	CGP
Chemical Industry	CMI
Manufacture of Building Materials and other Non-metallic Mineral Products	BNM
Manufacture and Processing of Metals and Metal Products	MPM
Manufacture of Machinery and Equipment	MEM
Construction	CSI
Transport, Storage, Post, Information Transmission, Computer Services & Software	TPT
Wholesale and Retail Trades, Hotels and Catering Services	WHC
Real Estate, Leasing and Business Services, Financial Intermediation and Other Services	OSI

Source: *China Statistical Yearbook*, 2010.

We collect total outputs (X), exports (E_x) and imports (I_m) directly from the I-O table. According to the assumption, we can calculate the final use (Y, which includes household consumption, government consumption, gross fixed capital formation, changes in inventories, and export in the I-O table), the direct input requirement coefficient matrix (A) and the direct requirement coefficient matrix of the intermediate input from imports (M). All data are adjusted by using the PPP conversion rate.

6.4.2 CO_2 Emissions and Intensity[81]

To account for CO_2 emissions, we first collect primary energy (coal, oil and natural gas)[82] consumption data at the sectoral level for 2002 and 2007. Following the IPCC manual (Houghton *et al.*, 1996), the direct CO_2 emissions for all sectors can be multiplied by the consumption of each fuel with its coefficient[83], and then further divided by the total output, X, to obtain the direct emissions per unit of industrial output, S. Then, we can derive the embodied emissions per unit of final use, S', which equal $S(I-A)^{-1}$ (see Table 6.3).

Table 6.3: China's Direct CO_2 Emissions and Emission Intensity: 2002 and 2007

Industrial Sector	2002			2007		
	CO_2 (10000 ton)	S (kg/PPP $)	S' (kg/PPP $)	CO_2 (10000 ton)	S (kg/PPP $)	S' (kg/PPP $)
ARG	3 026.75	0.0345	0.4822	4 360.09	0.0323	0.3922
MNI	27 434.81	0.8655	1.7732	36 424.62	0.4522	1.4514
FBT	4 844.21	0.1089	0.6424	5 480.94	0.0475	0.5213
TWL	2 681.71	0.0558	0.8075	5 021.75	0.0420	0.7608
OMI	4 896.22	0.1147	0.9167	9 091.18	0.0903	0.8509
EHW	131 019.78	5.0302	6.0321	248 866.53	2.7603	5.0207
CGP	66 042.87	3.3337	4.9253	135 661.29	2.2157	3.5489
CMI	24 240.48	0.3658	1.7500	32 264.26	0.1885	1.5573
BNM	16 792.70	0.9417	2.2613	31 944.73	0.5057	1.7766
MPM	25 023.74	0.3812	1.8863	47 380.23	0.2178	1.5693
MEM	2 928.21	0.0215	1.0383	3 430.23	0.0085	0.9784
CSI	1 044.54	0.0121	1.1884	1 054.37	0.0061	1.1298
TPT	2 483.06	0.0553	1.1108	1 752.58	0.0149	0.8676
WHC	1 509.32	0.0202	0.5493	1 619.40	0.0134	0.4206
OSI	1 247.83	0.0073	0.5181	1 513.38	0.0052	0.4783

Note: S: direct emission intensity; S':embodied emission intensity.
Source: Author's calculation.

From Table 6.3, it is evident that the direct and embodied CO_2 emission intensities (S and S') have decreased in all industry sectors between 2002 and 2007. For example, the

[81] Some papers (e.g. Ma and Chen, 2011 and Pan *et al.*, 2008) assume that the carbon intensity is same across industrial sectors. They use the national carbon intensity of output to represent sector intensity; or use the national carbon intensity of energy use and total energy consumption to estimate CO_2 emissions in each sector directly, and then derive the sector emission intensity of output.
[82] According to the World Bank, at least 70 percent of total CO_2 emissions are from the burning of primary energy.
[83] The details can be seen in Chapter Four, section 4.4.1.

direct emission intensity of the chemical industry (CMI) declined by 48%, while the embodied emission intensity declined by 11%.

Because of a coal-dominated electricity system, the electricity, heat and water supply industry (EHW) has the highest direct emissions intensity, as its S is 5.03 kg per US$ in 2002 and 2.76 kg per US$ in 2007. The second on the list is the coking, gas and petroleum processing industry (CGP), with the direct emissions intensity of 3.33 kg per US$ in 2002 and 2.22 kg per US$ in 2007. Next come the mining industry (MNI) and export-oriented industries, such as the chemical industry (CMI) and the manufacturing industry (BNM and MPM). The direct carbon emissions intensity in other sectors tends to be negligible in comparison. Besides the service sectors, the construction industry (CSI) and the machinery and equipment manufacturing industry (MEM) have the smallest direct emissions intensity. However, when taking indirect emissions into account, the emission intensities (S') of these sectors will be magnified significantly, especially in 2007.

S'(embodied carbon emissions per unit of final use) means the total (both direct and indirect) emissions generated in the supply chain to produce one unit of final goods and services, including the emissions embodied in the intermediate use. According to Lin and Sun (2009), the magnified effect in upstream industries (such as mining and electricity) is less significant than downstream industries (such as the machinery and equipment manufacturing). Compared with their S, the S' of CSI and MEM are magnified 185 and 115 times in 2007, respectively, which indicates that both industries' final products (e.g. the infrastructure or machine) have a lot of embodied CO_2 emissions in their intermediate inputs from their upstream industries, such as the steel, electricity and cement production sectors, which have large direct emissions intensity.

The carbon emission intensities of trading partners are from World Bank (2011). In 2002, the emission intensity of China was 1.0077 kg/PPP US$, which was the 16th largest in the world; while in 2007, it was 0.9255 kg/PPP US$, 11th largest in the world. As shown in Table 3, compared to China's major trading partners, China is much more carbon intensive. Therefore, we cannot use the domestic emission intensity to estimate imported CO_2 emissions. If we do, this would result in overestimates (for example, Liu and Ma, 2010 and Ma and Chen, 2011). In this chapter, we assume that the emission intensity of China's imports is equal to the mean intensity for China's top 20 import trading partners. The top 20 trading partners of China account for more than 75% of China's total imports. Based on the share of imports of each country and its emission intensity, the average emission intensity for China's imports ($\hat{S}$) can be estimated by the weighted average method, which is shown in the last row of Table 6.4

Table 6.4: Emission Intensities of Top 20 Trading Partners of China

2002			2007		
Trading Partners	**Import's share (%)**	**Intensity (kg/PPP$)**	**Trading Partners**	**Import's share (%)**	**Intensity (kg/PPP$)**
Japan	18.11	0.3561	Japan	14.01	0.2916
Taiwan	12.89	0.6317	Korea	10.85	0.4089
Korea	9.68	0.4974	Taiwan	10.57	0.3926
USA	9.23	0.5135	USA	7.26	0.3988
Germany	5.56	0.3670	Germany	4.75	0.2691
Hong Kong	3.63	0.1974	Malaysia	3.00	0.5400
Malaysia	3.15	0.5793	Australia	2.70	0.4979
Russia	2.85	1.3176	Philippines	2.42	0.2525
Singapore	2.39	0.2894	Thailand	2.37	0.5400
Australia	1.98	0.6009	Russia	2.06	0.6985
Thailand	1.89	0.6703	Brazil	1.92	0.1986
Indonesia	1.53	0.5435	Saudi Arabia	1.84	0.7237
Italy	1.46	0.2933	Singapore	1.83	0.1480
France	1.44	0.2231	India	1.53	0.5022
Canada	1.23	0.5564	France	1.40	0.1770
Saudi Arabia	1.16	0.8562	Iraq	1.39	1.0630
UK	1.13	0.3104	Angola	1.35	0.2710
Philippines	1.09	0.3712	Hong Kong	1.34	0.1358
Brazil	1.02	0.2536	Indonesia	1.30	0.4384
Iraq	0.79	0.9803	Canada	1.15	0.4308
Other countries	17.77	0.5508	Other countries	24.97	0.4612
Emission intensity of trading partners		**0.5047**	**Emission intensity of trading partners**		**0.4036**

Source: World Bank, 2011 and author's estimation.

Using domestic embodied carbon emission intensity (S'), average carbon emission intensity for imports ($\hat{S}$), and I-O tables, we can directly calculate production-based CO_2 emissions (EDP), consumption-based CO_2 emissions (EDC), CO_2 emissions embodied in exports (EEX), in imports (EEI) and balance of CO_2 emissions embodied in international trade (BEET) in 2002 and 2007, respectively.

6.5 Empirical Results

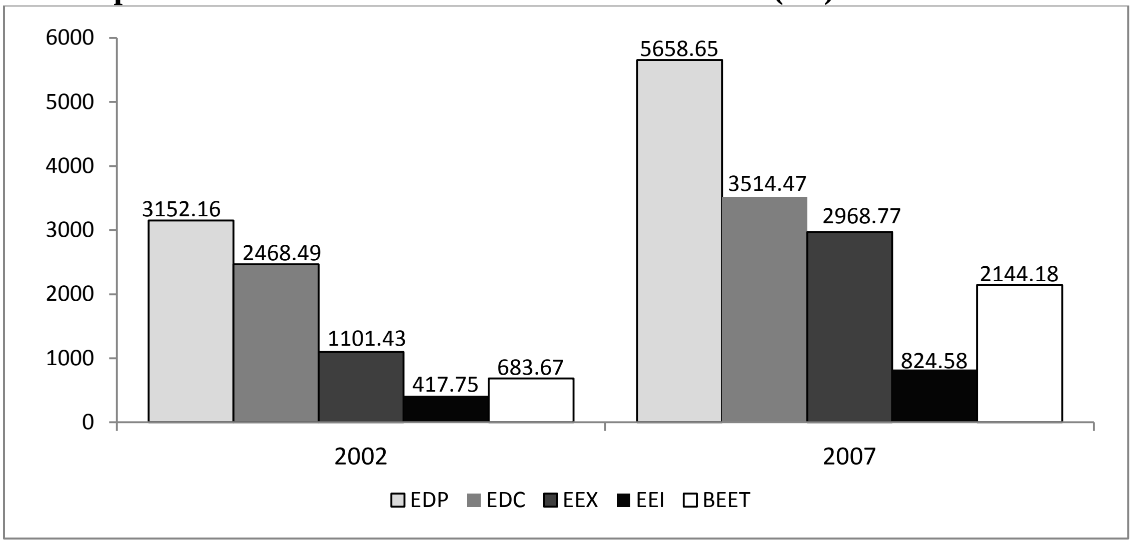
6.5.1 Aggregate CO_2 Emissions Embodied in International Trade

As shown in Figure 6.1, China's embodied CO_2 emissions increased rapidly from 2002 to 2007. China generated around 3152 Mt (million tons) of CO_2 from domestic production (EDP) in 2002. It reached 5659 Mt in 2007, almost doubling the 2002 emissions. Because of the exclusion of CO_2 emissions from residential energy consumption, our estimations are a little bit lower than the data reported by IEA and *China's Energy Statistical Yearbook* (See Table 6.5). This provides some support for the method we used to estimate China's embodied CO_2 emissions. The consumption-based CO_2 emissions (EDC) also increased rapidly from 2468 million tons to 3514 Mt, which were significantly less than the EDP. Emissions from consumption are less than those from production by 22% in 2002 and 38% in 2007. This indicates that the recent widely used production-based approach has exaggerated China's emissions responsibility. The surplus of CO_2 emissions from international trade (emissions embodied in exports are greater than those in imports) results in the difference between EDP and EDC.

At the same time, the size of emissions embodied in exports and imports were also significant. About 1101 Mt of CO_2 emissions were embodied in exports (EEX) and the emission avoided by imports (EEI) was 418 Mt in 2002. Being a net exporter of CO_2 emissions, China's emissions embodied in the international trade balance (BEET) were around 684 Mt. In other words, 684 Mt of CO_2 emissions (around 22% of China's total CO_2 emissions) were caused by producing goods for foreign markets. In the five years following entry into WTO, primarily due to the increase in global trade, the CO_2 emissions embodied in international trade increased dramatically. In 2007, China's

BEET was 2144 Mt, three times that in 2002; and EEX was approximately 38% higher than the EEI. China was continuously retaining a surplus of CO_2 emissions from international trade. Besides the expansion of domestic investment and consumption, China's surging energy consumption and CO_2 emissions are also derived by the demand from developed countries for cheap goods produced in China. These countries avoid directly generating the consequent CO_2 emissions, but are at least partly responsibility for the high growth of China's CO_2 emissions.

Figure 6.1: Embodied CO_2 Emissions in China's Domestic Production, Consumption and International Trade in 2002 and 2007 (Mt)



Note: Emissions in this figure do not include the emissions from residential consumption. EDP, emissions embodied in domestic production; EDC, emissions embodied in domestic consumption; EEX, emissions embodied in exports; EEI, emissions embodied in imports; BEET, balance of emissions embodied in international trade.
Source: Author's estimations.

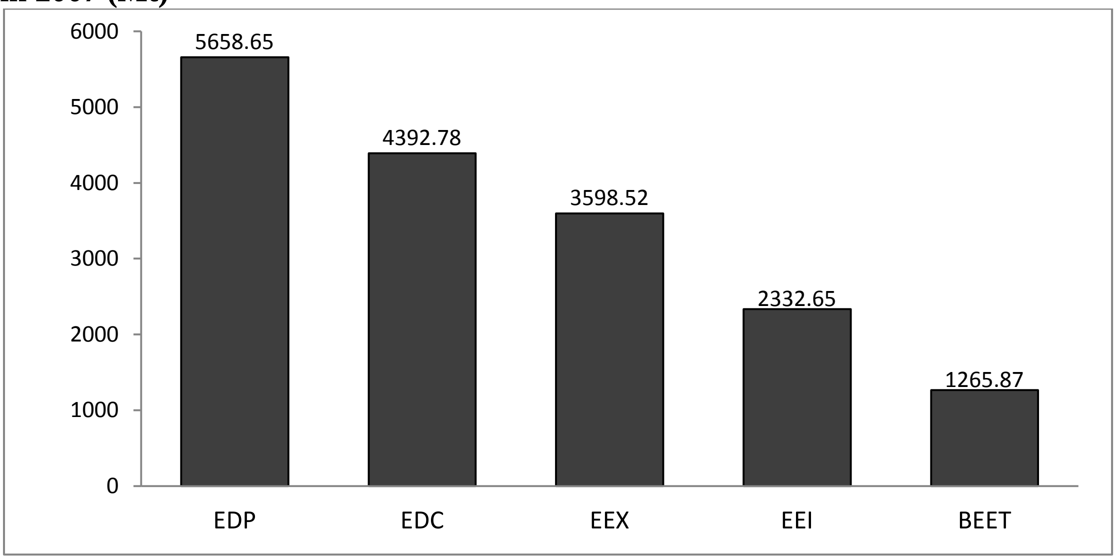
Table 6.5: Comparison of China's CO_2 Emissions Embodied in Domestic Production (EDP) (Mt)

	2002	**2007**
IEA	3440	6072
China Energy Statistical Yearbook	3456	6047
Our Estimations	3152	5658

Source: Author's estimations, IEA (2011), and *China Energy Statistical Yearbook* (2010).

For comparison, we also use the EAI assumption, which, like most other single-region IO models (Weber *et al.*, 2008; Sanchez Choliz and Duarte, 2004), assumes that the emission intensity of the exporting countries is the same as the domestic intensity. Figure 6.2 shows China's CO_2 emissions embodied in trade under the EAI assumption in 2007. The EEI was up to 2333 Mt, which was 2.8 times higher than the former 825 Mt, calculated by the emission intensity of the trading partners, because of China's lower energy efficiency and higher carbon intensity compared with its trading partners. Lin and Sun (2010) conducted a similar analysis and estimate the EEX in 2005 at around 3357 Mt and EEI at 2333 Mt, which support our estimate. This method overestimates the EDC, EEI and EEX (due to consideration of the re-exports) (Ahmad and Wyckoff, 2003; Peters and Hertwich, 2008a), but the EEI overestimate is much greater than the EEX, such that the resulting BEET estimate is much lower than the previous case. Therefore, the assumption about the CO_2 intensities of major trading partners is important.

Figure 6.2: China's CO_2 Emissions Embodied in Trade under the EAI Assumption in 2007 (Mt)



Source: Author's estimation.

6.5.2 CO_2 Emissions Embodied in International Trade by Sectors

On a sectoral basis, Tables 6.6 and 6.7 show the embodied emissions in exports (EEX), imports (EEI) and net exports (BEET) by each sector in 2002 and 2007. In 2002, the most carbon intensive export sector is MEM, accounting for 34.8% of the total emissions embodied in exports, followed by TLF (14%) and CMI (11.3%), the sum of which represents almost 60% of total emissions embodied in exports and 58% of total exports. Also, around 70% of emissions embodied in imports were produced by MEM (48.2%), CMI (13.3%) and MPM (8.4%). In 2007, there were four sectors whose shares in total exported emissions were above 10%: MEM (42.7%), MPM (13.7%), CMI (11.3%) and TLF (10.9%), and their export volume and exported emissions respectively accounted for 74% and 79% of the total; while the largest three emissions import sectors were MEM (45.5%), MNI (14.0%) and CMI (12.3%), whose imported emissions respectively accounted for 72% of total.

We find that the MEM sector played a significant role. Around 40% of the exported emissions resulted from the production of MEM for consumption in other countries. As China's largest export sector, MEM took around 33.8% of total exports in 2002 and 42.4% in 2007; and part of this sector's exports belong to the processing trade, which needs direct and indirect intermediate input imported from overseas. The producing and reprocessing in MEM is carbon-intensive, due to relatively high embodied emissions intensity (S'). And also MEM was the biggest carbon net-export sector with net exports of 182 Mt of CO_2 in 2002 and 891 Mt of CO_2 in 2007.

Generally, the sectors that contribute more exported emissions and also more exports volume are MEM and TLF. However, carbon-intensive sectors, MPM, CMI, and CGP, provide less export volume but contribute a large share in exported emissions. The cleanest sector, WHC, exports more but with less exported emissions.

According to the BEET, the 15 sectors can be divided into two groups. The ARG and MNI are in the first group with net-imported emissions (negative BEET), which indicates these sectors avoided emitting domestically through international trade. Both the AGR and MNI sectors produce low value-added products and materials, which are the intermediate inputs for others industries. These sectors were in deficit in their trade balances. Mainly due to increases in imported oil, MNI was the largest emissions net-import sector in 2007. The remaining sectors are in the second group (positive BEET), which increased China's CO_2 emissions as a result of providing goods and services for the international market, especially for MEM, MPM and TLF. Therefore, the great majority of China's BEET was contributed by the manufacturing industry, reflecting the comparative advantage of these sectors. If we use domestic emission intensity instead of that of the trading partners, two more sectors, CGP and CMI, are added to the first group (See Table 6.8). These two sectors also were in trade deficit in 2007 and with higher carbon emission intensities in China.

Table 6.6: Embodied Emissions in International Trade by Sectors in 2002

	Share in total exports (%)	Share in total imports (%)	EEX (Mt)	EEI (Mt)	BEET (Mt)	Share in total exported emissions (%)	Share in total imported emissions (%)
ARG	1.53	2.53	7.59	10.56	-2.97	0.69	2.53
MNI	1.45	6.19	25.24	25.88	-0.64	2.29	6.19
FBT	2.89	1.96	19.00	8.17	10.83	1.73	1.96
TLF	17.76	6.05	154.17	25.28	128.89	14.00	6.05
OMI	6.72	3.29	63.64	13.76	49.88	5.78	3.29
ETW	0.17	0.04	9.61	0.16	9.45	0.87	0.04
CGP	0.85	1.93	40.66	8.08	32.59	3.69	1.93
CMI	7.03	13.32	124.28	55.64	68.65	11.28	13.32
BNM	1.35	0.73	30.11	3.07	27.04	2.73	0.73
MPM	4.93	8.41	93.44	35.15	58.29	8.48	8.41
MEM	33.75	48.18	383.78	201.29	182.49	34.84	48.18
CSI	0.34	0.30	4.14	1.24	2.91	0.38	0.30
TPT	4.69	1.08	52.79	4.53	48.27	4.79	1.08
WHC	9.33	0.01	53.45	0.06	53.39	4.85	0.01
OSI	7.20	5.96	39.52	24.89	14.62	3.59	5.96

Note: The shares in total imports volume and total imported emissions are the same due to using the average national emissions intensity of import trading partners, not trading partners' sectoral emission intensities, to calculate the imported emissions.
Source: Author's estimations.

Table 6.7: Embodied Emissions in International Trade by Sectors in 2007

	Share in total exports (%)	Share in total imports (%)	EEX (Mt)	EEI (Mt)	BEET (Mt)	Share in total exported emissions (%)	Share in total imported emissions (%)
ARG	0.70	3.15	7.93	25.93	-18.00	0.27	3.15
MNI	0.67	13.97	27.03	115.17	-88.14	0.91	13.97
FBT	2.00	2.14	30.48	17.62	12.86	1.03	2.14
TLF	14.54	1.93	324.14	15.90	308.25	10.92	1.93
OMI	6.31	3.69	155.78	30.41	125.38	5.25	3.69
ETW	0.07	0.02	9.19	0.20	8.99	0.31	0.02
CGP	0.80	1.96	78.23	16.15	62.08	2.64	1.96
CMI	7.58	12.30	335.81	101.43	234.38	11.31	12.30
BNM	1.55	0.51	76.80	4.20	72.60	2.59	0.51
MPM	9.12	6.63	406.08	54.64	351.44	13.68	6.63
MEM	42.35	45.54	1266.93	375.53	891.39	42.68	45.54
CSI	0.43	0.30	13.90	2.46	11.43	0.47	0.30
TPT	4.69	2.03	116.26	16.74	99.52	3.92	2.03
WHC	4.97	0.71	60.65	5.83	54.82	2.04	0.71
OSI	4.23	5.14	59.54	42.35	17.19	2.01	5.14

Note: The shares in total imports volume and total imported emissions are the same due to using the average national emissions intensity of import trading partners, not trading partners' sectoral emission intensities, to calculate the imported emissions.
Source: Author's estimations.

Table 6.8: Embodied Emissions in International Trade by Sector in 2007 under the EAI Assumption (Mt)

Sector	EEX	EEI	BEET
ARG	9.37	25.20	-15.84
MNI	30.09	404.19	-374.11
FBT	35.31	22.76	12.55
TLF	386.30	29.97	356.33
OMI	184.54	64.11	120.43
ETW	9.56	2.49	7.07
CGP	85.58	142.05	-56.47
CMI	397.47	501.37	-103.90
BNM	86.16	18.50	67.66
MPM	473.33	212.47	260.85
MEM	1604.81	810.37	794.44
CSI	16.47	6.90	9.57
TPT	136.99	35.99	101.00
WAC	70.61	6.08	64.53
OSI	71.94	50.19	21.76
TOTAL	**3598.52**	**2332.65**	**1265.87**

Source: Author's estimations.

Finally, in light of the rapidly increasing domestic emissions of CO_2, the State Council of China has adopted a binding goal to reduce CO_2 emission intensity by 40-45% of 2005 levels by 2020. Using the I-O table for 2007 we have recalculated China's embodied CO_2 emissions to determine how many Mt of carbon emissions will need to be reduced to achieve this goal. Not surprisingly, EDP, EDC and EEX will need to fall significantly, to 3112 Mt, 2165Mt and 1771Mt, respectively. And if we assume that the emission intensity of import trading partners does not change, the BEET falls to 947 Mt.

6.6 Conclusion

This chapter applied a single-region IO model to calculate the CO_2 emissions embodied in China's exports and imports. Based on China's recent I-O tables for 2002 and 2007, we divided the economy into 15 sectors.

The results reveal that the EHW has both the largest direct emissions intensity and embodied emissions intensity because of the coal-dominated electricity supply system. The embodied emissions intensities of CSI and MEM are much higher than their direct emissions intensities, which indicates that these sectors consume more carbon-intensive intermediate inputs from their upstream industries.

The analysis finds that international trade plays an important role in China's aggregate CO_2 emissions and sectoral emissions. During the period 2002 to 2007, China's EEX exceeded EEI, leading to a significantly positive and growing BEET, which indicates that China has a surplus of CO_2 emissions from trade. The net exported emissions were 21.7% of emissions produced in 2002, and increased to 37.9% in 2007. Given the growth of export volumes, these results are not inconsistent with Pan *et al.* (2008)'s 19% in 2001 and 30% in 2006, and Wang and Watson (2007)'s 24% in 2004. Compared with EEI, EEX increased rapidly due to China's strong growth in exports, which is higher than its growth in imports. First, the huge volume of exports promotes the expansion of China's domestic production and boosts EDP, which increased from 3152 Mt in 2002 to 5659 Mt in 2007, consistent with IEA (2011) and *China's Energy Statistical Yearbook* (2010). Our results show that the ratio of EEX to EDP increases from 35% in 2002 to 52% in 2007. This is consistent with Wang and Watson (2007) and Ma and Chen (2011)'s findings that the ratio ranges from 30% to 60% from 2000 to 2009. Second, the increase in foreign demand increases the difference between EEX and EEI, which is 2144 Mt in 2007, more than three times that of 2002. Therefore, the growth in exports has increased pressure on China to reduce its CO_2 emissions, although China can benefit from imports by avoiding some emissions.

On the sectoral basis, MEM has the largest amount of EEX, EEI and BEET in all 15 sectors, which is consistent with results found by Lin and Sun (2010) and Pan *et al.* (2008). The main reasons are that MEM is China's largest export sector, and it has relatively high embodied emission intensity. Around 70% of exported emissions come mainly from the MEM, MPM, CMI and TLF sectors, while more than 60% of imported emissions are produced by MEM, MNI, CMI, and MPM sectors. In addition, two sectors, MNI and ARG, were the carbon net-import sectors, indicating they avoided emitting domestically through international trade. Both of them were in trade deficit and mainly provided intermediate inputs to other sectors. The manufacturing and service sectors were carbon net-export sectors, which increased CO_2 emissions of China as a result of providing products to foreign countries.

Economic growth and trade liberalisation stimulate energy consumption and CO_2 emissions. Our results reveal that from 2002 to 2007, China's CO_2 emissions doubled, but by utilising the EDC approach, China would be responsible for 38% less emissions than would be the case with the EDP approach (see Figure 6.1), which indicates that current methods exaggerate China's responsibility for CO_2 emissions to a certain degree (Ma and Chen, 2011). This discrepancy is consistent with our estimate of China's BEET surplus for 2007 which was three times higher than in 2002, reflecting China's rapidly increasing scale of production, much of which is for foreign consumption.

Although China has been the largest CO_2 emitter in the world, many Chinese products are not consumed domestically, but are exported to other countries, especially the developed countries. Therefore, the developed countries should take responsibility for the emissions embodied in the products they import and consume form China. For China, care must be taken to harmonize its trade structure with environmental protection and carbon reduction, for example, encouraging exporting low-carbon goods, improving energy efficiency.

CO_2 emissions are widely associated with global warming. Chapters Five and Six examined China's CO_2 emissions by using both production-based and consumption-based approaches. Unlike CO_2 emissions, SO_2 emissions, production wastes and COD have a strong local effect. This pollution is also a by-product of products and subject to regulations. Therefore, in the next chapter we will investigate SO_2 emissions and production wastes in China.

Chapter Seven

Economic Growth and SO_2 Emissions and Production Wastes in China: A Panel Cointegration Analysis

7.1 Introduction

With continuously increasing environmental degradation, a question raised is whether countries can achieve sustainable economic growth. The answer depends on the relationship between economic growth and environmental quality degradation which is explored by the EKC literature in Chapter Two. There are mixed conclusions in the literature, and recently they have been criticised because of employing possibly unsatisfactory econometric techniques. The purpose of this chapter is to examine the relationship between economic growth, energy consumption, trade and environment in China from 1980 to 2009 by incorporating recent econometric techniques to overcome some of these difficulties.

SO_2 emissions and production wastes (wastewater, waste gas and solid waste) have been analysed as the indicators of environmental quality in this chapter. China is the world's largest emitter of SO_2, which is the most important air pollution problem in China. SO_2 and its atmospheric products have both local and regional effects on the atmospheric environment, as well as adverse effects on human health (Lu *et al.*, 2010). Khajuria *et al.* (2011) point out that production wastes are the more relevant environmental pressure indicators, because more waste means more disposal loads, more management costs and more environmental externalities.

This chapter is organised as follows: section 7.2 surveys Chinese literature; section 7.3 presents the econometric specification; section 7.4 describes the variables and data source; section 7.5 discusses the estimation procedures; section 7.6 reports the empirical results; and section 7.7 provides conclusions.

7.2 Empirical Evidence in China

The EKC hypothesis has been used to undertake systematic analysis in China in the last decade. In empirical works relating to China, parametric analysis is often adopted to examine the existence of an inverted U-shape relationship between economic growth and environmental quality. The environmental quality is usually measured by emissions of air and water pollutants.

Groot *et al.* (2004) is the first paper to investigate the EKC hypothesis for China using cross-section data. They use the standard EKC model with a sample of Chinese 30 regions in the period 1982-1997. There are three forms of pollution: emissions in absolute levels, per capita terms and per unit of Gross Regional Product terms. They find that the relationship between emissions and income depends on the type of pollutants and on how the dependent variable is constructed. Only waste gas in absolute levels is found to follow an inverted-U pattern. Solid waste in absolute levels is found to follow an N-shaped curve.

Shen (2006) uses Chinese provincial data from 1993 to 2002 to investigate the existence of an EKC relationship between per capita income and per capita pollution emissions (COD, SO_2, Dust, Arsenic, and Cadmium). Considering the simultaneity problem between income and pollution, Shen (2006) first constructs a simultaneous equations model and then employs the Hausman test to check it. The results confirm that the simultaneity between income and pollution exists in all pollutants. The 2SLS method is applied to estimate the model. Shen (2006) finds that the inverted U-shape curve exists in COD, Arsenic, and Cadmium emissions with the turning points of 6,547 yuan, 13,879 yuan and 7,500 yuan, respectively; meanwhile, SO_2 shows a U-shaped curve and Dust indicates no relationship with income.

Based on Chinese provincial panel data in the period 1992-2003, He (2008) uses both reduced and structural models[84] to test the validity of the EKC hypothesis for industrial SO_2 emissions. The result of the reduced model shows that the EKC curve exists between Chinese per capita industrial SO_2 emissions and income with the turning point of 10,000 yuan. However, after adding a population variable, the coefficient of income square is not significant.

Cointegration analysis is also found in the case of China. Jalil and Mahmud (2009) investigate the long-run relationship between CO_2 emissions, income, energy consumption, and foreign trade in China, using time series data from 1975 to 2005. A recent single cointegration approach, autoregressive distributed lag (ARDL), reports a quadratic relationship between income and CO_2 emissions, with the turning point of 12,992 yuan, which supports the EKC hypothesis. Furthermore, Granger causality tests indicate one-way causality running from economic growth to CO_2 emissions. Their results also show that income and energy consumption are the main determinants of CO_2 emissions while trade has no significantly impact in the long run.

Applying the bounds testing approach and the ARDL methodology, Jayanthakumaran *et al.* (2012) examine the long- and short-run relationship between growth, trade, energy

[84] In the structural model, pollution determinants are first identified as scale, composition, and technique effects; and then include the trade effect. The estimated results reveal industrial scale enlargement has a pollution-increasing role, while the technical progress and composition effects appear to have pollution-decreasing roles.

use and endogenously determined structural breaks. Their results are similar to Jalil and Mahmud (2009), suggesting that China's CO_2 emissions are mainly determined by per capita income, structural changes and energy consumption.

7.3 Econometric Specification

In this chapter we explore the EKC hypothesis by incorporating a balanced panel from 29 Chinese provinces from 1980 to 2009. According to the standard EKC model, the logarithm of the environmental quality indicator is modelled as a quadratic function of the logarithm of income. It is required to provide a strict and careful examination in econometrics, because a long-run relationship between per capita income and emissions is posited by the EKC hypothesis. Before checking the shape of any empirical EKC, investigating the stationarity of the variables is necessary. If a trending behaviour is exhibited among variables, the variables are non-stationary. In addition, the variables can be integrated with a given order, if the trend is stochastic. If integrated variables are added in a regression model, the significance tests are not reliable, because the presence of stochastic trends may change the distribution of the tests towards an unknown direction and yield spurious results. Therefore, before checking the existence of an EKC, the first step should be verifying whether the underlying regression equation is spurious (Galeotti *et al.*, 2006).

Recently, there have been a few papers taking into account non-stationarity when investigating the relationship between per capita emissions and income. However, most of them have been cross-country studies (for example, Perman and Stern, 2003; Galeotti *et al.*, 2006; Narayan and Narayan, 2010; Jaunky, 2011. See details in Chapter Two). Besides cross-country studies, single-country empirical studies are more reliable and have recently become more common, but usually adopt time series data regressions (for example, Liu, 2006; Soytas *et al.*, 2007; Soyas and Sari, 2009; Halicioglu, 2009). Although increasing studies have been undertaken in China using cross-province panel data (for example, Groot *et al.*, 2004; Shen, 2006; He, 2008), only two studies, Jalil and Mahmud (2009) and Jayanthakumaran *et al.* (2012), are found to take non-stationarity of the variables into account, based on country-level time series data.

The country-specific panel data approach is appropriate in this study for the following reasons. First, according to Vincent (1997) and Stern (2004), the cross-country version of the EKC could be a misleading, statistical artefact, whereas examining the individual country should be more valuable. Second, using disaggregated data provides additional degrees of freedom and permits the inclusion of controls for regional heterogeneity (Freeman, 2003). This chapter focuses on a panel of 29 Chinese provinces observed over the period 1980-2009. Because there are some differences among Chinese provinces, cross-provincial panel data can provide more information, and the sample is more homogeneous in political freedom, legal institutions, cultural norms and corruption compared to cross-country data.

In order to examine the validity of the EKC hypothesis, a quadratic equation is specified to test the long-run relationship between emissions, foreign trade, economic growth and energy consumption. The estimated equation for this chapter is as follows:

$$E_{it} = \alpha_i + \mu_t + \overset{+}{\beta_1} Y_{it} + \overset{-}{\beta_2} Y_{it}^2 + \overset{+/-}{\beta_3} open_{it} + \overset{+}{\beta_4} energy_{it} + \varepsilon_{it} \quad (7.1)$$

where subscript i refers to provinces, and t refers to the sample year, 1980 to 2009. The dependent variable, E, is one of the pollutants measured in terms of per capita emissions (SO_2 and production wastes). The independent variables are real GDP per capita (Y), foreign trade ($open$) which is measured as the ratio of exports plus imports to GDP, and *energy* indicates per capita energy consumption. α_i is the provincial specific intercept, time dummy, μ_t, represents the time-specific effect, β_i is the regression coefficient and ε_{it} is the error term. The expected sign of each coefficient is discussed in Section 7.4.

7.4 Description of Data and Variables

The purpose of this chapter is to answer the question: what is the long-run relationship between production wastes and SO_2 emissions and economic growth in China? The method was to gather a panel sample of as many time series as possible for the chosen explanatory variables[85]. The sample is unfortunately restricted by lack of data to 30 years from 1980 to 2009 through 29 Chinese provinces[86]. The data contain a balanced panel. Our main sources of data are the *Comprehensive Statistical Data and Materials on 60 Years of New China* (2009), *China Statistical Yearbook* (2010) and *China Environmental Statistical Yearbook* (various issues).

As already noted, the dependent variable is the emission of production wastes and SO_2 which is the proxy for environmental quality, while the explanatory variables are income, trade openness and energy consumption.

[85] Levin *et al.* (2002)-test is appropriate for moderate-sized panels with N between 10 and 250, and T between 25 and 250.

[86] We selected 29 of the 31 provinces and municipalities directly under the administration of the central government in mainland China: Beijing, Tianjing, Hebei, Shanxi, Inner Mongolia, Liaoning, Heilongjiang, Shanghai, Jiangsu, Zhajiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. Chongqing and Tibet are excluded from our sample for two reasons: (1) Chongqing was a part of Sichuan province, and was upgraded to a municipality in 1996. The relevant data for Chongqing are added to those for Sichuan province for consistency. (2) Data for Tibet are not available in most years.

Gross Domestic Production per capita (Y)

GDP is the market value of all final goods and services produced in an economy, which is the most widely used measure of an economy's success. The growth rate of GDP is in focus because it indicates an economy's performance. By contrast, GDP per capita is a more useful measure when comparing the economic situation across regions, which will be the main focus of this study.

According to the EKC hypothesis, economic development results in an increase in pollution initially (positive sign of GDP per capita) and thereafter a decrease after reaching a certain level of economic progress (negative sign of square of GDP per capita). In the early stage of development, economic growth is the key objective, and then more inputs are used which results in more pollution (scale effect); while as incomes rise, people increase their demand for a clean environment and then impose higher pollution penalties and shift towards clean production processes to reduce emissions (technique effect).

To calculate the real GDP per capita, we convert the current values of provincial GDP into constant values at 1980 prices, firstly using the provincial consumer price index (1980=100), and then convert the constant GDP values into per capita values using provincial population at the end of the year.

Trade openness (open)

A high degree of openness implies that regions have more economic activities. Although the concept of trade openness is simple in theory, there is no widely accepted way to measure it. Generally, there are three types of measures of openness in the literature. Based on trade restrictions/distortions, some papers use average tariff, average of quantitative barriers, and frequency of non-tariff barriers (for example, Pritchett, 1996; Harrison, 1996; Edwards, 1998; Yanikkaya, 2003). However, Pritchett (1996) argues that these measures are imperfect, because partial measures of the overall restrictions/distortions are induced by trade policies, and data do not provide information on how binding barriers to trade are, and exclude less-easily quantifiable barriers to trade. Sachs and Warner (1995) and Wacziang and Welch (2003) have proposed various 'qualitative' indices allowing for classifying countries according to their trade and global policy regime. The drawback of these indices is that they only provide a very rough classification of countries (from rather closed to rather open). Both of these two measures are used in cross-country studies, and the data are only available for a few countries and years.

The third measure is based on trade volumes, which is widely used in empirical studies and related to the global definition of trade openness. The most popular one is the trade dependency ratios (e.g. Frankel and Romer, 1999; Irwin and Tervio, 2002; Frankel and Rose, 2002; Dollar and Kraay, 2004). The main advantage is that the data required are available for all countries and provinces, and over a long period. Therefore, in our study, we adopt the most common measure of trade openness as,

$$open_{it} = \frac{\exp ort_{it} + import_{it}}{GDP_{it}}; i = province, t = year \qquad (7.2)$$

In theory, the impact of trade openness on the environment is not clear. The expected sign can be either positive or negative depending on whether China has a comparative advantage in pollution-intensive goods (composition effect). The sign is negative if China has a comparative advantage in the production of less pollution-intensive industries. Then the composition of its output will become cleaner after trade. On the other hand, trade may result in China specialising in pollution-intensive goods. Hence, the positive sign is also possible.

Energy consumption per capita (energy)

Total energy consumption includes consumption of coal, oil, gas and hydro-electricity. In order to meet the demands for energy, all economies are believed to rely on fossil fuels continuously. No country is able to decouple its energy industries from combusting fossil fuels which generate emissions. Therefore, we expect a positive relationship between per capita energy consumption and emissions.

7.5 Estimation Procedures

In trying to establish the long-run relationship between the variables of equation (7.1), we use annual data from 29 Chinese provinces and cover the period 1980-2009. Since the model uses panel data, in order to avoid spurious results, obviously we must 1) establish the integrating properties of each variable using panel unit root tests; 2) test the cointegrating properties of the relationship between all variables using panel cointegration tests, if a long-run relationship holds; 3) estimate equation (7.1) by using a suitable method; and then, 4) examine the dynamic causal relationship between the variables. In this section, the methods used in this chapter will be introduced.

7.5.1 Panel Unit Root Tests

Examining whether the variables in equation (7.1) contain a panel unit root is the first step. To avoid spurious correlations, the estimation of the regression equation (7.1) requires the data to be stationary. When dealing with panel data, because the procedure is more complex, the Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests can result in inconsistent estimators. Hence, the stationarity of the series should be tested by using different types of tests. While there are a number of panel unit root tests, in this chapter we use the panel unit root test proposed by Levin *et al.* (2002) (*LLC-test*), Im *et al.* (2003) (*IPS-test*), Breitung (2000) (*Breitung-test*) and Pesaran (2007) *(CIPS-test)*. The reason for heterogeneity and autocorrelation is the existence of different time trends and intercepts for individuals in panel. However, the first-generation unit roots tests, the LLC, IPS, and Breitung tests, disregard cross-sectional dependency, while the second-generation unit root test, the CIPS test, takes into account the possibility of cross-sectional dependency. Moreover, since each panel unit root test has its statistical shortcomings, in terms of size and power properties, it is better to use different tests to generate an overwhelming body of evidence to determine the order of integration of the data.

LLC-test

The LLC-test tests the null hypothesis that each individual series contains a unit root when $\rho_i = 0$ against the alternative hypothesis that each individual series is stationary when $\rho_i < 0$:

$$H_0 : \rho_1 = \rho_2 = ... = \rho_N = 0$$

$$H_1 : \rho_1 = \rho_2 = ... = \rho_N < 0$$

Including the individual intercepts and trends, the LLC-test is based on the following models:

$$\vartriangle y_{it} = \delta y_{i,t-1} + \sum_{L=1}^{pi} \theta_{iL} \vartriangle y_{i,t-L} + \alpha_{0i} + \varepsilon_{it} \tag{7.3}$$

$$\triangle y_{it} = \delta y_{i,t-1} + \sum_{L=1}^{pi} \theta_{iL} \triangle y_{i,t-L} + \alpha_{0i} + \alpha_{1i} t + \varepsilon_{it} \tag{7.4}$$

where t = 1, 2, …, T is the sample period and i = 1, 2, …, N indexes the province. Equation (7.3) with the individual effects (α_i) only and, equation (7.4) with a time trend ($\alpha_{1i} t$) as well as individual effects are estimated using pooled OLS. The term $\sum_{L=1}^{pi} \theta_{iL} \triangle y_{i,t-L}$, containing lagged dependent variables, is included to make the error term asymptotically white noise. The parameter δ is equal to $\rho - 1$ and assumed to be constant across the cross-sectional units for each of these models. The error term ε_{it} is distributed independently across cross-sectional provinces.

Levin *et al.* (2002) recommend applying this test to panels with a time dimension between 25 and 250 and cross-section dimension between 10 and 250. However, there are some restrictive aspects of the LLC-test. First, it tests the null that all series have a unit root, and rejection indicates that all series are stationary. Second, the parameters ρ are assumed to be homogeneous across sections. To overcome these disadvantages Im *et al.* (2003) (*IPS-test*) proposed a test based on averaging the individual ADF statistics.

IPS-test

The IPS-test tests the null hypothesis that all series have a unit root against the alternative hypothesis that some of the series are stationary, but possibly not all. That means, the null is the same as the LLC-test; however, under the alternative, the parameter ρ is allowed to be different across units. The two hypotheses of the *IPS*-test are expressed as:

$$H_0 : \rho_i = 0, \text{ for all } i$$

$$H_1 : \begin{cases} \rho_i < 0 & for \ i = 1,...,N_1 \\ \rho_i = 0 & for \ i = N_1+1,...,N \end{cases} \text{ with } 0 < N_1 \leq N$$

The IPS-test is conducted using the following models:

$$\triangle y_{it} = \delta_i y_{i,t-1} + \sum_{L=1}^{pi} \theta_{iL} \triangle y_{i,t-L} + \alpha_{0i} + \varepsilon_{it} \tag{7.5}$$

$$\triangle y_{it} = \delta_i y_{i,t-1} + \sum_{L=1}^{pi} \theta_{iL} \triangle y_{i,t-L} + \alpha_{0i} + \alpha_{1i} t + \varepsilon_{it} \tag{7.6}$$

Here, the parameters δ are individual specific as opposed to the LLC-test. The *IPS* test deals with a unit root test for *N* cross-sectional units and defines the *t*-bar statistic as a simple average of the individual ADF *t*-statistics for each time series. The standardised *t-bar* statistic is calculated as:

$$t - bar = \sqrt{N}(t_\alpha - k_t) / \sqrt{v_t} \tag{7.7}$$

where *N* is the size of the panel and t_α is the average of the individual ADF *t*-statistics for each of the provinces with and without a trend. The parameters k_t and v_t are estimates of the mean and variance of each provinces $t_{\alpha i}$.

Breitung-test

Both the IPS-test and LLC-test have the disadvantage of requiring T (time dimension) to be large relative to N (cross-section dimension). Besides, they are sensitive to the specification of the deterministic trend being individual-specific or not. Breitung (2000) argues that the IPS-test and LLC-test have size distortions as N/T increases, that is, they reject the null hypothesis too often. Furthermore, there is a substantial loss of power if individual deterministic trends are included. The Breitung-test is free of these criticisms.

The remaining features and the hypothesis are the same as in the LLC-test, which assumes a common unit root process among the series.

Pesaran CIPS-test

As the second-generation unit root test, the CIPS-test is different from the previous tests because it is based on the assumption of cross–sectional dependency. The hypotheses of the CIPS-test are given by:

H_0: $\rho_i = 0$ for all i, which means that the series of all provinces contain a unit root

H_1: $\rho_i < 0$, one or more provinces reject the unit root

The CIPS-test is based on a regression:

$$\triangle y_{it} = \rho y_{i,t-1} + \eta_i t + \alpha_i + \delta_i \theta_t + \varepsilon_{it} \tag{7.8}$$

where α_is indicate the individual constants, $\eta_i t$ denotes the individual time trends, θ_t is the common time effect, whose coefficients, δ_i, are assumed to be non-stochastic and they measure the impact of common time effect on series i, $\varepsilon_{it} \sim i.i.d.N(0,\sigma^2)$ over t, and ε_{it} is independent of ε_{js} and θ_s for all $i \neq j$ and s,t.

Cross-sectional dependence is allowed through the common time effects which are proxied by the cross-section mean of y_{it} and its lagged values. Pesaran (2007) suggests modified IPS statistics (CIPS) based on the average of individual cross-sectionally augmented ADF (ACDF), which can be estimated from:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} t_i(N,T) \tag{7.9}$$

where $t_i(N,T)$ is the t-statistic of the OLS estimate of ρ in equation (7.8).

7.5.2 Panel Cointegration Tests

Checking whether there is a long-run relationship among variables is the second step using panel cointegration tests, if panel unit root tests show that the series are non-stationary and have the same integration order. The literature on panel cointegration tests is relatively new, going back only to the end of the 1990s (for example, Pedroni, 1999 and 2004; and McCoskey and Kao, 1998). Generally, the panel cointegration tests can be divided into two groups. One is the residual-based test with a null hypothesis of no cointegration. An example of this group is Pedroni (1999, 2004). The other group is the error-correction-based test proposed by Westerlund (2007) and Persyn and Westerlund (2008), with the null hypothesis that the error-correction term in a conditional error-correct model is equal to zero. In this chapter, both the residual-based and error-correction-based approaches, namely Pedroni (1999, 2004) tests and Westerlund (2007) tests, will be applied to validate the existence of a long-run relationship for panel data.

Pedroni (1999, 2004)-tests

Extending the Engle-Granger framework, Pedroni (1999, 2004) proposes seven tests for cointegration that allowed for heterogeneous intercepts and trend coefficients across cross-section. The model is considered as follows:

$$y_{it} = \alpha_i + \delta_i t + \beta_{1i} x_{1it} + ... + \beta_{Ki} x_{Kit} + e_{it} \tag{7.10}$$

where there are K regressors, which are allowed to be endogenous. The parameter α_i allows for the possibility of province-specific fixed effects and β_i allows for variation across individual provinces. $e_{it} = \rho_i e_{i,t-1} + \varepsilon_{it}$ is the disturbance from the panel regressions and, ρ_i represents the autoregressive coefficient of the residuals in province i.

The seven different tests[87] can be divided into two groups. The four test statistics (panel $\nu - statistic$, panel $\rho - statistic$, panel PP-statistic and panel ADF-statistic) in the first group, the panel cointegration statistics, are based on pooling along the within-dimension. The null hypothesis of no cointegration is as follows:

$H_0 : \rho_i = 1$ for all i, against the alternative hypothesis is

$H_1 : \rho_i = \rho < 1$ for all i, hence under the alternative hypothesis, the within-dimensional estimation assumes a common value for $\rho_i = \rho$.

The three test statistics (group $\rho - statistic$, group PP-statistic and group ADF-statistic) in the second group, the group mean cointegration statistics, are based on pooling along the between-dimension. These tests allow for heterogeneity across provinces. Therefore, the null hypothesis of no cointegration is the same as the first group, while the alternative hypothesis is less restrictive. The two hypotheses are expressed:

$H_0 : \rho_i = 1$ for all i,

$H_1 : \rho_i < 1$ for all i.

[87] PP and ADF statistics are parametric and non-parametric tests.

The seven statistics are shown below:

$$\text{Panel } \nu - statistic: \; Z_{\nu} = \left(\sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2} \right)^{-1} \tag{7.11}$$

$$\text{Panel } \rho - statistic: Z_{\nu} = \left(\sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2} \right)^{-1} \sum_{i=1}^{N} \sum_{i=1}^{T} L_{11i}^{-2} (\hat{e}_{i,t-1} \triangle \hat{e}_{it} - \hat{\lambda}_{i}) \tag{7.12}$$

$$\text{Panel PP-statistic: } Z_{\nu} = \left(\hat{\sigma} \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2} \right)^{-1/2} \sum_{i=1}^{N} \sum_{i=1}^{T} L_{11i}^{-2} (\hat{e}_{i,t-1} \triangle \hat{e}_{it} - \hat{\lambda}_{i}) \tag{7.13}$$

$$\text{Panel ADF-statistic: } Z_{t}^{*} = \left(\hat{S}^{*2} \sum_{i=1}^{N} \sum_{i=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{*2} \right)^{-1/2} \sum_{i=1}^{N} \sum_{i=1}^{T} L_{11i}^{-2} \hat{e}_{i,t-1}^{*} \triangle \hat{e}_{it}^{*} \tag{7.14}$$

$$\text{Group } \rho - statistic: \; \tilde{Z}_{\rho} = \sum_{i=1}^{N} \left(\sum_{i=1}^{T} \hat{e}_{i,t-1}^{2} \right)^{-1} \sum_{i=1}^{T} \left(\hat{e}_{i,t-1} \triangle \hat{e}_{it} - \hat{\lambda}_{i} \right) \tag{7.15}$$

$$\text{Group PP-statistic: } \tilde{Z}_{t} = \sum_{i=1}^{N} \left(\hat{\sigma}^{2} \sum_{i=1}^{T} \hat{e}_{i,t-1}^{2} \right)^{-1/2} \sum_{i=1}^{T} \left(\hat{e}_{i,t-1} \triangle \hat{e}_{it} - \hat{\lambda}_{i} \right) \tag{7.16}$$

$$\text{Group ADF-statistic: } \tilde{Z}_{\rho}^{*} = \sum_{i=1}^{N} \left(\sum_{i=1}^{T} \hat{S}_{i}^{2} \hat{e}_{i,t-1}^{*2} \right)^{-1/2} \sum_{i=1}^{T} \left(\hat{e}_{i,t-1}^{*} \triangle \hat{e}_{it}^{*} \right) \tag{7.17}$$

The distributions of these seven test statistics are standardised normal since they can be rescaled. For the panel $\nu - statistic$, the large positive values indicate rejection of the null of no cointegration; while for the six remaining statistics, the large negative values indicate rejection of the null. The critical values are reported by Pedroni (1999). Pedroni (2004, p.619) points out that "*these tests allow for heterogeneous short-run dynamics, heterogeneous fixed effects and deterministic trends as well as individual specific slope coefficients*". Harris and Sollis (2003) point out that different tests may generate different conclusions. In practice it is not easy to choose which test is more appropriate.

They argue that the strength of the group mean tests is that they are less restrictive; non-parametric tests are the best way to correct for autocorrelation but have poor size properties and tend to over-reject the null when it is true; and the ADF-type tests have better power if the errors follow an autoregressive process.

According to Kremers *et al.* (1992), the assumption of "common factor restriction"[88] is the reason that causes the lack of power of residual-based tests to reject the null hypothesis of no cointegration even in cases in which cointegration is strongly suggested by the theory. In order to avoid the limitations of the residual-based tests, Westerlund (2007) proposes the error-correction-based tests.

Westerlund (2007)-tests

Westerlund (2007) proposes four error-correction-based panel tests with the null hypothesis of no cointegration. The tests are based on the estimation of the following error correction equation:

$$\Delta y_{it} = \delta_i' d_t + \alpha_i (y_{i,t-1} - \beta_i' x_{i,t-1}) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{p_i} \gamma_{ij} \Delta x_{i,t-j} + e_{it} \qquad (7.18)$$

where Δ is the first difference operator, y denotes the dependent variable, and x represents a vector of independent variables. $d_t = (1,t)'$ indicates the set of deterministic components, which means Δy_{it} is yielded with both a constant and a trend. The coefficient β_i indicates the cointegration coefficient between dependent variable and independent variables. The parameters α_{ij} are the corresponding short-run adjustment

[88] The assumption of common factor restriction refers to the fact that "*the long-run cointegrating vector for the variables in their levels is equal to the short-run adjustment process for the variables in their differences*" (Westerlund, 2007, p.710).

coefficients of $\triangle y_{it}$. The linear combination $(y_{i,t-1} - \beta_i^{'} x_{i,t-1})$ is by assumption stationary. The key parameter in equation (7.18) is α_i which determines how fast the system corrects back to the equilibrium relationship after a sudden shock. A significantly negative α_i indicates that there is error-correction and y_{it} and x_{it} are cointegrated. Alternatively, if $\alpha_i = 0$, there is no error-correction, suggesting no cointegration.

The four statistics offered by Westerlund (2007) can be divided into two groups. Two of them, G_τ and G_α, are referred to as group-mean statistics:

$$G_\tau = \frac{1}{N}\sum_{j=i}^{N}\frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \tag{7.19}$$

$$G_\alpha = \frac{1}{N}\sum_{i=1}^{N}\frac{T\hat{\alpha}_i}{\hat{\alpha}_i(1)} \tag{7.20}$$

The null and alternative hypotheses are formulated as:

$H_0 : \alpha_i = 0$ for all i

$H_1 : \alpha_i < 0$ for at least one i, suggesting that if evidence of cointegration is found for at least one of the cross-sectional units, the null hypothesis should be rejected.

The second group of statistics is the panel statistics (P_τ and P_α):

$$P_\tau = \frac{\hat{\alpha}}{SE(\hat{\alpha})} \tag{7.21}$$

$$P_\alpha = T\alpha \tag{7.22}$$

The null hypothesis remains the same,

$H_0 : \alpha_i = 0$ for all i, versus

$H_1 : \alpha_i < 0$ for all i, suggesting that if evidence of cointegration is found for the panel as a whole, the null hypothesis should be rejected.

Westerlund (2007, p.737) concludes that "*the four tests are able to accommodate individual-specific short-run dynamics, including serially correlated error terms and non-strictly exogenous regressors, individual-specific intercept and trend terms*". Therefore, if weak exogeneity is satisfied, there are several advantages in Westerlund (2007)-tests. Firstly, the tests have greater power over the residual-based tests (such as Pedroni-tests and Kao-tests); secondly, the tests allow for heterogeneity across the individual units of the panel; and thirdly, the tests account for cross-sectional dependency.

In the case of panel statistics, autoregressive order is the same for all cross-sections. If the null hypothesis is rejected the parameter is less than one in absolute value and variables of concentration are cointegrated for all panel members. In the case of group statistics, autoregressive order is allowed to vary over cross-section and the test statistics are the mean of individual statistics. If the null hypothesis is rejected, cointegration holds for at least one individual. Group mean test allow the source of heterogeneity among the panel members (Dreger and Reimers, 2006).

7.5.3 Panel Cointegration Estimation

The main point is that panel cointegration tests do not provide the estimates. For the long-run relationship, the cointegration vector is nearly common for all panel members. In fact, the ordinary least squares (OLS) method requires that the regressors are exogenous. Generally, a biased result is yielded by using OLS to estimate the long-run equation. Therefore, Kao and Chiang (2000) argue that the OLS estimators cannot be used for valid inference. A fully modified ordinary least square (FMOLS) estimation is proposed by Pedroni (2000), as an alternative method of panel cointegration estimation, which is asymptotically efficient and allows for serial correlation and endogeneity of regressors in the cointegration equation. Therefore, the FMOLS will be applied in this chapter.

FMOLS was developed by Pedroni (2000) to estimate and test hypotheses for cointegrating vectors in dynamic panels. The FMOLS estimator involves a two-step procedure. In the first step, the long-run covariance is estimated on the basis of the OLS-regression estimates and subsequently the OLS estimator is corrected by factors derived in the first step. The following panel system is considered:

$$\begin{cases} y_{it} = \alpha_i + \beta x_{it} + \mu_{it} \\ x_{it} = x_{i,t-1} + \varepsilon_{it} \end{cases} \quad i = 1,...,N \tag{7.23}$$

Vector error process $\xi_{it} = [\mu_{it}, \varepsilon_{it}]^T$ is stationary, which is equivalent to cointegration of the analysed variables, and has a covariance matrix denoted by $\Omega_i = \begin{bmatrix} \Omega_\mu & \Omega_{\mu\varepsilon} \\ \Omega_{\varepsilon\mu} & \Omega_\varepsilon \end{bmatrix}$. The FMOLS estimator is given by:

$$\hat{\beta}_{FMOLS} = \frac{1}{N}\sum_{i=1}^{N}(\sum_{t=1}^{T}(x_{it} - \overline{x}_i)^2)^{-1}(\sum_{t=1}^{T}(x_{it} - \overline{x})y_{it}^* - T\hat{\gamma}_i) \tag{7.24}$$

where y_{it}^* is the transformed endogenous variable and $T\hat{\gamma}_i$ is the adjustment term in the presence of a constant.

The null and alternative hypotheses can be formulated as:

$$H_0 : \beta_i = \beta_0 \text{ for all } i$$

$$H_1 : \beta_i \neq \beta_0 \text{ for all } i$$

Comparing the pooled FMOLS estimator with the group mean FMOLS estimator, Pedroni (2000) suggests that the t-statistic for the latter estimator allows for a more flexible alternative hypothesis, which is an advantage of the group mean estimator. Because the group mean estimator depends on the between-dimension of the panel, it permits heterogeneity of the cointegrating vectors, which means it can provide a common cointegrating vector under the null hyppthesis; while the pooled estimator does not, as it is based on the within dimension of the panel.

7.5.4 Panel Causality Test

The presence of a long-run cointegration relationship reveals that a causal relationship may exist between the variables, but it does not explain the direction of the causal relationship between them (Granger, 1988). Therefore, in order to analyse the direction of causality, the two-step Granger causality procedure, using a panel-based Vector Error Correction Model (VECM), should be performed (Engle and Granger, 1987). The first step is to estimate the long-run parameters in equation (7.1) in order to obtain the estimated residuals, which can be done in section 7.4.3; and the second step is to build a Granger causality model by using these residuals lagged one period as the error correction term. The Granger causality model can be specified as follows:

$$\triangle LnE_{it} = \pi_{1i} + \sum_p \pi_{11ip} \triangle LnE_{it-p} + \sum_p \pi_{12ip} \triangle LnY_{it-p} + \sum_p \pi_{13ip} \triangle LnY^2_{it-p} + \sum_p \pi_{14ip} \triangle Lnenergy_{it-p} + \sum_p \pi_{15ip} \triangle Lnopen_{it-p} + \psi_{1i} ECT_{it-1} + \varepsilon_{1it} \quad (7.25)$$

$$\triangle LnY_{it} = \pi_{2i} + \sum_p \pi_{21ip} \triangle LnE_{it-p} + \sum_p \pi_{22ip} \triangle LnY_{it-p} + \sum_p \pi_{23ip} \triangle LnY^2_{it-p} + \sum_p \pi_{24ip} \triangle Lnenergy_{it-p} + \sum_p \pi_{25ip} \triangle Lnopen_{it-p} + \psi_{2i} ECT_{it-1} + \varepsilon_{2it} \quad (7.26)$$

$$\triangle LnY^2_{it} = \pi_{3i} + \sum_p \pi_{31ip} \triangle LnE_{it-p} + \sum_p \pi_{32ip} \triangle LnY_{it-p} + \sum_p \pi_{33ip} \triangle LnY^2_{it-p} + \sum_p \pi_{34ip} \triangle Lnenergy_{it-p} + \sum_p \pi_{35ip} \triangle Lnopen_{it-p} + \psi_{3i} ECT_{it-1} + \varepsilon_{3it} \quad (7.27)$$

$$\triangle Lnenergy_{it} = \pi_{4i} + \sum_p \pi_{41ip} \triangle LnE_{it-p} + \sum_p \pi_{42ip} \triangle LnY_{it-p} + \sum_p \pi_{43ip} \triangle LnY^2_{it-p} + \sum_p \pi_{44ip} \triangle Lnenergy_{it-p} + \sum_p \pi_{45ip} \triangle Lnopen_{it-p} + \psi_{4i} ECT_{it-1} + \varepsilon_{4it} \quad (7.28)$$

$$\triangle Lnopen_{it} = \pi_{5i} + \sum_p \pi_{51ip} \triangle LnE_{it-p} + \sum_p \pi_{52ip} \triangle LnY_{it-p} + \sum_p \pi_{53ip} \triangle LnY^2_{it-p} + \sum_p \pi_{54ip} \triangle Lnenergy_{it-p} + \sum_p \pi_{55ip} \triangle Lnopen_{it-p} + \psi_{5i} ECT_{it-1} + \varepsilon_{5it} \quad (7.29)$$

where $\triangle$ denotes the first difference of the variable; i and t indicate the province and time period, respectively; p is the lag length determined automatically by the Schwarz Information Criterion (SIC); ECT is the lagged error correction term derived from the long-run cointegrating relationship; the term ψ is the adjustment coefficient and ε is the disturbance term assumed to be uncorrelated with zero means.

The Wald F-test is applied to examine the direction of any causality relationship among the variables. The short-run causality runs from ΔLnY and ΔLnY^2 to ΔLnE ($\Delta Lnenergy$ or $\Delta Lnopen$), if the joint null hypothesis $\pi_{12ip} = \pi_{13ip} = 0\forall_{ip}$ ($\pi_{42ip} = \pi_{43ip} = 0\forall_{ip}$ or $\pi_{52ip} = \pi_{53ip} = 0\forall_{ip}$) is rejected. The presence of two variables measuring economic growth (ΔLnY and ΔLnY^2) requires cross-equation restrictions to determine the causality from ΔLnE ($\Delta Lnenergy$ or $\Delta Lnopen$) to economic growth. Therefore, the short-run causality from ΔLnE ($\Delta Lnenergy$ or $\Delta Lnopen$) to ΔLnY and ΔLnY^2 is supported if the null hypothesis $\pi_{21ip} = 0\forall_{ip}\ and\ \pi_{31ip} = 0\forall_{ip}\ (\pi_{24ip} = 0\forall_{ip}\ and\ \pi_{34ip} = 0\forall_{ip};\ or\ \pi_{25ip} = 0\forall_{ip}\ and\ \pi_{35ip} = 0\forall_{ip})$ is rejected. However, for the long-run causality, we test the coefficient of the error correction term. For example, if the null hypothesis $\psi_{1i} = 0\forall_i\ (\psi_{4i} = 0\forall_i\ or\ \psi_{5i} = 0\forall_i)$ is rejected, the ΔLnE ($\Delta Lnenergy$ or $\Delta Lnopen$) responds to deviations from the long-run equilibrium; while if the null hypothesis $\psi_{2i} = \psi_{3i} = 0\forall_i$ is rejected, the ΔLnY and ΔLnY^2 jointly respond to deviations from long-run equilibrium.

7.6 Estimated Results

Our estimation procedure is based on the empirical model discussed in section 7.3. As we defined that, the objective of this chapter is to test the long- and short-run relationship between emissions, economic growth and trade liberalisation. We will use panel cointegration estimation to analyse our results. We have sorted out the results in three steps: 1) we will analyse the stationarity of the series by using panel unit root tests; 2) we will see whether the series are cointegration by using panel cointegration tests; 3) we will estimate the cointegration relations; and 4) we will examine the causality relationship between variables.

7.6.1 Stationarity of the Series

Results of the First Generation Panel Unit Root Test

We start with the test suggested by LLC (Levin *et al.*, 2002) and Breitung t-stat (Breitung, 2000) on the common unit root (each individual series is stationary). And then we also use IPS (Im *et al.*, 2003) on the individual unit root (some of the individual series are stationary). All the tests are carried out by using E-Views 7 software. The optimal lag length is automatically selected using the Akaike Information Criterion (AIC). Table 7.1 represents the results of the unit root in panel data.

From Table 7.1 we can see that for level of the series most of the p-values show insignificant results when we have individual intercept only or both intercept and trend. This implies that all of the series are non-stationary at level. When we have taken the first difference the null hypothesis is strongly rejected for all tests at the 1% level; according to this all of the series are I(1). The LLC test performs well when we have both individual intercept and linear trend. When we have only individual intercept, the LLC test shows some of the series are stationary at level, such as Lnopen (t-values is -2.0490). This can be considered as the drawback of LLC test. When we have both intercept and trend, similar results are found for the Breitung t-stat (the t-value of Lnopen is -3.2710). However, this problem is solved by the IPS test, which shows that some of the individual series are stationary at first difference for both intercept, and intercept and trend

Table 7.1: First Generation Panel Unit Root Tests Results

Test Variable	LLC		IPS		Breitung t-stat.	
	Level	1st Difference	Level	1st Difference	Level	1st Difference
Only Individual Intercept						
Lnww	2.3666 (0.9910)	-19.3007*** (0.0000)	3.0566 (0.9989)	-19.4540*** (0.0000)	NA	NA
Lnwg	6.7992 (1.0000)	-10.6777*** (0.0000)	12.2458 (1.0000)	-14.1678*** (0.0000)	NA	NA
Lnsw	3.5187 (0.9998)	-19.1688*** (0.0000)	6.8179 (1.0000)	-20.0763*** (0.0000)	NA	NA
$LnSO_2$	-0.9603 (0.1684)	-19.3675*** (0.0000)	-1.5899 (0.0559)	-19.4962*** (0.0000)	NA	NA
LnY	-0.1045 (0.4584)	-11.2488*** (0.0000)	6.2490 (1.0000)	-9.8812*** (0.0000)	NA	NA
LnY^2	2.2568 (0.9880)	-10.6368*** (0.0000)	8.3424 (1.0000)	-9.4601*** (0.0000)	NA	NA
Lnopen	-2.0490** (0.0202)	-17.1717*** (0.0000)	-0.5268 (0.2853)	-12.1457*** (0.000)	NA	NA
Lnenergy	5.6825 (1.0000)	-9.8307*** (0.0000)	10.9217 (1.0000)	-13.0678*** (0.0000)	NA	NA
Individual Intercept and Individual Linear Trend						
Lnww	-0.5653 (0.2859)	-17.1188*** (0.0000)	-0.1524 (0.4394)	-17.2391*** (0.0000)	0.9347 (0.8250)	-11.0141*** (0.0000)
Lnwg	0.7447 (0.7718)	-7.4768*** (0.0000)	0.6553 (0.7438)	-13.0925*** (0.0000)	3.1011 (0.9990)	1.7169 (0.9570)
Lnsw	2.8160 (0.9967)	-17.3611*** (0.0000)	-0.6580 (0.2857)	-20.3316*** (0.0000)	2.6529 (0.9960)	-9.9130*** (0.0000)
$LnSO_2$	-0.3511 (0.3627)	-17.4875*** (0.0000)	-0.4293 (0.3124)	-18.6371*** (0.0000)	-0.1980 (0.4215)	-14.1131*** (0.0000)
LnY	-0.91103 (0.1811)	-9.3896*** (0.0000)	1.0342 (0.8487)	-6.7691*** (0.0000)	4.3199 (1.0000)	-8.5508*** (0.0000)
LnY^2	-1.6104 (0.0537)	-8.5757*** (0.0000)	-0.3569 (0.6253)	-6.3276*** (0.0000)	5.5625 (1.0000)	-8.1093*** (0.0000)
Lnopen	2.8551 (0.9977)	-13.8409*** (0.0000)	-0.6652 (0.2634)	-11.0651*** (0.0000)	-3.2710*** (0.0012)	-4.4796*** (0.0000)
Lnenergy	0.5441 (0.7068)	-3.2153*** (0.0007)	0.1109 (0.5442)	-10.0945*** (0.0000)	0.7858 (0.7840)	-5.8364*** (0.0000)

Note: P-values are in parenthesis; *** and ** denote the significance level at the 1% and 5%, respectively.

Results of the Second Generation Panel Unit Root Test

Taking into account the probability of cross-sectional dependence in our panel variables, we apply the second generation panel unit root test, the Pesaran CIPS-test recently proposed by Pesaran (2007). STATA 11 software is used to run the test, and a lag length of 1 is selected due to our sample size. The results for the variables both in levels and in first differences are reported in Table 7.2. For both cases (constant only, and constant and trend), Pesaran CIPS-test statistics are unable to reject the null hypothesis that all variables have a unit root in levels. The result is consistent with the first generation tests. As the unit root hypothesis can be rejected at the 1% significance level for the first differences, we can conclude that the variables are integrated of the same order, I(1), which is the necessary condition for cointegration in a bivariate context.

Table 7.2: Second Generation Panel Unit Root Test Results

Test **Variables**	**Pesaran CIPS-test**			
	Constant only		**Constant &trend**	
	Level	**1st difference**	**Level**	**1st difference**
Lnww	-1.645 (0.718)	-2.690(0.000)***	-2.103(0.884)	-2.959(0.000)***
Lnwg	-2.027(0.064)	-2.925(0.000) ***	-2.028(0.948)	-3.117(0.000) ***
Lnsw	-1.768(0.460)	-3.208(0.000) ***	-2.376(0.351)	-3.450(0.000) ***
$LnSO_2$	-1.751(0.497)	-2.917(0.000) ***	-2.361(0.385)	-3.170(0.000) ***
LnY	-1.462(0.962)	-3.184(0.000) ***	-1.776(0.999)	-3.445(0.000) ***
LnY^2	-1.376(0.980)	-3.003(0.000) ***	-1.514(1.000)	-3.274(0.000) ***
Lnopen	-2.018(0.070)	-3.456(0.000) ***	-2.416(0.269)	-3.570(0.000) ***
Lnenergy	-1.852(0.287)	-3.732(0.000) ***	-2.204(0.730)	-4.030(0.000) ***

Note: P-values are in parenthesis; ***denotes the significance at the 1% level.

7.6.2 Panel Cointegration

Since all of the series are non-stationary of same order then our next step is to analyse the cointegration relationship. We will check the existence of cointegration between dependent variable (emissions per capita) and independent variables (economic growth, openness and energy consumption). For comparison both Pedroni (1999, 2004) and Westerlund (2007) panel cointegration tests are applied.

Result of Pedroni (1999, 2004) tests

We have used EViews 7 to run the panel cointegration program made by Pedroni (2004). The optimal lag length is selected based on the Akaike Information Criterion (AIC) with a max lag of 4 in both cases (constant only, and both constant and trend).

Simone (2008) suggests that the variance (Panel $v - stat$) and rho (Panel $\rho - stat$ and Group $\rho - stat$) statistics are more reliable when the time dimension is large enough – at least equal to 100; while the parametric tests (Panel pp-stat and Group pp-stat) appear to have the highest power for small T (Bonham and Gangnes, 2007). Because our time series observation is only 30 years (1980-2009), it is better to concentrate on parametric and non-parametric results (Panel pp-stat, Group pp-stat, Panel ADF-stat and Group ADF-stat). Table 7.3 presents the test results.

In Table 7.3 we can see that all tests (Panel pp-stat, Group pp-stat, Panel ADF-stat and Group ADF-stat) are significant at the 1% level in all cases except panel ADF-stat for Lnww in the case of constant and trend, which is significant only at the 10% level. The tests rejected the null hypothesis of no cointegration for all cases, suggesting there is a strong cointegration in all variables according the Pedroni (1999, 2004) panel cointegration tests results.

Table 7.3: Padroni (1999, 2004) Panel Cointegration Test Results

Dep.Var.	Lnww		Lnwg		Lnsw		$LnSO_2$	
Tests	**No trend**	**With trend**	**No trend**	**With trend**	**No trend**	**With trend**	**No trend**	**With trend**
Panel $\nu - stat$	-1.5540 (0.9399)	-3.3693 (0.9996)	1.6369* (0.0508)	0.2371 (0.3924)	0.6947 (0.2436)	-1.6959 (0.9550)	1.5446* (0.0612)	-0.5634 (0.7134)
Panel $\rho - stat$	0.5694 (0.7155)	1.6861 (0.9541)	0.7695 (0.7792)	2.8407 (0.9977)	-0.8584 (0.1953)	0.8317 (0.7972)	-0.0481 (0.4808)	1.7482 (0.9598)
Panel PP-stat	-7.6999*** (0.0000)	-12.8778*** (0.0000)	-4.8172*** (0.0000)	-5.1612*** (0.0000)	-6.1909*** (0.0000)	-6.4515*** (0.0000)	-4.9671*** (0.0000)	-4.8095*** (0.0000)
Panel ADF-stat	-3.5482*** (0.0002)	-1.47199* (0.0778)	-6.4414*** (0.0000)	-5.3374*** (0.0000)	-8.4312*** (0.0000)	-7.9569*** (0.0000)	-7.5849*** (0.0000)	-6.8222*** (0.0000)
Group $\rho - stat$	3.3659 (0.9996)	4.3059 (1.0000)	2.3666 (0.9910)	4.6547 (1.0000)	2.4710 (0.9933)	4.0544 (1.0000)	3.0419 (0.9988)	4.9259 (1.0000)
Group PP-stat	-7.1395*** (0.0000)	-11.1230*** (0.0000)	-7.2436*** (0.0000)	-9.0805*** (0.0000)	-6.8738*** (0.0000)	-8.3633*** (0.0000)	-4.4348*** (0.0000)	-5.2154*** (0.0000)
Group ADF-stat	-4.4515*** (0.0000)	-5.7974*** (0.0000)	-7.0540*** (0.0000)	-6.3931*** (0.0000)	-8.0494*** (0.0000)	-7.9351*** (0.0000)	-9.2540*** (0.0000)	-7.9320*** (0.0000)

Note: Null hypothesis is no cointegration; P-values are in parenthesis; ***, ** and * denote the significance at the 1%, 5% and 10% level, respectively; lag length is selected automatically based on AIC with a max lag of 4.

Results of Westerlund (2007) tests

Breitung and Pesaran (2008) argue that residual-based panel cointegration tests result in low power for small samples. Therefore, the second generation panel cointegration tests should be used to check the existence of panel cointegration. We choose to use the Westerlund (2007) test, which seems to be more powerful than residual-based panel cointegration tests, and STATA 11 software is used to run the tests. The number of lags and leads is selected based on the rule of $4(T/100)^{2/9}$. For the estimation of the various long-run variances needed to compute the error correction tests, we follow the recommendation of Westerlund (2007) and use the Newey and West (1994) estimator for heteroscedasticity.

In the two group-mean based tests (G_τ and G_α), a rejection provides evidence in favour of cointegration at least in one province, which is the same as in many traditional panel cointegration tests. Therefore, the tests results may be heterogeneous across provinces. On the other hand, in the two panel data based tests (P_τ and P_α), the alternative hypothesis is that there is cointegration for all provinces, suggesting the homogeneity across provinces. The computed values of the test statistics are presented in Table 7.4 along with two sets of p-values, one based on the asymptotic normal distribution, the other on the bootstrapped distribution using 200 replications to overcome possible finite sample bias. The results are mixed: whereas the group (G_α) and the panel fixed-effects (P_α) statistics fail to reject the null hypothesis, the panel time trend (P_τ) and group (G_τ) statistics reject the null at least at the 10% level in most of cases (for $LnSO_2$ and Lnsw, only G_τ statistic is significant at the 10% level with a deterministic trend). Since two out of the four statistics reject the null-hypothesis of no cointegration, we choose to interpret the results as a partial evidence in favour of cointegration[89].

For the panel cointegration test, Pedroni (1994, 2004) suggests seven tests which are residual-based, while Westerlund (2007) provides four tests which are error-correction-based. According to our results, both the Pedroni (1994, 2004) and Westerlund (2007) tests rejected the null hypothesis of no cointegration, suggesting the existence a long run relationship between our dependent variable (emissions per capita) and independent variables (income per capita, its square, energy per capita and openness). Hence we can move to the next step—cointegration estimation.

[89] Westerlund (2007) argues that the P_τ test is more reliable because it is more robust. In the case of a small sample, the normalisation of P_α statistic by T may cause the test statistic to reject the null hypothesis too frequently. His Monte Carlo simulations also show that the P_τ statistic is more powerful and robust to cross-sectional correlations.

Table 7.4: Westerlund (2007) Panel Cointegration Test Results

	Lnww								**Lnwg**							
	Constant only				**Constant and trend**				**Constant only**				**Constant and trend**			
	value	z-value	p-value	p*-value	value	z-value	p-value	p*-value	value	z-value	p-value	p*-value	value	z-value	p-value	p*-value
G_τ	-2.432	0.075	0.530	**0.070***	-2.661	1.206	0.886	**0.095***	-2.517	-0.407	0.342	**0.030****	-2.839	0.145	0.558	**0.045****
G_α	-3.514	6.636	1.000	0.945	-2.495	9.263	1.000	1.000	-4.133	6.202	1.000	0.370	-3.157	8.850	1.000	0.995
P_τ	-13.340	-1.634	**0.051***	**0.035****	-13.381	0.769	0.779	**0.080***	-11.388	0.168	0.567	**0.015****	-14.074	0.076	0.530	**0.035****
P_α	-3.295	4.270	1.000	0.675	-2.093	7.378	1.000	0.965	-3.641	4.024	1.000	0.340	-2.884	6.883	1.000	0.925
	Lnsw								**$LnSO_2$**							
	Constant only				**Constant and trend**				**Constant only**				**Constant and trend**			
	value	z-value	p-value	p*-value	value	z-value	p-value	p*-value	value	z-value	p-value	p*-value	value	z-value	p-value	p*-value
G_τ	-3.008	-3.171	**0.001*****	**0.000*****	-2.768	0.570	0.716	**0.050***	-2.608	-0.920	0.179	**0.035****	-2.772	0.546	0.707	**0.055***
G_α	-3.679	6.520	1.000	0.885	-3.017	8.937	1.000	0.990	-3.142	6.898	1.000	0.980	-3.424	8.684	1.000	0.995
P_τ	-13.122	-1.433	**0.076***	**0.015****	-12.267	1.884	0.970	0.125	-10.365	2.213	0.987	**0.080***	-8.491	5.663	1.000	0.775
P_α	-3.920	3.825	1.000	0.420	-3.285	6.633	1.000	0.860	-3.322	4.250	1.000	0.745	-3.464	5.520	1.000	0.880

Note: The null hypothesis is no cointegration. Optimal lag/lead length is determined by the Akaike Information Criterion with a maximum lag/lead length of 3. Width of Bartlett-kernel window set to $4(T/100)^{2/9} \approx 3$. The p-values are for one-tailed test on the normal distribution. The p^{*}-values are bootstrapped. Number of bootstraps to obtain bootstrapped p-vales which are robust against cross-sectional dependencies set to 200.

7.6.3 Panel Cointegration Estimation

Having established that the variables are non-stationary and exhibit long-run cointegration in the previous subsections, we now estimate the long-run relationship between emissions, economic growth, trade liberalisation and energy consumption in China using panel group mean FMOLS developed by Pedroni (2000).

We have used the WinRats 8.0 software for our estimation, and the program FMOLS is available on estima[90]. The FMOLS estimator not only yields consistent and efficient estimates of the parameters in a small sample (in our case 30 years and 29 provinces), but it corrects for the endogeneity of the regressors and serial correlation. Hamit-Haggar (2012, p.362) argues that "*the FMOLS is the most appropriate method to be applied in presence of heterogeneous cointegrated panels*". The results for panel FMOLS are reported in Table 7.5, while the results of FMOLS regression estimates for individual provinces are shown in Table 7.6-7.7.

Results of Panel FMOLS

Table 7.5 presents estimates of the cointegration vectors for equation (7.1). Column (1) shows the long-run elasticities of emissions per capita with respect to the relevant regressors; while this basic equation is also estimated with common time dummies in order to deal with potential cross-sectional dependency arising from negative common shocks, such as the 1998 Asian Financial crisis and the 2007 Global Financial crisis (reported in column 2).

The estimates for equation (7.1) suggest that most of the variables have a significant effect with the expected sign on the emissions per capita in the long run. For example,

[90] www.estima.com is the developer of WinRats and WinRats programs.

energy consumption per capita (Lnenergy) has a positive and significant impact on all emissions (except solid waste) at the 1% level, indicating that consuming more energy per capita will result in environmental degradation; the positive and significant impacts of trade liberalisation (LnOpen) are found for all emissions (with common time dummies), confirming the Pollution Haven Hypothesis (PHH) and suggesting that China may have a comparative advantage in pollution-intensive goods; capturing the impact of common shocks to the provinces in the panel through common dummies, for all emissions per capita, the coefficients of income per capita (LnY) are positive and significantly at least at the 10% level, and square of income per capita (LnY^2) is negative at the 1% significance level, indicating the existence of EKC for all our analysis emissions in China. This result with common time dummies is more reliable as it excludes the impact of common shock that is shared across individual members.

The equation (7.1) is also estimated with dummy variables Dummy02 and Dummy93, which are reported in Table 7.5 as column 3 and 4. These two dummy variables reflect the process of Chinese reforms, after 1993 focused more on enterprise reform and FDI reform and after 2002 more on trade (See Chapter Three and Four). As can be seen from Table 7.5, Dummy93 has an expected positive and significant effect on all emissions, indicating industrialisation causes more pollution; while the impacts of Dummy02 are mixed: 1) for water pollutant (wastewater, Lnww), there is a significantly negative effect, suggesting maybe the second wave of reform, especially trade reform, is good for water quality; 2) positive and significant effects are found for two air pollutants (waste gas and SO_2), indicating air quality deteriorated due to trade reform; 3) no relationship was found for solid waste. The inclusion or exclusion of the dummies does not significantly change the coefficients for the main variables in equation (7.1).

Table 7.5: Results of FMOLS Panel Cointegration Estimation

	Lnww				Lnwg			
	1	2	3	4	1	2	3	4
lnY	0.30*	0.21*	0.38**	0.29***	0.65*	1.19**	0.61***	0.69***
LnY^2	-0.10***	-0.01***	-0.06***	-0.04***	-0.05*	-0.15***	-0.05***	-0.08***
LnOpen	0.04***	0.07***	0.05***	0.06***	0.03***	0.05***	0.03***	0.04***
LnEnergy	0.39***	0.70***	0.33***	0.40***	1.32***	0.37***	1.22**	1.07**
Dummy02	--	--	-0.04***	-0.04***	--	--	0.05***	0.02***
Dummy93	--	--	--	0.04***	--	--	--	0.13***
	Lnsw				**$LnSO_2$**			
	1	2	3	4	1	2	3	4
lnY	2.11***	1.56***	2.20**	1.91**	0.61*	2.82***	0.43*	0.58**
LnY^2	-0.30***	-1.33***	-0.32***	-0.29***	-0.03***	-0.10***	-0.06***	-0.05***
LnOpen	-0.51	0.23***	-0.45	-0.34	0.01***	0.01***	0.01***	0.03***
LnEnergy	-2.22	1.16	-1.78	-1.00	0.72***	0.19***	0.63***	0.55***
Dummy02	--	--	-0.54	-0.55	--	--	0.17***	0.20***
Dummy93	--	--	--	0.54***	--	--	--	0.07***

Note: (1) without common time dummies; (2) with common time dummies; (3) includes dummy variable Dummy02; (4) includes two dummy variables, Dummy02 and Dummy93.
Dummy93 equals 1 for the year before and equal 1993 and 0 otherwise;
Dummy02 equals 1 for the year before and equal 2002 and 0 otherwise;
***, **, and * show significance at the 1%, 5%, and 10% level, respectively.

Due to the importance of SO_2 emissions, we further estimated the turning point based on the equation (7.1) with common time dummies (Table 7.5, column 2):

$$lnSO_{2it} = 2.82lnY_{it} - 0.10lnY_{it}^2 + 0.01lnOpen_{it} + 0.19lnEnergy_{it}$$

We found that the impact of trade openness is relatively small: a 1% increase in openness results 0.01% growth of per capita SO_2. A 1% increase in per capita energy use raises per capita SO_2 growth by 0.19%. Per capita income had a long run positive impact on per capita SO_2. A 1% increase in per capita income will lead to a 2.82%

increase in per capita SO_2. On the other hand, a 1% increase in per capita income squared will lead to a 0.10% decrease in per capita SO_2. The turning point is RMB 8,955 Yuan (constant at 1980 price), which is consistent with the estimation of He (2008) (RMB 9,236—11,311 Yuan, constant at 1990 price). It indicates that the per capita SO_2 emissions first increase, and then decline when per capita income achieves RMB 8,955 Yuan. When income level is relatively low, production and energy effects dominate and lead to increase in SO_2 emissions, because economic growth is the most important thing at the beginning of development. When income achieves a certain level, income and technological effects dominate and SO_2 emissions decline, because people demand clean environment and increase their support for environmental policies and push government to implement stricter regulations. However, only Beijing and Shanghai were on the right side of the turning point by the end of 2009.

Results of FMOLS for Individual Provinces

The results of FMOLS regression estimates for individual provinces are reported in Table 7.6 and 7.7. As can be observed from the tables, the results vary between different pollutants.

For per capita of wastewater (Lnww), the coefficients of trade openness (Lnopen) are significantly positive for many provinces (17 out of 29, including eight coastal provinces: Fujian, Guangdong, Hainan, Hebei, Jiangsu, Shandong, Tianjin and Zhejiang; four central provinces: Anhui, Hubei, Jiangxi, and Shanxi; and five western provinces: Guangxi, Qinghai, Sichuan, Shaanxi and Yunnan), and significantly negative for only few provinces (11 out of 29, including three coastal provinces: Beijing, Liaoning and Shanghai; four central provinces: Henan, Heilongjiang, Hunan and Jilin; four western provinces: Gansu, Guizhou, Ningxia and Xinjiang). The coefficients of energy consumption (Lnenergy) are significantly positive for 20 provinces (including eight coastal, five central and seven western provinces). The EKC curves can be found for 18 provinces (including nine coastal provinces: Beijing, Fujian, Guangdong, Hainan, Jiangsu, Liaoning, Shanghai, Tianjin and Zhejiang; four central provinces: Anhui, Henan, Heilongjiang and Hunan; five western provinces: Guangxi, Guizhou, Ningxi, Shaanxi and Xinjiang).

For waste gas per capita (Lnwg), we find a significant positive impact of trade openness for 17 provinces (seven coastal, five central and five western provinces) and negative impact for 11 provinces (four coastal, two central and five western). The coefficients of energy consumption are significantly positive for 20 provinces (10 coastal, five central and five western provinces). The existence of the EKC curve is supported in 12 provinces (seven coastal, three central and two western provinces).

For per capita solid waste (Lnsw), the coefficients of trade openness are significantly positive for 15 provinces (six coastal, four central and five western provinces) and significantly negative for nine provinces (three coastal, three central and three western). A significant positive impact for energy consumption is found for nine provinces (six coastal and three western provinces). We found that EKC curves only hold in seven provinces (four coastal, two central and one western provinces).

For per capita SO_2 emissions ($LnSO_2$), the coefficients of trade openness are significant for most provinces, especially positive for 23 provinces (10 coastal, five central and nine western provinces) and negative for five provinces (one coastal and four central provinces). The significant positive impact of energy consumption can be seen in 19 provinces (eight coastal, four central and seven western provinces). The evidence of an

EKC curve is found in 10 provinces (seven coastal, one central and two western provinces).

Table 7.6: Results of FMOLS for Provinces: Wastewater and Waste Gas

	Wastewater				Waste gas			
Province	**Lnopen**	**Lnenergy**	**LnY**	**LnY²**	**Lnopen**	**Lnenergy**	**LnY**	**LnY²**
Anhui	0.01(-4.09)***	1.07(4.15)***	**0.95(-4.23)***	**-0.16(-4.04)***	-0.30(-5.42)***	2.76(2.46)**	-5.26(-1.74)	0.34(-2.31)**
Beijing	-0.04(-24.42)***	1.47(3.35)***	**19.45(10.04)***	**-1.23(-19.94)***	0.04(-43.50)***	1.20(2.51)**	**0.72(2.03)**	**-0.04(-16.41)***
Fujian	0.21(-12.00)***	-1.01(-0.11)	**2.15(4.39)***	**-0.10(-17.99)***	0.09(-5.84)***	1.64(4.45)***	**2.08(2.63)***	**-0.16(-9.74)***
Guangdong	0.02(-18.78)***	1.49(2.36)**	**0.94(-16.93)***	**-0.15(-16.25)***	-0.05(-18.81)***	1.15(2.66)***	**0.87(3.13)***	**-0.04(-13.80)***
Gansu	-0.14(-5.70)***	0.33(-4.07)***	-0.10(-5.54)***	-0.18(-1.54)	0.04(-11.31)***	0.23(-2.36)**	-9.75(-0.10)	0.77(-1.62)
Guangxi	0.26(-5.70)***	1.37(1.54)	**2.51(2.35)**	**-0.26(-8.55)***	-0.51(-12.38)***	-1.19(0.79)	**1.59(2.35)**	**-0.08(-7.77)***
Guizhou	-0.15(-5.17)***	0.65(3.63)***	**6.21(2.33)**	**-0.50(-5.33)***	-0.17(-8.20)***	-1.07(0.24)	-4.77(-2.31)**	0.38(-3.42)***
Hainan	0.04(-37.87)***	0.30(20.25)***	**0.85(-30.10)***	**-0.06(-16.01)***	-0.01(-27.17)***	1.45(4.83)***	1.88(2.16)**	0.15(-8.45)***
Hebei	0.01(-10.87)***	0.51(-3.91)***	1.26(3.40)***	-0.06(-1.17)	0.22(-4.81)***	1.55(2.46)**	-2.34(-2.82)***	0.17(-9.04)***
Henan	-0.12(-28.70)***	0.59(-5.04)***	**1.24(-4.50)***	**-0.07(-0.78)***	0.08(-8.56)***	1.60(2.69)***	**5.42(3.24)***	**-0.39(-12.87)***
Heilongjiang	-0.18(-25.38)***	-1.20(0.75)	**9.96(5.91)***	**-0.76(-16.43)***	0.27(-11.11)***	-0.37(-1.70)	-12.68(-6.35)***	0.88(-0.79)
Hubei	0.21(-5.59)***	0.03(-3.04)***	0.18(-5.39)***	0.04(-7.51)***	-0.28(-10.88)***	1.19(2.01)**	**1.11(2.08)**	**-0.07(-10.16)***
Hunan	-0.13(-20.81)***	0.44(-7.77)***	**4.19(5.27)***	**-0.36(-29.20)***	0.13(-11.25)***	0.48(-5.12)***	-4.99(-0.94)	0.40(-1.11)
Inner Mongolia	0.54(-1.93)	0.13(-2.59)***	-5.98(-1.73)	0.41(-2.00)**	0.26(-3.15)***	1.18(2.41)**	2.53(0.38)	-0.17(-4.00)***
Jilin	-0.20(-24.19)***	0.93(-0.55)	2.74(1.82)	-0.25(-18.24)***	-0.18(-27.00)	0.89(-0.99)	0.45(-0.66)	-0.02(-16.85)***
Jiangsu	0.19(-23.85)***	0.49(-10.26)***	**1.06(2.20)**	**-0.11(-50.92)***	0.47(-5.05)***	0.55(-2.94)***	-3.90(-5.35)***	0.26(-11.10)***
Jiangxi	0.42(-8.28)***	0.13(-7.23)***	5.75(-6.83)***	0.38(-1.19)	0.23(-11.70)***	0.67(-2.94)***	**7.25(-10.64)***	**-0.56(-7.19)***
Liaoning	-0.24(-13.21)***	0.27(-3.74)***	**6.54(3.64)***	**-0.48(-13.85)***	0.01(-6.94)***	1.61(2.07)**	**9.14(-4.36)***	**-0.59(-2.50)**
Ningxia	-0.04(-22.37)***	0.34(-13.40)***	**4.09(5.53)***	**-0.35(-9.97)***	0.13(-5.09)***	0.96(-0.24)	1.67(0.74)	-1.20(-1.51)
Qinghai	0.10(-4.39)***	0.44(-1.07)	10.41(2.63)***	-0.69(-0.94)	-0.08(-9.48)***	2.66(5.68)***	2.57(2.13)**	-0.73(-0.27)
Sichuan	0.10(-8.66)***	0.12(-2.11)**	-4.27(-2.43)**	0.27(0.86)	0.16(-9.09)***	1.49(1.96)**	0.95(-0.02)	-0.08(-4.69)***
Shandong	0.09(-3.52)***	0.67(-1.23)	-1.97(-2.51)**	0.12(1.17)	-0.12(-6.87)***	1.03(2.20)**	1.05(0.04)	-0.05(-11.70)***
Shanghai	-0.48(-17.56)***	0.50(5.91)***	**11.16(4.66)***	**-0.68(-12.42)***	0.52(-4.40)***	1.44(2.34)**	**7.42(2.28)**	**-0.47(-8.44)***
Shaanxi	0.13(-17.50)***	0.54(-3.98)***	**5.07(5.05)***	**-0.33(-7.46)***	-0.32(-26.79)***	0.97(-0.27)	**2.83(2.53)**	**-0.18(-13.19)***
Shanxi	0.02(-7.75)***	0.46(-0.96)	-2.13(-3.05)***	0.11(-1.01)	0.02(-6.11)***	1.03(0.04)	-5.03(-1.59)	0.40(-1.11)
Tianjin	0.35(-7.79)***	0.54(-2.22)**	**3.48(4.35)***	**-0.16(-12.43)***	0.21(-5.43)***	1.48(2.34)**	**7.53(-4.76)***	**-0.47(-2.50)**
Xinjiang	-0.01(-7.93)***	-0.82(-0.44)	**4.67(2.62)***	**-0.37(-12.39)***	0.13(-5.40)***	-1.52(1.03)	-1.72(-1.54)	0.12(-6.31)***
Yunnan	0.22(-9.41)***	0.43(-13.46)***	-0.37(-1.96)**	0.02(1.39)	-0.06(-7.30)***	2.19(6.39)***	2.76(1.14)	-0.27(-10.31)***
Zhejiang	0.05(-6.49)***	1.43(1.29)	**1.39(2.03)**	**-0.16(-13.80)***	-0.06(-2.65)***	2.64(1.81)	**2.77(2.58)**	**-0.25(-5.47)***

Note: t-values are in parentheses; ***, **, and * show significance at the 1%, 5%, and 10% level, respectively; the EKC curves are in bold.

Table 7.7: Results of FMOLS for Provinces: Solid Waste and SO_2

	Solid waste				SO_2			
Province	**Lnopen**	**Lnenergy**	**LnY**	**LnY^2**	**Lnopen**	**Lnenergy**	**LnY**	**LnY^2**
Anhui	-1.97(-1.84)	8.96(1.09)	**58.70(2.40)****	**-4.29(-2.76)*****	-0.23(-7.34)***	1.59(2.19)**	1.80(0.32)	-0.19(-5.98)***
Beijing	-0.01(-5.77)***	-17.40(-0.07)	**67.53(8.80)*****	**-4.05(-10.98)*****	0.05(-24.15)***	1.56(-2.76)***	**12.29(6.63)*****	**-0.79(-17.28)*****
Fujian	1.02(6.54)***	0.98(6.98)***	**6.08(1.98)****	**-0.46(-6.41)*****	0.19(7.10)***	1.20(3.31)***	2.87(1.02)	-0.22(-9.57)
Guangdong	0.24(-3.21)***	-0.49(-1.58)	-8.67(-2.25)**	0.49(-1.57)	0.04(-12.04)***	-0.62(-1.21)	**1.96(2.67)*****	**-0.14(-10.51)*****
Gansu	-0.84(-4.69)***	1.40(0.26)	2.28(0.16)	-0.35(-2.09)**	0.02(-9.22)***	0.54(-1.12)	-1.29(-1.03)	0.08(-5.24)***
Guangxi	0.44(3.33)***	1.28(1.65)	3.48(0.42)	-0.30(-2.64)**	0.16(15.40)***	0.93(-0.48)	**4.41(3.30)*****	**-0.37(-15.91)*****
Guizhou	-0.75(-4.80)***	1.26(2.05)**	27.38(4.13)***	-2.08(-1.68)	0.06(-4.17)***	0.92(-2.18)**	-0.76(-0.44)	-0.03(-15.91)***
Hainan	0.56(-1.04)	1.24(2.11)**	4.65(0.24)	-0.57(-1.39)	0.28(6.79)***	0.05(-2.01)**	0.11(-0.13)	-0.02(-2.02)**
Hebei	0.76(2.17)**	-0.68(-0.29)	-9.35(-1.74)	0.54(-1.00)	0.03(6.92)***	0.53(-2.30)**	**3.86(2.63)*****	**-0.29(-15.26)*****
Henan	-1.75(-6.44)***	-0.95(-0.06)	3.93(0.54)	-0.49(-3.47)***	-0.23(-6.81)***	-1.17(-0.46)	3.63(1.14)	-0.28(-7.02)***
Heilongjiang	0.72(2.05)**	6.39(1.13)	-18.14(-0.70)	0.71(-0.15)	0.22(-10.47)***	1.15(0.35)	-11.78(-5.24)***	0.79(-1.19)
Hubei	0.97(2.93)***	-0.61(-0.26)	-15.10(-2.07)**	0.87(-0.22)	0.72(13.63)***	2.15(4.07)***	**5.36(2.98)*****	**-0.48(-13.01)*****
Hunan	-0.76(-3.39)***	1.32(0.38)	-5.12(-1.06)	0.34(-1.47)	-0.001(-9.99)***	-0.01(-0.54)	-2.71(-3.29)***	0.20(-9.21)***
Inner Mongolia	0.32(6.28)***	1.54(1.41)	**9.29(2.33)****	**-0.84(-7.05)*****	0.33(-4.10)***	1.59(1.97)**	1.35(0.13)	-0.17(-5.77)***
Jilin	-1.13(-6.75)***	1.26(2.93)***	**31.46(5.01)*****	**-2.42(-7.84)*****	-0.27(-22.26)***	0.59(-3.38)***	0.23(-0.70)	-0.03(-13.16)***
Jiangsu	2.13(4.66)***	3.25(4.34)***	**35.02(5.81)*****	**-2.40(-7.93)*****	0.13(-13.39)***	0.12(-9.36)***	**1.98(2.73)*****	**-0.14(-27.61)*****
Jiangxi	0.28(2.41)**	-0.47(-1.60)	-27.86(-4.58)***	1.90(1.83)	0.36(8.07)***	-0.58(-1.45)	-13.75(-7.42)***	0.99(-0.04)
Liaoning	-0.63(-2.65)***	5.60(5.18)***	6.94(0.60)	-0.44(-2.05)**	-0.24(-7.68)***	0.85(-2.44)**	-1.44(-0.93)	0.06(-5.16)***
Ningxia	-0.05(-3.23)***	0.48(-1.50)	7.27(0.94)	-0.67(-3.42)***	0.06(-10.94)***	0.43(-6.29)***	**6.43(3.09)*****	**-0.45(-11.19)*****
Qinghai	2.25(1.29)	5.27(1.25)	-29.58(-1.48)	2.23(0.78)	0.50(-1.37)	2.76(1.98)**	-12.73(-1.78)	0.75(-0.42)
Sichuan	0.09(5.66)***	1.45(3.17)***	-11.27(-1.80)	0.75(-0.52)	0.15(-5.41)***	0.06(-2.49)**	-7.11(-1.45)	0.47(-1.35)
Shandong	0.86(-0.19)	1.47(3.16)***	3.55(0.45)	-0.49(-3.61)***	0.28(-3.35)***	0.01(-4.41)***	**0.22(-3.48)*****	**-0.03(-8.67)*****
Shanghai	-3.32(-3.21)***	-10.33(-1.45)	-77.07(-2.29)**	4.70(1.75)	0.22(-3.01)***	-0.03(-1.23)	11.54(1.56)	-0.71(-4.10)***
Shaanxi	0.44(-2.44)**	1.25(4.24)***	-7.51(-1.54)	0.50(-1.22)	0.06(19.26)***	0.72(-2.21)**	0.18(-0.62)	-0.04(-10.47)***
Shanxi	0.11(-1.41)	-2.03(-1.06)	-13.53(-0.98)	0.99(-0.01)	0.09(5.96)***	0.50(-0.73)	1.57(0.16)	-0.11(-4.14)***
Tianjin	1.08(2.75)***	-6.62(0.03)	**47.05(4.93)*****	**-3.06(-6.64)*****	0.46(-2.78)***	0.69(-3.47)***	**9.30(-4.28)*****	**-0.55(-2.84)*****
Xinjiang	0.48(-3.18)***	-0.40(-1.15)	-1.08(1.16)	-0.03(-7.23)***	0.03(-8.19)***	-1.55(1.47)	-2.45(-2.66)***	0.13(-8.48)***
Yunnan	0.37(3.27)***	2.86(1.15)	0.69(-0.07)	0.04(-2.70)**	0.18(-6.99)***	0.69(-2.08)**	-2.05(-2.44)**	0.11(-8.83)***
Zhejiang	0.33(2.55)**	-1.93(-1.48)	-0.98(-0.50)	0.06(-3.16)***	0.12(4.34)***	1.47(2.80)***	**5.79(2.43)****	**-0.43(-9.67)*****

Note: t-values are in parentheses; ***, **, and * show significance at the 1%, 5%, and 10% level, respectively; the EKC curves are in bold.

7.6.4 Panel Causality Test

The existence of a panel long-run cointegration relationship between emissions, energy consumption, openness, and economic growth indicates that there should be causality in at least one direction. We have used EViews 7 to run the panel Granger Causality test, and the results are displayed in Table 7.8.

SO_2 Emissions

In the short run, there are three bidirectional causality relationships: 1) between SO_2 emissions and energy consumption, indicating an increase in energy consumption will lead to an increase in SO_2 emissions, and an increase in SO_2 emissions also means more energy use; 2) between SO_2 emissions and trade openness, indicating trade liberalisation will lead to an increase in SO_2 emissions, which supports the Pollution Haven Hypothesis, and at the same time, due to the scale effect, more production causing more SO_2 emissions will lead to more trade; and 3) between economic growth and energy consumption, indicating that energy plays an important role in promoting China's economic growth, and economic growth will boost energy use. Moreover, there are two unidirectional causality relationships running: 1) from economic growth to SO_2 emissions, suggesting the scale effect; and 2) from trade openness to economic growth. However, there is no causality running from SO_2 emissions to economic growth, from growth to trade openness, and between trade openness and energy use.

According to the coefficient of the lagged ECT, a long-run relationship exists between the variables, in equation 7.1, due to the statistical significance of the ECT term. The coefficients of the ECT are significant in both the SO_2 emission equation and the trade openness equation, implying that there are two long-run panel causality links: 1) running from economic growth, energy consumption and trade openness to SO_2

emissions; and 2) running from SO_2 emissions, trade and economic growth to energy consumption.

Production Wastes

In the short run, we found unidirectional causality relationships running: 1) from economic growth to all three wastes and energy consumption, 2) from trade openness to wastewater, waste gas; 3) from trade to economic growth in the case of wastewater; 4) from energy consumption to waste gas. There is a bidirectional causality relationship between economic growth and energy consumption in the case of waste gas. Furthermore, long-run causality relationships are found in the cases of wastewater and waste gas, suggesting that energy consumption, trade openness and economic growth are the causalities for wastewater and waste gas.

Table 7.8: Results of Panel Causality Test

Indep.Var. / Dep. Var.	Short-run				Long-run
	$\Delta Lnww$	$\Delta Lnenergy$	$\Delta Lnopen$	$\Delta LnY, \Delta LnY^2$	ECT
$\Delta Lnww$	--	0.60 (0.44)	4.43** (0.03)	10.64*** (0.00)	-3.01* (0.05)
$\Delta Lnenergy$	1.06 (0.29)	--	2.31 (0.13)	4.21** (0.03)	-0.98 (0.27)
$\Delta Lnopen$	1.75 (0.18)	0.45 (0.49)	--	0.62 (0.42)	0.03 (0.84)
$\Delta LnY, \Delta LnY^2$	1.17 (0.30)	0.51 (0.47)	3.97** (0.03)	--	-0.22 (0.64)
Indep.Var. / Dep. Var.	**Short-run**				**Long-run**
	$\Delta Lnwg$	$\Delta Lnenergy$	$\Delta Lnopen$	$\Delta LnY, \Delta LnY^2$	ECT
$\Delta Lnwg$	--	3.83** (0.03)	2.74* (0.07)	7.34*** (0.00)	-2.97* (0.05)
$\Delta Lnenergy$	2.13 (0.14)	--	0.53 (0.46)	3.76** (0.03)	-0.77 (0.38)
$\Delta Lnopen$	2.61 (0.10)	0.85 (0.35)	--	0.27 (0.59)	0.37 (0.50)
$\Delta LnY, \Delta LnY^2$	1.11 (0.26)	3.29** (0.04)	3.51** (0.04)	--	-0.52 (0.46)
Indep.Var. / Dep. Var.	**Short-run**				**Long-run**
	$\Delta Lnsw$	$\Delta Lnenergy$	$\Delta Lnopen$	$\Delta LnY, \Delta LnY^2$	ECT
$\Delta Lnsw$	--	0.25 (0.62)	0.04 (0.84)	2.97* (0.05)	-0.44 (0.53)
$\Delta Lnenergy$	0.32 (0.57)	--	0.76 (0.40)	3.01*(0.05)	-0.65 (0.44)
$\Delta Lnopen$	0.75 (0.40)	0.82 (0.36)	--	0.32 (0.58)	0.04 (0.84)
$\Delta LnY, \Delta LnY^2$	2.24 (0.13)	2.01 (0.16)		--	-0.34 (0.52)
Indep.Var. / Dep. Var.	**Short-run**				**Long-run**
	$\Delta Lnso2$	$\Delta Lnenergy$	$\Delta Lnopen$	$\Delta LnY, \Delta LnY^2$	ECT
$\Delta Lnso2$	--	4.68** (0.02)	6.01** (0.01)	9.92*** (0.00)	-3.68** (0.04)
$\Delta Lnenergy$	3.46** (0.04)	--	1.72 (0.19)	4.86** (0.02)	-2.43* (0.09)
$\Delta Lnopen$	2.91* (0.05)	1.24 (0.25)	--	0.68 (0.40)	0.44 (0.51)
$\Delta LnY, \Delta LnY^2$	2.40 (0.11)	2.83* (0.06)	5.69** (0.02)	--	-0.72 (0.42)

Note: Partial F-statistics reported with respect to short-run changes in the independent variables, while t-statistics reported with respect to long-run. Probability values are in parenthesis. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

7.7 Conclusion

In this chapter we have tried to investigate the relationships between environment, economic growth, trade openness and energy consumption in China by using a quadratic EKC model. The panel data from 29 Chinese provinces from 1980 to 2009 are used in this chapter.

Recently, in the expanding EKC literature, some criticisms have been raised towards the econometric methodology used. In this chapter, our attempt is to overcome some of these difficulties by incorporating recent econometric techniques. First, we employed a single-country panel data set which has a relatively large time dimension, in order to alleviate the problems of heterogeneity, cross unit cointegration and cross-section dependence. Second, we investigate the stationarity properties of the variables by using both the first and second generation unit root and cointegration tests, which allow for cross-sectional dependence. Third, we performed panel FMOLS, which is asymptotically efficient and allows for serial correlation and endogeneity of regressors in the cointegration equation.

Our results show that all of the series are integrated of order one, I(1). The first generation unit root tests strongly suggest that our variables are non-stationary, which is also confirmed by the second generation unit root test. We also find a strong cointegration in our estimation based on both residual-based and error-correction-based tests.

On the bases of panel cointegration tests we apply the panel FMOLS test for estimation. The FMOLS estimates indicate that for the panel of provinces, there is strong evidence of a long-run positive relationship between emissions (except solid waste) and energy consumption (significant at 1%). The significant long-run relationship between emissions and trade openness is either positive or negative depending on different pollutants and different estimators. Furthermore, a statistically significant EKC shape between all emissions and economic growth is found in the case of FMOLS with common time dummies. However, within the provinces, the EKC does not hold in all provinces but in a few eastern coastal provinces. Furthermore, a positive and significant impact by foreign trade is found for these pollutants at the national level, confirming the Pollution Haven Hypothesis and suggesting that China may have a comparative advantage in pollution-intensive goods. The provincial results showed that the impact of trade was different across provinces, maybe due to the differences of economic structure and composition of trade. The effect of energy consumption was significantly positive on SO_2, wastewater, and waste gas in the whole country and most provinces.

More short-run causality relationships were found in the case of SO_2 emissions. There exist three bidirectional causal relationships between emissions and trade, emissions and energy consumption, economic growth and energy consumption; while unidirectional causality is running from trade to growth, and growth to emissions. Additionally, in the case of production wastes, unidirectional causality exists from growth to wastes and energy consumption. Moreover, our results also show that energy consumption, trade openness and economic growth are the long-run causes for all pollutants.

This chapter investigated the long-run and short-run relationships between economic growth, trade openness, energy consumption and several local pollutants, such as SO_2 emissions and production wastes. Due to a lack of data over long period, COD is not included in this chapter. In the next chapter, we will examine that.

Chapter Eight

International Trade and COD in China:

A Simultaneous System Analysis[91]

8.1 Introduction

In the previous chapter, we adopted panel cointegration analysis to investigate the long-run and short-run relationship between economic growth, trade openness, energy consumption and environmental quality, which is measured by production wastes (wastewater, waste gas and solid waste) and SO_2 emissions. However, the most prevalent measure of water quality in China, COD, is not included in the previous analysis, because provincial COD data have been collected and published only since 1990, which is insufficient to do panel unit root and cointegration tests[92]. Therefore, the purpose of this chapter is to examine the impact of economic growth and trade openness on water pollution (COD) in China from 1990 to 2009, using a simultaneous-equations system proposed by Dean (2002).

The rest of this chapter is outlined as follows. Section 8.2 reviews the empirical literature in China. Section 8.3 presents the model. Section 8.4 introduces the data and estimation technique. Section 8.5 reports the empirical results. Section 8.6 concludes.

8.2 Literature Review

The empirical studies are mainly focused on the impact of trade liberalisation on China's environment with regard to the relative size of the composition, technical, and

[91] This chapter is an extended version of my Master's Thesis which is on Economical Modelling.
[92] Levin *et al.* (2002) suggest that moderate-sized panels should contain 25 periods and 10 provinces at least.

scale effects. The results reveal that trade liberalisation leads to a complex combination of both positive and negative effects on the environment.

Dean (2002) examines the effects of trade liberalisation on water pollution discharges in Chinese provinces from 1987 to 1995. Dean attempts to disentangle the effects of scale, composition and technique using a reduced-form HO trade model and assuming that environment is a factor of production. Considering the multiple effects of trade liberalisation, a simultaneous-equation system is created. Dean proposes that trade directly affects the environment, depending on the type of output (composition effect) and indirectly through income growth (the scale effect increases pollution while the technique effect reduces it). The results show that increases in the terms of trade seem to lead to more pollution, which provides evidence to support the pollution haven hypothesis, while the positive technique effect also seems clear. Therefore, Dean (2002) concludes that trade liberalisation has a beneficial environmental impact.

Chai (2002) examines the environmental impact of trade liberalisation on the Chinese manufacturing sector. Her findings are consistent with international evidence. First, Chai (2002) finds that there are various positive effects of trade liberalisation on the environment, such as promoting specialisation in areas of comparative advantage, allowing China to access and to adopt the best international practices in pollution abatement technology, and enable China to transfer environmental costs to other countries. Secondly, the analysis shows that these positive effects were outweighed by a negative scale effect. Finally, Chai concludes that China should tighten the environmental policies to reduce pollution.

Shen (2008) adopts the methodology provided by Antweiler *et al.* (2001) to examine the composition effect of trade liberalisation on China's environment. Regarding the composition effect, there are two main hypotheses in the literature: the factor endowment hypothesis (increasing trade may cause more pollution in a capital-intensive country and less pollution in a labour-intensive country) and the pollution haven hypothesis (increasing trade may transfer pollution from developed countries with strict environmental regulations to developing countries with weak regulations). Shen (2008) takes Dean's approach a step further in that an effort is made to identify the three effects. Using provincial data from 1993 to 2002, the results show that evidence for the factor endowment hypothesis is found in most pollutants ($SO_{2,}$ dust, COD, and arsenic); while evidence for the pollution haven hypothesis is not found. Combining all the effects, he finds that for $SO_{2,}$ and dust, an increase in trade liberalisation may result in more emissions; for COD, arsenic and cadmium, trade liberalisation will reduce emissions.

Jayanthakumaran and Liu (2012) investigate the relationship in China between trade, growth and emissions using provincial data for SO_2 and COD from 1990 to 2007. They adopt a three-step procedure, which combines both the EKC and the trade-related emissions hypothesis. First, they find the inverted U-shape for both SO_2 and COD, and estimate the turning points. Second, Dean (2002)'s model is adopted in order to capture the impact of trade on the environment. The results from the overall sample show that scale effects of SO_2 and COD dominated the technique effect; and for COD both direct and indirect impacts were positive, which confirms the pollution haven hypothesis – increasing trade will lead to more COD emissions. Third, they split the sample into two sections, above and below the estimated national turning point income, which was obtained from the first step, and then applied Dean (2002)'s model. The results show that rising income per capita was associated with a rising direct impact and falling indirect impact for SO_2 and COD, so that provinces with a higher income tended to show a relatively better technique effect. Furthermore, for COD, the indirect impact was greater than the direct impact, which generated a negative net impact and an overall reduction.

Moreover, according to Jayanthakumaran and Liu (2012), both Chinese exports and imports are becoming cleaner over time, which can reflect changes in the composition of the trade bundle. From 1980 to 2009, the shares of chemicals and textiles (they are more water pollution-intensive industrial sectors) of China's total exports and imports decreased, while the percentage of machinery (clean industrial sector) increased rapidly (see Section 3.4.3 in detail). In addition, trade liberalisation introduces clean technologies from developed countries, which causes water pollution drop over time.

Generally, the scale effect has been found to increase pollution in China, while the composition effect tends to shift towards cleaner goods. However, the overall impact of trade on the environment is not clear. The objective of this chapter is to investigate the impact of trade on China's water pollution, focusing on COD only. We extend the analysed time period and add an energy use variable to capture its effect and see how the results differ from Dean (2002)'s.

8.3 Model Specification

The model to be employed in this analysis is similar to the one developed by Dean (2002)[93]. Dean proposed a simple simultaneous system which describes income growth and emission growth as functions of the level of trade restriction. In this system, trade influences the growth of emissions in two ways. Firstly, a decrease in trade restrictions

[93]A brief outline of the model can be seen in Appendix.

will increase the relative price of dirty goods and cause increased specialisation in dirty goods and therefore an increase in emissions, which is a direct impact of trade on the composition of output (the composition effect). Secondly, lower levels of trade restriction will increase real income and then reduce the growth of emissions because it decreases the willingness of individuals to supply the environment as a factor of production at any level of emissions change, which is the indirect impact of trade, via its effect on income growth (the scale and technique effects) (Jayanthakumaran and Liu, 2012).

Theoretically, pollution is viewed as the outcome of economic growth, trade liberalisation and energy consumption; and at the same time, in the real world, pollution may reduce production. For example, environmental degradation may reduce the supply of environmental input; health problems induced by pollution may reduce the productivity of human resources. Therefore, income growth and environmental quality are jointly determined. If only a single equation with multiple variables is used to estimate the relationship between income growth and environmental quality, it will yield biased and inconsistent results (Shen, 2006). Hence, from this view, using a simultaneous equations model for the estimation should be more appropriate.

Following the specification by Dean (2002), the simultaneous equations model can be given as follows:

$$\Delta lnY_{it} = \alpha_0 + \overset{+}{\alpha_1}\Delta \ln COD_{it} + \overset{+}{\alpha_2}\Delta lnL_{it} + \overset{+}{\alpha_3}\Delta lnK_{it} + \overset{+}{\alpha_4}\Delta open_{it} + \overset{+}{\alpha_5}\Delta lnenergy_{it} + \alpha_6 Trend + \varphi_{it} \quad (8.1)$$

$$\Delta \ln COD_{it} = \beta_0 + \overset{+/-}{\beta_1}\Delta \ln Y_{it} + \overset{+/-}{\beta_2}\Delta open_{it} + \overset{+/-}{\beta_3}\Delta \ln TOT_{it} + \overset{+}{\beta_4}\Delta lnenergy_{it} + \alpha_5 Trend + \mu_{it} \quad (8.2)$$

where Δ indicates first difference. Subscript i refers to provinces, and t refers to the sample years, 1990 to 2009. Y refers to industrial output. L and K denote the labour force and capital stock in the industrial sector, respectively. Foreign trade (open) is measured as the ratio of exports plus imports to GDP, and energy indicates the total consumption of primary energy. TOT denotes the terms of trade to capture the relative world prices. Trend denotes a linear time trend. μ, and φ are error terms.

Following the theoretical implication, the expected signs of all the explanatory variables are shown above the equations. In the production function (equation 8.1), output (Y) is a function of labour (L), capital (K), energy consumption (energy), foreign trade (open), and pollution (COD). The signs of capital change (ΔlnK), labour change (ΔlnL) and energy consumption change (Δlnenergy) are expected to be positive due to more inputs being used in production, as more output is generated. Furthermore, pollution emissions growth (ΔlnCOD) is also expected to positively contribute to production. Because emission (or use of the environment) is being treated as an input, the total amount of Y is positively related to the emissions at any point in time. Meanwhile, the ratio of trade to GDP change (Δlnopen) is expected to have a positive sign, since increase in openness will raise factor productivity and thereby income.

Equation (8.2) is an emission growth equation. The sign of income growth (ΔlnY) is a priori indeterminate. The variable of income growth (ΔlnY) is applied here to capture both scale and technique effects[94]. More output requires more factor input and results in more pollution (scale effect); while as income rises, people increase their demand for a clean environment, and then impose higher penalties and shift toward clean production processes to reduce pollution emissions (technique effect). The sign is positive if the

[94] See more details of scale, technique and composition effects in Chapter Three.

scale effect is greater than the technique effect. Conversely, if the technique effect dominates the scale effect, a negative sign results. Because the prices of exports relative to imports are used to capture the influence of comparative advantage on emissions growth, it can be broken down into two components: the world terms of trade and trade openness (using ratio of trade to GDP as a proxy). The world terms of trade change (ΔTOT) and the ratio of trade to GDP change (Δopen) are expected to enter with either a positive sign or a negative sign according to whether China has or does not have a comparative advantage in pollution-intensive goods (composition effect). The sign is negative if China has a comparative advantage in the production of less pollution-intensive industries. Then its output composition will become cleaner after trade liberalisation. If China has a comparative advantage in pollution-intensive industries, trade liberalisation may result in China specialising in these industries. Therefore, positive signs are also possible. Consumption of primary energy (energy), especially coal and oil, is the main source of environmental pollution. Hence, the sign of energy consumption (Δlnenergy) is expected to be positive. Finally, a time trend is added into both equations to control the time effect on the dependent variables.

Concerning the model specification here, it should be noted that there are four differences with the model specification of Dean (2002). First, Dean (2002) uses the lagged investment in fixed assets to estimate capital stock directly. We use the perpetual inventory method to construct the capital stock series for 29 provinces in China, since capital cannot be measured simply by its original purchase price (adjusted for change in the price level) but should be adjusted for quality deterioration during its lifetime (Chow, 2006). Second, the trade to GDP ratio is used here to measure openness instead of black market premium, because many studies used trade shares in GDP as a proxy of openness and find a positive and strong relationship with growth (e.g. Dollar and Kraay, 2004; Yanikkaya, 2003; Jin, 2004; Sarkar, 2007). Third, we consider the impact of energy consumption on economic growth and environmental pollution. Energy consumption in the industrial sector accounted for 70% of overall energy consumption during the last 10 years. Four, all the variables in equations (8.1) and (8.2) except TOT are taken by the first differences of logarithm to get something similar to Dean's model. Following a conventional method, log is not taken for TOT, because the world terms of trade are negative in most years. In addition, with this small sample of annual observations, the introduction of a time trend reduces the degrees of freedom substantially; and some of the macroeconomic explanatory variables in the models may be non-stationary. Therefore, the first-difference form which addresses all the concerns is adopted to estimate the models.

8.4 Data Description and Estimation Technique

8.4.1 Data Description

The sample is composed of 29 provinces, municipalities, and autonomous regions over the period 1990-2009. Chongqing is excluded from the sample, because Chongqing became a municipality directly under the jurisdiction of the central government in 1996. In order to maintain consistency, the relevant data for Chongqing are added to those for the province of Sichuan. Tibet is not included in our analysis, due to lack of data.

Income (Y) is measured as the value of industrial output at the provincial level. To obtain inflation-adjusted data for output value, we deflate nominal output value using an index based on a survey of ex-factory prices for industrial output, which has been undertaken by China's Statistical Bureau since 1984.

The traditional factors of production included in the model are simply the labour force and physical capital stock. Labour force (L) is measured by the number of employees in the industrial sector by province at the year-end.

For the capital input (K), we estimate the fixed capital stock in the 1990 constant price as the measure for capital. The capital stock is computed following the perpetual inventory method (PIM) introduced by Goldsmith (1951). The PIM consist of adding the net investment data of the current year to an assumed base year of capital stock. Based on a geometric diminishing model of relative efficiency, the capital stock for each province can be computed by following equation (8.3):

$$K_t = K_{t-1}\,(1-\delta) + I_t \tag{8.3}$$

where K is capital stock, I is net investment, δ is the depreciation rate and t denotes time. The calculation takes the following steps: (1) use the deflator to obtain a fixed-asset investment series in constant 1990 prices. For the statistical data in China, there are two kinds of data series which can be used in the PIM (investment in fixed assets and the gross fixed capital formation). Only investment in fixed assets is available for the provincial level, so the investment in fixed assets is used to estimate provincial capital stock in this chapter. Under Standardised National Accounting, Xu (2002) explains that the value of investment in fixed assets at constant prices is actually calculated using the "price index of fixed asset investment". The provincial level data of price index of fixed asset investment are available from *China Statistical Yearbook*, various issues. (2) The base year (1990) initial capital stock for each province is originated from Zhang (2008). (3) As a fixed asset gets older, both its efficiency and price go down. Following Perkins (1998), Wang and Fan (2000), Wang and Yao (2001), and Guo *et al.* (2006), we adopt 5% as capital depreciation rate. Therefore, the real capital stock of each province in the period 1990–2009 can be estimated according to equation (8.3).

The total energy consumption (energy) includes consumption of coal, oil and gas in the industrial sector, obtained from *China Energy Statistical Yearbook* (1990-2009).

The world terms of trade (TOT) are used to capture relative world prices. Data are from the World Bank. The ratio of total trade to GDP (open) is used as a proxy for trade openness. The value of total trade is exports plus imports, and obtained from *China Statistical Yearbook* (1990-2010). There are two GDP measures listed in *China Statistical Yearbook*: the value-added method, and the expenditure method. According to Shen (2008), the expenditure method is probably more appropriate to reflect provincial output, because each province publishes the provincial GDP at the beginning of a year and provincial officials have the incentive to exaggerate provincial GDP and its growth rate. So we apply the expenditure measures of provincial GDP in this chapter. Since only the official data for the provincial Consumer Price Index (CPI) are available, we adjust GDP by CPI (setting CPI in 1990=100).

8.4.2 Estimation Technique

Since this is a simultaneous model with two equations (8.1) and (8.2), the variables of emissions growth and income growth are endogenous, and those variables' disturbance term is posited to be correlated with the disturbance term of another variable on which it has a direct effect. The single polynomial equation estimation may yield biased and inconsistent estimates, thus necessitating the two-stage least squares (2SLS) method.

The two stages in 2SLS refer to the fact that new dependent or endogenous variables are created to substitute for the original ones in the first stage; and then, in the second stage, the regression is computed in OLS fashion, but using the new variables created in the first stage (Bollen, 1996). To use 2SLS, the instrumental variable must be found, which is used to create the new variables in the first stage of 2SLS. The instruments are the exogenous variables, which are statistically independent of the error term in the model, and must be reasonably well correlated with the endogenous variable (Dunning, 2008). In most linear simultaneous equations systems, all the exogenous variables in the system are used to be the instruments for all the endogenous variables (Shen, 2006). In the system here, equation (8.2) has only four exogenous variables, and equation (8.1) has six. The variables of change of ratio of trade to GDP and energy consumption change are the same in both equations. Therefore, in the system here, the instruments are capital change, labour force change, energy consumption change, change of ratio of trade to GDP, and terms of trade change.

Since emissions growth and income growth across provinces are likely to differ based on variation in the types of industrial concentration in a province, fixed effects were included. There are two main assumptions for the fixed effects model, homoscedastic regression disturbances and abstracts from serial correlation. Both assumptions might be too restrictive and lead to inefficient estimates. Therefore, we test for heteroscedasticity and autocorrelation.

Following Green (2003), we test for group-wise heteroscedasticity with a modified Wald test, testing the null hypothesis of homoscedasticity. If χ^2 is significant, the null hypothesis is rejected, suggesting the presence of heteroscedasticity.

With respect to serial correlation, the Wooldridge test discussed by Wooldridge (2002) indicates the presence of first-order autocorrelation. If the F-statistics are significant, the null hypothesis of no first-order autocorrelation is rejected, suggesting the presence of first-order autocorrelation in the error term.

8.5 Results of Estimation

Before estimating the model, we examine the correlation coefficients of independent variables. Table 8.1 shows that correlation coefficients are relatively low in log differences, and hence we can conclude that there is no multicollinearity problem. In order to correct the problem of multicollinearity, the first differencing is also commonly adopted. If the variables are highly correlated in levels, first differences often reduce the correlation of the variables.[95]

Table 8.1: Correlation Coefficients

Equation (8.1)

	L	**K**	**Open**	**TOT**	**Energy**	**COD**
L	1.00					
K	0.25	1.00				
Open	0.15	-0.09	1.00			
TOT	-0.05	0.10	-0.25	1.00		
Energy	0.29	0.20	0.12	-0.10	1.00	
COD	0.03	0.05	0.03	0.05	0.07	1.00

Equation (8.2)

	Y	**Open**	**TOT**	**Energy**
Y	1.00			
Open	0.12	1.00		
TOT	-0.32	-0.25	1.00	
Energy	0.28	0.12	-0.10	1.00

Note: All variables are measured in log differences except that 'TOT' is measured in differences.

[95] In fact, high correlation was observed when variables were measured in levels.

Table 8.2 shows the standard diagnostic test for equation (8.1) and (8.2) residuals autocorrelation (Wooldridge test) and homoscedasticity (modified Wald test) problems. The results of the modified Wald test for group-wise heteroscedasticity are significant at the 0.01 level for both equations, suggesting the presence of heteroscedasticity in the error term. We implement a test for serial correlation in the idiosyncratic errors of a linear panel data model discussed by Wooldridge (2002). The null hypothesis of no first-order serial correlation is accepted. Consequently, we use fixed effects with robust standard errors to correct our results for heteroscedasticity. Wooldridge (2002) argues that this makes the results valid in the presence of any heteroscedasticity or serial correlation when T is small relative to N.

Table 8.2: Regression Diagnostics

Equations	**Modified Walt Test**		**Wooldridge Test**	
	χ^2-statistics	**Status of H_0**	**F-statistics**	**Status of H_0**
8.1	$\chi^2_{(29)} = 71.32$ Prob> χ^2=0.0000	Reject H_0	F(1,28)=0.100 Prob>F=0.7547	Accept H_0
8.2	$\chi^2_{(29)} = 2067.38$ Prob> χ^2=0.0000	Reject H_0	F(1,28)=2.243 Prob>F=0.1454	Accept H_0

Source: Author's calculation.

Table 8.3 presents the empirical results of estimating the model in equations (8.1) and (8.2) in which income growth and emission growth are determined simultaneously.

Table 8.3: Estimated Results

	Equation (8.1)		**Equation (8.2)**
Cons.	0.007***	Cons.	-0.004 ***
ΔlnCOD	-0.035	ΔlnY	-1.223***
ΔlnL	0.242***	Δlnopen	0.139***
ΔlnK	0.349**	ΔTOT	5.59e-14 *
Δlnenergy	0.248***	Δlnenergy	0.573***
Δlnopen	0.182***	Time Trend	-0.009*
Time Trend	0.007***		
R^2	0.21	R^2	0.05
F-test	22.65***	F-test	5.48***
Obs.	551	Obs.	551

Notes: 1. ΔlnE=COD growth; ΔlnL=labour change; ΔlnK=capital change; Δlnopen=the ratio of trade to GDP change; Δlnenergy=energy consumption change; ΔTOT=world terms of trade; all variables are measured in log differences except Time Trend, and TOT which is measured in differences;

2. ***Significant at the 1% level; **significant at the 5% level; *significant at the 10% level;

3. Includes fixed effects for provinces. Standard errors corrected for group-wise heteroscedasicity.

Source: Author's estimation.

First, foreign trade will affect emissions growth directly, via its effect on the relative price of pollution-intensive goods. There are two variables assigned to capture this effect. The first is TOT, and the other is trade to GDP ratio. From equation (8.2), it can be seen that foreign trade (open) has a strong positive relationship with the growth of COD. A 1% increase in trade openness raises the COD growth by 0.14%. This result suggests that China may have a comparative advantage in COD pollution-intensive goods, and it confirms the pollution haven hypothesis. Therefore, the direct composition effect of trade leads to an adverse impact on China's water environment.

Second, foreign trade will affect emission growth indirectly via its effect on income growth (the scale effect increases emissions while the technique effect decreases emissions). This indirect impact is measured by the coefficient of the ratio of trade to GDP in equation (8.1) multiplying the coefficient of the income growth in equation (8.2). The indirect impact via income growth shows that a 1% increase in trade (open) produces an increase of 0.18% in income growth (see equation 8.1), and a 1% increase in income growth (Y) causes a reduction in COD growth by 1.22%, therefore, a reduction of 0.22% (=-1.22*0.18) of COD growth. Since the variable of income growth refers to a combination of scale and technique effects in equation (8.2), this negative relationship between income growth and COD growth would indicate that the technique effect of trade outweighs the scale effect. As income rises, people increase their demands for a clean environment, and then industrial firms have the incentive to shift towards cleaner production processes to reduce pollution. So the indirect income effect of trade on environment is to reduce the water pollution problem.

Therefore, the net impact of trade on the environment can be calculated as the net values of the direct impact (measured by the coefficient of trade openness (Δlnopen) in equation 8.2) and indirect impact (measured by the coefficient of openness (Δlnopen) in equation 8.1 multiplying the coefficient of income growth (ΔlnY) in equation 8.2). The net impact is that a 1% increase in foreign trade causes a net reduction of 0.08% (=direct impact 0.14% + indirect impact -0.22%) in COD growth.

The empirical result indicates that the technique effect not only dominates the scale effect, but also dominates thte composition effect. The negative net impact suggests that trade is good for reduction of water pollution in China. Our results are similar in some respects to Dean (2002) and Jayanthakumaran and Liu (2012). For example, Dean (2002) found that a 0.99% increase in the growth rate of income causes a decline in the growth rate of emissions of 0.03% (-0.36%*0.09%); while Jayanthakumaran and Liu

(2012) concluded that a 1% increase in trade increased COD by 0.06% (direct impact), and the indirect impact of trade through rising income reduces COD by 0.12% (-0.37%*0.32%).

The energy consumption change (Δlnenergy) has a significant positive effect on COD growth: a 1% increase in energy consumption raises COD growth by 0.57%. This is consistent with the previous chapter, indicating energy consumption is a main source of environmental degradation.

Turning to the estimated results for the income growth equation (8.1), most of the estimated coefficients are highly significant and consistent with the expected signs. The traditional factors such as labour force growth, capital growth and energy consumption change contribute positively to the industrial output growth. The COD growth has a negative influence on income growth. This might be due to the differing concentrations of pollution-intensive industries across provinces.

8.6 Conclusion

Following the methodology of Dean (2002) and Antweiler *et al* (2001), who assume that the supply of a clean environment is endogenous, a system of equations is applied in this chapter, which simultaneously determine growth of income and growth of environmental damage in China. The system captures the impact of trade liberalisation on the growth of emissions in two ways: direct effect via changes in relative prices of exports; and indirect effect via income growth. This chapter uses the Chinese provincial data from 1990 to 2009 to estimate this model.

The results reveal that China's experience with the trade–environment nexus is consistent with international evidence; see for example, Copeland and Taylor (1994) and Antweiler *et al.* (2001). On the one hand, foreign trade has had a negative effect on the environment. Results show that improvement in the relative price of exports to imports (TOT) and increased trade openness (open) lead to an increase in COD growth. The composition effect of trade (direct impact) would be to damage water quality in China. On the other hand, foreign trade has had a positive indirect effect on the environment. The results also indicate that increased trade openness raises income growth, and then growth of income reduces COD growth. The technique effect of trade (indirect impact) has a beneficial effect on water quality in China.

In addition, our results show that the indirect impact is greater than the direct impact. Therefore, the net impact of trade indicates that trade is good for the environment, which is consistent with the results found by Dean (2002), Shen (2008), and Jayanthakumaran and Liu (2012).

Finally, evidence for the pollution haven hypothesis is found in China due to the composition effect having a positive relationship with environmental damage. This is consistent with Dean (2002) and Cole (2000a)'s finding that developing countries possess a comparative advantage in pollution-intensive production. Meanwhile, the results also explain the Environmental Kuznets Curve well.

Chapter Nine

Summary and Recommendations

9.1 Summary of the Study

Over the past 30 years, China's real GDP has increased tenfold. This achievement has mainly come from China's market-oriented reforms since 1978. The reforms initially start from the agricultural sector by granting autonomy to rural households regarding land use and crop selection. This process then expanded to include the gradual relaxation of price controls, fiscal decentralisation, and increasing autonomy for state-owned enterprises. The above actions resulted in the development of private enterprise in services and light manufacturing, a diversified banking system, the development of stock markets, a rapid growth in the non-state sector which increased industrial competition, and an economy more open to increased foreign trade and investment (Liu, 2009).

By 2010, China became the world's second largest economy, surpassing Japan. Its GDP reached US$5.9 trillion in 2010, and per capita GDP was US$4,423, due to its population increasing by 1.3 billion by the end of 2010. The increased GDP per capita from US$205 in 1980 to US$4,423 in 2010 was regarded as "Chinese miracle"[96]. Meanwhile, China has experienced huge structural changes – rapid and widespread industrialisation and expansion of service sectors. The secondary (mining, manufacturing and utilities supply) and tertiary (service) sectors together contributed around 90% to GDP in 2010 (*China Statistical Yearbook*, 2011).

[96] Data are from IMF, World Economic Outlook Database, 2012.

However, this rapid economic growth has been associated with a series of environmental problems, which have increased significantly in the past 30 years. The Chinese economy has relied heavily on the secondary industry, which accounted for 45% of GDP during the reform period[97]. China produces and exports steel, coal, electricity, cement, fertiliser, and woven cotton fabrics in the recent past. These products are subject to a higher level of carbon emissions. Moreover, although medium- and small-sized enterprises have contributed to economic growth, most of them require more raw materials and produce relatively pollution-intensive goods. Urbanisation and modern transportation systems have resulted in the reduction of environmental quality in cities. Coal mining, transportation, and fossil fuel combustion have also degraded the ecosystem and polluted rural and urban areas. Rapid industrialisation is heavily dependent on increasing inputs of energy (especially coal and oil), and depletion of natural resources as well (Zhang, 2012a).

According to a recent report from MEP (2012), China's seven major river systems are polluted; lakes and reservoirs are degraded. Around 89% of cities are subject to low air quality standards; and acid rain occurred in 227 cities in 2011 (48.5% of all monitored cities according to MEP, 2012). Although the Chinese government has taken some actions to reduce ecological degradation in some areas (the amounts of most pollutants, e.g. SO_2, industrial wastewater, industrial COD and discharge of industrial solid waste in both absolute and per capita terms, have declined in recent years[98]), China is still the largest emitter of CO_2 and SO_2.

[97] Details are in Chapter Three.
[98] Details are discussed in Chapter Four.

These problems have led researchers and policy makers to reflect on the effects of the extensive growth model. Several studies have investigated the relationship between economic growth, trade, energy and environment over recent years. Unfortunately, there are no comprehensive and consistent conclusions from previous studies. Therefore, disentangling this issue is important and the research contained in this thesis is necessary.

The primary purpose of this thesis was to examine the environmental performance of China during the period 1980-2009. In order to achieve this objective, we selected the most important and prevalent environmental quality indicators to study:

CO_2 Emissions

The problem of climate change is very likely due to the increase in greenhouse gas emissions, especially CO_2 emissions. China is the world's top CO_2 emitter now, and the emissions are expected to increase, due to continuous economic growth and heavy reliance on coal consumption. Considering its impact on a global scale, two entirely different methodologies, the production- and consumption-based approaches, have been adopted. The expectation is to establish the amount of CO_2 emissions and the determinants at the domestic level, and to establish the amount which is relocated due to foreign trade in order to get a comprehensive view.

To identify the main factors influencing the rapid growth in CO_2 emissions in China is the first issue of this study. Considering the existence of obvious differences across China's provinces and industrial sectors, a comparative analysis of the changes in CO_2 emissions across provinces and sectors is provided. This study firstly estimated provincial and sectoral CO_2 emissions from 1980 to 2009, following the IPCC manual, because these data are not published by the government, and cannot be found from existing studies. And then the factor decomposition LMDI method was used to decompose CO_2 emissions in this study, due to its advantages of path independency, ability to handle zero values and consistency in aggregation. The contribution of this study is that we provide the characteristics for each province, not only at the national level or industrial sectoral level.

Besides the expansion of domestic consumption and investment, China's increasing CO_2 emissions are associated with its high level of foreign trade. Most products exported to developed countries embody CO_2 emissions, which lead to a geographic separation of consumers and the CO_2 emissions emitted during the production of consumable items (Peter and Hertwich, 2008b). Under the current production-based accounting rule, the emissions associated with exports are fully attributable to China, and China is criticised by other countries for its increasing emissions. This required a reasonable measure based on domestic consumption (Peters, 2008; Peters and Hertwich, 2008b; Weber and Peters, 2009). In order to give a more complete and impartial picture of China's responsibilities for carbon reduction after it jointed the WTO, a single-country input-output model was applied to calculate the CO_2 emissions embodied in China's exports and imports, based on its recent input-output tables for 2002 and 2007. The contribution of this study is that we assumed the average emission intensity for China's top 20 import trading partners is representative of those of China's imported production, while most existing studies assumed that the emission intensity of imported production is the same as the domestic production, which overestimates the embodied emissions in imports due to the higher emission intensity of China.

SO_2 Emissions and Production Wastes

Besides CO_2, China is also the world's largest emitter of SO_2, which is the most important air pollution problem in China. SO_2 and its atmospheric products (e.g. sulphate, sulphuric acid) can affect the atmospheric environment from local to regional and global scales, as well as having adverse effects on human health (Lu *et al.*, 2010). The production of wastes (wastewater, waste gas and solid waste) is the more relevant environmental pressure indicator (Khajuria *et al.*, 2011), because more waste means more disposal loads, more management costs and more environmental externalities. Moreover, there is a relatively long period of recorded data in China.

This study examined these local environmental pollutants using the extended EKC model, based on the panel data approach (29 Chinese provinces each with 30 annual observations from 1980 to 2009). Most existing Chinese EKC studies tested the reduced form equation together with control variables derived from theory, but ignored the econometric weaknesses in estimation techniques (Groot *et al.*, 2004; Shen, 2006; He, 2008); while recently two papers, Jalil and Mahmud (2009) and Jayanthakumaran *et al.* (2012), were found to take the non-stationarity of the variables into account but based on country-level time series data. The contribution of this study is using relatively new panel cointegration and panel causality techniques to test the EKC model in China, which can overcome some of the econometric weaknesses. For example, a single-country panel data set with relatively large time dimension can alleviate the problems of heterogeneity, cross-unit cointegration and cross-section dependence; using both the first and second generation unit root and cointegration tests investigates the stationarity properties of the variables; and panel FMOLS is applied which allows for serial correlation and endogeneity of regressors in the cointegration equation.

COD

COD is the most prevalent measure of water pollution in China, which can lead to algal blooms and indicates the presence of water-borne pathogens (Hu, 2010). COD is the only pollutant which is showing a reduction trend during the past 20 years. Due to lack COD data over a long period, panel cointegration analysis is not applied. Following Dean (2002) and Jayanthakumaran and Liu (2012), this study adopted a simultaneous equations system to examine the impact of trade on water pollution (COD) in China by using a panel data approach (29 provinces over the period 1990-2009). Considering the endogeneity problem, the 2SLS method is performed to yield consistent estimates. This study adds an energy consumption variable in both emission and income growth equations to capture its impact. Moreover, it extends the analysed time period to see the recent situation, and the differences between our results and Dean (2002)'s.

9.2 Major Findings

To reveal China's environmental performance, all the major results from national, provincial, and sectoral levels were combined. The results at different levels supported our hypotheses. The combination of the findings from the three levels can be used to draw up specific recommendations for the government.

9.2.1 CO_2 Emissions

- ***Factor decomposition analysis***

Firstly, this study constructed the energy-related CO_2 emissions at the national, sectoral and provincial levels from 1980 to 2009. The estimated national CO_2 emissions are much in accordance with IEA data, showing the rapid growth trend, especially after 2002. The sectoral estimation showed that the emissions from the industrial sector account for the majority and show a rising trend, indicating that rapid industrialisation has promoted CO_2 emissions in China. In 2007, the top four industrial sectors (utilities production and supply sector, coking-gas-petroleum processing sector, metals manufacturing sector, and mining sector) generated about 82.8% of total CO_2 emissions. The provincial estimation also showed that CO_2 emissions originated mainly from major industrial regions, such as Shandong, Hebei, Henan, Jiangsu and Liaoning, which account for 39%. Therefore, efforts should be focused on the industrial sector and these industrial provinces during the mitigation of emissions.

Secondly, the CO_2 emission intensities have shown a reduction trend during the past 30 years, which is consistent with many other studies (e.g. Fan *et al.*, 2007; Leggett *et al.*, 2008; Chen, 2011). The highest emission intensities were found in the industrial sector, especially the production and supply of utilities sector, and the processing of coking-gas-petroleum sector, which are the top two CO_2 emitters; while the western and central provinces, such as Ningxia, Shanxi, Guizhou, Xinjiang and Inner Mongolia, showed a higher emission intensity than the eastern coastal areas, such as Shanghai, Beijing and Guangdong.

Moreover, the sectoral and provincial decomposition results are consistent with existing studies (e.g. Wu *et al.*, 2006; Liu *et al.*, 2007; Chen, 2011), which revealed that economic growth was the main factor causing an increase in CO_2 emissions, and the population growth effect was not even a third of the economic growth effect. However, energy intensity played a big role in lowering CO_2 emissions, which offset about 33-41% of the combined effect of economic growth and population growth. The impacts of the carbon emission coefficient and economic structure were varied across sectors/provinces and relatively small. The economic structure effect is only found to exhibit a positive effect on CO_2 mitigation in the primary and industry sectors. The carbon emission coefficient effect contributes to the decrease in CO_2 emissions in the transport and other services sectors, as well as 21 out of 29 provinces.

- ***Input-output analysis***

The previous production-based accounting analysis showed that economic growth was the major factor driving the rapid growth of CO_2 emissions in China, especially in the industrial sector and industrial provinces. Actually, due to the increase in foreign trade, a proportion of the products they produced was exported to meet the overseas demand, which embodied CO_2 emissions that were fully attributable to China. Therefore, the production-based accounting approach is of questionable fairness and effectiveness.

Firstly, our consumption-based accounting analysis showed that in 2007, China would be responsible for 37.9% less emissions than would be the case with the production-based accounting. This discrepancy is consistent with the estimation of China's balance of emissions embodied in its international trade surplus for 2007, which was three times higher than in 2002, reflecting China's rapidly increasing scale of production, much of which is for foreign consumption. Thus, in our view, a consumption-based accounting approach gave a more appropriate estimation of CO_2 emissions that China should be taking responsibility for.

Secondly, we found that the net exported emissions increased from 21.7% in 2002 to 37.9% in 2007. The results are consistent with those of Pan *et al.* (2008) and Wang and Watson (2007). Pan *et al.* (2008) show the increase as 19% in 2001 and 30% in 2006. Wang and Watson (2007) show the net exported emissions as 24% in 2004. Our results further show that the ratio of EEX to EDP increases from 35% in 2002 to 52% in 2007.

This is consistent with Wang and Watson (2007) and Ma and Chen (2011)'s findings that the ratio ranges from 30% to 60% from 2000 to 2009.

Moreover, we found that the manufacture of machinery and equipment sector, manufacture of textiles, wearing apparel and leather products sector, chemical industry sector, and manufacture and processing of metals and metal products sector were the sectors with the highest level of embodied emissions, accounting for around 77% of China's overall emissions embodied in exports. This is consistent with Lin and Sun (2010) and Pan *et al.* (2008). These sectors are highly energy intensive and so any attempts to reduce carbon leakage will need to focus substantially on these sectors. In addition, the results of EDC, EEX and EEI under the EAI assumption were overestimated compared with our estimates, suggesting the importance of the assumption of CO_2 intensity on the part of the trading partners.

9.2.2 SO_2 Emissions and Production Wastes

- ***Panel cointegration analysis***

Firstly, we found that a statistically significant EKC shape between local pollutants (SO_2 and production wastes) and economic growth holds throughout the country and in most eastern coastal provinces, indicating that China, especially the developed eastern areas, has entered the decreasing part of the EKC. This suggests that technology diffusion, leapfrogging, and institutional imitation through learning among countries at different stages of development, may have played an important role in reducing pollution (Jiang, *et al.*, 2008). Furthermore, a positive and significant impact of foreign trade is found for these pollutants at the national level, confirming the Pollution Haven Hypothesis and suggesting that China may have a comparative advantage in pollution-intensive goods. The provincial results showed that the impact of trade was different across the provinces, maybe due to differences in economic structure and composition of trade. The effect of energy consumption was significantly positive on SO_2, wastewater, and waste gas in the whole country and most provinces.

Due to the importance of SO_2 emissions, we further estimated the turning point based on equation (7.1) with common time dummies (the estimated coefficients can be seen in Table 7.5). We found that the impact of trade openness is relatively small – a 1% increase in openness results in 0.01% growth of per capita SO_2. A 1% increase in per capita energy use raises per capita SO_2 growth by 0.19%. Per capita income had a long-run positive impact on per capita SO_2. A 1% increase in per capita income will lead to a 2.82% increase in per capita SO_2. On the other hand, a 1% increase in per capita income squared will lead to a 0.10% decrease in per capita SO_2. The turning point is RMB 8,955 Yuan (constant at 1980 price), which is consistent with the estimation of He (2008) (RMB 9,236-11,311 Yuan, constant at 1990 price). This indicates that the per capita SO_2 emissions first increase, and then begin to decline when per capita income achieves RMB 8,955 Yuan. However, only Beijing and Shanghai were on the right side of the turning point by the end of 2009.

9.2.3 COD

- ***Simultaneous system analysis***

COD is the only pollutant which is maintaining the trend towards reduction in both absolute and per capita terms during the period of 1990-2009. From this analysis, we found that foreign trade may be good for China's water quality. The direct composition effect was estimated to be significantly positive on COD growth, which was evidence for the Pollution Haven Hypothesis. However, the indirect impact was significantly negative, indicating the technique effect outweighed the scale effect. It also provided some support for the EKC hypothesis, as rising income was associated with falling COD growth due to the better technique effect. Moreover, this indirect impact was higher than the direct impact which generated a negative net impact on COD that revealed an overall reduction in COD, which is consistent with results found by Dean (2002), Shen (2008), and Jayanthakumaran and Liu (2012) (see Table 9.1). This suggests that a rising income via increased international trade is lowering COD and good for water quality in China.

Table 9.1: Summary of Estimations on the Impact of Trade Liberalisation on the COD

Author and pollutant	Direct Impact (composition effect)	Indirect Impact (scale & technique effects)	Net Impact
Our Estimation	+	- (Technique dominates scale)	- (Indirect outweighs direct)
Dean (2002)	+	-	-
Shen (2008)	-	-	-
Jayanthakumaran and Liu (2012)	+	-	-

Note: **-** indicates beneficial impact (less pollution), + indicates adverse impact (more pollution);
Dean (2002) does not calculate the net impact, but she concludes trade liberalisation has a beneficial environmental impact due to the positive impact of technique effect.
Shen (2008) find the negative composition effect, suggesting the factor endowment hypothesis.

Source: Compiled by author.

9.2.4 Summary

Most local pollutants (such as SO_2, COD, discharged wastewater and solid waste) have been reduced at both absolute and per capita terms recently. CO_2 emissions increased rapidly due to heavy reliance on coal consumption, and mainly originated in a few industrial sectors and provinces. All analyses found that economic growth and energy consumption (especially coal and oil consumption) are the most important factors for driving emissions growth, which demonstrates the left side of the EKC curve. Our results also show that technological innovation is the major factor reducing emissions, for example lowering energy intensity (improvement of energy efficiency) and substituting less harmful technology (switching from highly polluting fossil fuel to less polluting fossil fuel or to non- fossil fuel), while trade liberalisation and structural change contribute to lowering the emissions as well, but only with appropriate policy and technological support. Therefore, the impact of technological progress, structural change and trade liberalisation together explains the right side of the EKC curve.

9.3 Policy Recommendations

Based on the major findings from each of the studies summarised in the previous section, we identify the key issues and make relevant policy suggestions as follows:

9.3.1 CO_2 emissions

Firstly, factor decomposition analysis reveals the large role of energy intensity in reducing CO_2 emissions. Therefore, the reduction of energy intensity (or improvement of energy efficiency) seems to be a useful implication for carbon mitigation policy. For example, employing energy-saving technologies and completing effective energy conservation management should be an effective way to decrease emissions for the regions with higher energy intensity and higher self-supply of coal (such as Shanxi, Guizhou and Inner Mongolia); implementing more economic incentive policies or giving assistance on tax and loans in large energy-intensive enterprises to enhance energy efficiency through the technology improvement.

Secondly, economic growth plays the largest role in increasing CO_2 emissions. However, we cannot stop or reduce growth, because there were 122.38 million people living in poverty in rural areas at the end of 2011 (*China Statistical Yearbook*, 2012).

Reducing the poverty rate by furthering economic growth is the main task in China. Therefore, poverty eradication and environmental protection are the most important conflicting goals China faces. Alternative policy options, including adjustment in energy structure and industrial structure, which will reduce CO_2 emissions and maintain economic growth, appear to be better choices.

(a) Energy structural change

China's economic growth relies heavily on coal use, which causes severe environmental pollution. Moreover, our results reveal that the carbon coefficient effect is relatively slight, and even leads to more emissions. Therefore, adjustment in energy structure seems to be a useful way, for example shifting to fuels that are less intensive in carbon (e.g. natural gas or nuclear fuel) and renewable energy technologies (e.g. wind power, water power, solar energy, etc.).

In the context of increasing energy demand and externalities, laws and regulations offer favourable incentives for the renewable energy industry to encourage development of renewable energy. With these supports, renewable energy development has made great advances, particularly wind energy. In 2010, China's annual wind power installation accounted for 46% of global installations, and replaced the US as the world's largest wind energy market in terms of cumulative capacity (Global Wind Energy Council, 2011). However, the use of renewable energy in industrial sectors is still negligible. According to Zhang (2012a), the capacity of wind-powered generators accounted for only 4.4% of total electricity-generating capacity in 2010. The main reasons appear to be the high transmission costs for renewable energy producers, and the high costs of transition from dirty energy to renewable energy for other industries. Therefore, more government fiscal support is required to encourage renewable energy use over all sectors.

(b) Industrial structural change

Both production- and consumption-base accounting approaches indicate that China's CO_2 emissions mainly originated in a few industrial sectors and a few industrial provinces. Therefore, more attention should be paid to these sectors and provinces to reduce CO_2 emissions. For example, supporting the clean industrial sectors, or the ones using clean technology, is necessary. This will exert pressure on dirty sectors/provinces to move towards clean production and exports.

Thirdly, our study indicates that population growth is also a major cause of CO_2 emissions growth, although it is not the sole one. The IPAT model and the Kaya identity[99] reveal that population growth degrades the environment, although technology can partially offset this. Population control[100] policy has lowered the population growth rate in China, and reduced pressure on the environment, although it was not designed for environmental protection (Hasketh et al., 2005). However, these policies are facing many criticisms, such as skewed sex ratios, aging society, social security unviability and human rights violations. Therefore, China needs to reconsider its population policy. Besides China's extreme policy, there is a more flexible way to lower the population growth rate. The policy measures should include establishing a sound social security system, which would reduce the need for family-supported financial security, and improving female status, education and job opportunities.

[99] See details in Chapter Five.
[100] In 1978 China introduced the "one child per family" policy to control overpopulation. As a result, the fertility rate (measured by the average number of births per woman) has been reduced from 2.91 in 1978 to 1.6 in 2010 (*China Statistical Yearbook*, 2011).

Moreover, the better way to minimise the cost of reducing CO_2 emissions is to develop and participate in the carbon markets, and to introduce a carbon tax. China is now the dominant party on the CDM market, which is believed to assist China building the institutional capacity to deal with climate change. Therefore, the successful EU carbon markets and carbon tax system, as well as its experience in the CDM, should encourage China to adopt these market-based instruments to lower emissions.

Our results show that the agriculture and forest sectors contribute less CO_2 emissions than industrial sector. Fang *et al*. (2001) argue that the forest transition in China, that is reforestation and afforestation programs, contribute to global carbon sequestration. Blaikie and Muldavin (2004) argue that these programs also improve local and regional environment. Finally, Xu *et al.* (2007) confirm the forest covers in China have increased in recent years. Therefore, the Chinese government should continue to implement reforestation and afforestation programs using best practice technology and financial compensation for affect farmers.

Last but not least, a large part of the CO_2 emissions China produced is consumed overseas, especially by developed countries. Therefore, these countries should take some responsibility to help China lower emissions, such as providing technological support, or fiscal supporting for research and development of new technology.

9.3.2 SO_2 Emissions and Production Wastes

The panel cointegration analysis reveals that although EKCs are found at the national level and in some rich provinces on the east coast, only Beijing and Shanghai have already reached the turning point; the majority of other regions are still on the left side of the EKC, and future economic growth will generate an adverse impact on the environment.

Since the beginning of reforms, China's economic activity has clustered on the eastern coastal region, receiving favourable support in terms of financial, taxation, land use and FDI policy from the central government, while economic growth is lacklustre in western provinces, and many of them have a high poverty rate. In order to reduce this regional imbalance, since 2000 the government has focused on the western region, which is predominantly inhabited by minority ethnic groups. The Great Western Development Program focuses on infrastructure construction, such as highways, railways, airports and gas pipelines (Zhange, 2012a). Although this strategy stimulates economic growth, it may result in the transfer of industrial emissions from the eastern to the western region. Because of low labour costs, abundant energy and natural resources, and the massive investment in infrastructure, the western region has attracted dirty industries from eastern areas, and is sensitive to pollution. Hence, balancing regional economic development and reducing poverty bring high environmental risks in the western areas. As Chua (1999) points out, environmental innovation can stimulate the environmental technologies industry in developed eastern regions; and then the benefits of these innovations can spill over to less developed western regions. Therefore, without a spillover effect, the environmental problem will be more severe in the western region (Chua, 1999; Graker, 2006; Fischer, 2008). Therefore, harmonising regional economic growth with environmental protection in the western area can be achieved by learning new cleaner production technologies from eastern provinces, instead of repeating their development path.

9.3.3 COD

From this analysis, it is clear that trade liberalisation leads to both benefits and costs on the water quality in China. First, further trade liberalisation policy is recommended to promote economic growth and raise incomes. Liberalisation brings a bundle of management experience, marketing channels, and technology, which provides a unique opportunity to learn from other countries' experience and thereby avoid some of their mistakes. Second, changing the current trade structures is necessary by supporting and raising the competitiveness of clean industries in the international market. Most importantly, the change of trade structure also need the support of technology. Moreover, promoting imports for heavily polluting industries and encouraging the application of advanced foreign technology by granting financial support and reducing tax should be considered. In addition, strengthening and enforcing environmental regulations is an effective way to prevent dirty industries transferring to China from other developed countries.

China has introduced a complete system of environmental regulations and rules[101]. However, policy enforcement in reality is weak. For example, a) local governments can reduce or waive the pollution fees in order to encourage business to attract more investment; and b) imposing the penalties for violating the standards is not easy. Poor enforcement can partially explain the overall poor environmental performance in China. Therefore, enhancing enforcement is one of the important issues. The replacement of local government by local environmental agencies may reduce the influence of local government, which often regards economic growth as the top priority. This would encourage local officials to comply with the policy by promoting or giving bonus.

[101] See details in Chapter Four.

9.4 Limitations and Future Studies

This study is limited in several respects. The first problem is data availability. In Chapter Five (factor decomposition analysis), CO_2 emissions can only be estimated for five major industrial sectors (primary, industry, construction, transport and service sectors) over 30 years, due to a lack of long-term energy consumption data for disaggregated sector. At the provincial level, sectoral energy data were not available for each province, which restricted the calculation of CO_2 emissions at the provincial sectoral level, and then restricted analysis of the impact of industrial structural change on provincial emission change. The consumption data of coal, oil and gas are not available over a long period at sectoral and provincial levels, which limited this study examination of the impact of each type on environment. In Chapter Seven (panel cointegration analysis), COD is not included, because provincial COD data have been collected only since 1990, which is insufficient to do panel unit root and cointegration tests. Future work needs to refine, extend and improve these approaches further.

For the input-output analysis (Chapter Six), although the average weighted emission intensity of China's top 20 trading partners was used to calculate the imported emissions, it does not fully consider all trading partners, and the divergence of each sector in different countries. In addition, calculation of exported emissions was under the assumption that the proportion of the imported intermediate inputs from each sector to all others is the same, which does not completely account for the full role of processing trade. Future research can be done to solve these problems when a global input-output table is available to access.

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Appendix

Table A3.1: Summary of China's Major Policy Changes during the Post-reform Period

Major reform	Beginning year	Policy change
Rural reform	1978-1979	Household Responsibility System: decision to turn collective farms to households Establishment of TVEs: TVEs given strong encouragement
	1988	Retrenchment of TVEs
SOEs Reform	1987	Contracted responsibility system introduced in SOEs
	1995	Shift to contractual terms for SOEs staff
	1997	Beginning of restructure SOEs
Non-SOEs Reform	1984	Self-proprietorships encouraged
	1994	Introduction of 'Company Law'
	1999	Constitutional amendment passed that explicitly recognised private ownership
	2002	Communist party endorses role of the private sector, inviting entrepreneurs to join
	2004	Constitution amended to guarantee private property rights
Trade Reform	1978	'Opening up' policy initiated, allowing foreign trade and investment to begin
	1985/1992	Reduction of tariff
	1985	Introduction of duty drawback system
	1994	Establishment of EXIM
		RMB began to be convertible on current account
		Multiple exchange rates ended
	2004-2005	Elimination of imports quotas and licences
FDI Reform	1979-1983	Implementation of 'the Equality Joint Venture Law'
	1988	Chinese-Foreign Cooperative Joint Venture Law passed
	1990s	More regions and sectors were opening up to FDI
	2000s	Restructured legal system

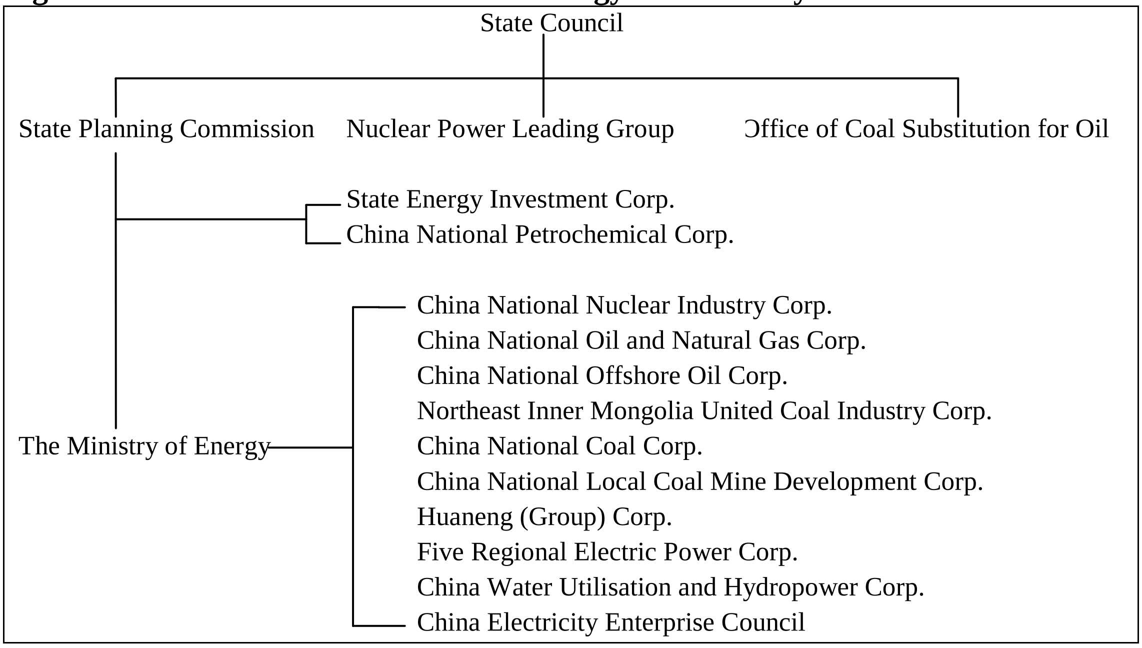
Source: Lee (2010) and compiled by author.

Table A4.1: Development of Energy Institution, 1980-1998

Year	Institution
1981	Establishment of State Energy Commission
1982-1983	Splitting of the Ministry of Petroleum into three organisations: CNOOC—for offshore oil Sinopec—for petroleum chemical industry CNPC—for onshore oil and gas
1983	Merging of the Ministry of Electric Power Industry and the Ministry of Water Resources Utilisation into the Ministry of Water Resources and Electric Power
1985	Establishment of the Huaneng Electricity Generation (in 1988 renamed the Huaneng Group, Inc.)
1988	Establishment of the Ministry of Energy Abolishment of the Ministry of Coal Industry, Petroleum Industry, Water Resources and Electric Power, and Nuclear Industry Formation of the National Energy Investment Corporation
1980s-1992	Establishment of offices (divisions) of energy conservation in commissions, line ministries, and local bureaus Setting up of more than 200 energy conservation technology centres
1993	Dissolving of the Ministry of Energy Re-establishment of the Ministry of Coal Industry and the Ministry of Electricity Industry Establishment the State Economic and Trade Commission
1994	Expansion of government ministries and energy corporations

Source: Zhao, 2001.

Figure A4.1: Structure of the Chinese Energy Bureaucracy in 1988



Source: Yang, *et al.*, 1995.

Table A4. 2: Government Agencies and their Functions in the Energy Sector

Government Agencies	**Function**
NDRC NEC NEA	Making national energy strategies and policies Formulating energy development plans Suggesting reform of relevant energy system Managing oil, natural gas, coal, electric power and nuclear Managing national oil reserves Developing policy measurements for energy conservation Energy pricing Total energy demand control and approval of large energy projects
Ministry of Land and Resources	Preparation of mineral resource-related laws and regulations Managing permits for exploration and mining of oil and natural gas Managing geological surveys and relevant information Managing charges and use of mineral resource compensation fees Managing oil and natural gas reserves
Ministry of Water Resources	Managing development of hydro power
Ministry of Industry and Information Technology	Regulating and developing industry and information industry Developing clean production and energy conservation Supervising industrial environmental protection
Ministry of Agriculture	Managing development of biomass, wind and solar
Ministry of Science and Technology	Managing energy R&D programs Formulating policy and plans for energy R&D Research and development for new and renewable energy resources
Ministry of Commerce	Managing permits and quotas for import/export on energy products Preparation of operation policy for oil product market Supervision and control market operation
Ministry of Environment Protection	Making environmental regulations Supervising implementation of laws and regulations Assessment of environmental impact reports on energy projects
Ministry of Finance	Management and supervision of investment and income
Ministry of Foreign Affairs	Overseas energy
State Administration of Work Safety	Supervising and monitoring energy enterprises to implement laws, regulations and policies for production safety Inspection of serious accidents in energy production
State Administration of Taxation	Collecting and managing the resource taxes for energy resources Collecting and managing taxes for use of mining areas or fields
State Electricity Regulatory Commission	Administering and regulating the electricity and power industry

Note: NRDC = the National Development and Reform Commission; NEC = the National Energy Commission; NEA = the National Energy Administration
Source: Xu, 2010 and Zhou *et al.*, 2010.

Table A4.3: Top Ten Priorities and Ten Key Projects

Top Ten Priorities
1. Establish a system for monitoring, evaluating, and public reporting of energy intensity 2. Eliminate and/or reduce production from inefficient industrial processes, technologies and facilities, reduce production from inefficient industrial facilities, encourage high technology industry, and shift production away from energy-intensive industries 3. Implement 'Ten Key Projects' 4. Implement 'Top-1000 enterprises energy conservation action' 5. Strengthen existing and create new financial incentives for energy efficiency, including preferential tax policies on energy conservation 6. Strengthen energy conservation laws, regulations and standards 7. Strengthen government programs to gather energy data 8. Establish a national energy conservation centre 9. Promote energy efficiency and conservation in government agencies 10. Expand media programs, strengthen training of energy conservation professionals
Ten Key Projects
1. Renovation of coal-fire industrial boilers using 70 million tons of coal annually 2. District level combined heat and power projects (saving 35 Mtce annually) 3. Waste heat and pressure utilisation (1.35 Mtce/year) 4. Oil conservation and substitution saving 38 million tons of oil 5. Motor system energy efficiency saving 20 terawatt-hours (TWh) 6. Energy systems optimisation 7. Energy efficiency and conservation in buildings saving 100 Mtce/year 8. Energy-efficient lighting saving 29 TWh 9. Government procurement of energy efficiency products 10. Monitoring and evaluation system

Source: Zhou *et al.*, 2010.

Construction of Carbon Dioxide Emission Coefficients

According to IPCC guidelines, we can construct carbon dioxide emission coefficients by multiplying the carbon emission factor of the corresponding fuel by the fraction of carbon oxidised and the molecular weight ratio of carbon dioxide to carbon. There are certain small variations in carbon emission factors reported by different sources (see Table A5.1). By comparison, we use the average of various energy-related carbon emission factors as the final one (Hu and Huang, 2008; Zhang *et al.*, 2010; Fang and Deng, 2011). Oxidisation factors vary across industries, ranging from 0.8 to 0.98. We use the default values, 0.98 for coal, 0.99 for oil and 0.995 for natural gas (IPCC, 2006). The molecular weight ratio of carbon dioxide to carbon is 44/12. Based on the data and methodology mentioned above, we calculated the carbon dioxide emission coefficient (see Table A5.2).

Table A5.1: Carbon Emission Factors from Different Sources (T C/TCE)

Source / Fuel type	DOE/EIA	IEEJ	CAE	MEP	MST	ERI/NDRC	Average
Coal	0.702	0.756	0.680	0.748	0.726	0.7476	0.7266
Oil	0.478	0.586	0.540	0.583	0.583	0.5825	0.5588
Natural Gas	0.389	0.449	0.410	0.444	0.409	0.4435	0.42241

Note: T C/TCE = ton of CO_2 per ton coal equivalent; TCE refers to the amount of energy released by burning one metric ton of coal. It is widely used in Chinese energy statistics.

DOE/EIA: US Department of Energy/Energy Information Administration; IEEJ: Institute of Energy Economics, Japan; CAE: Chinese Academy of Engineering; MEP: Ministry of Environmental Protection of China; MST: Ministry of Science and Technology of China; ERI/NDRC: Energy Research Institute, National Development and Reform Commission of China.

Source: Hu and Huang (2008); Zhang *et al.* (2010); Fang and Deng (2011).

Table A5.2: Carbon Dioxide Emission Coefficient

Fuel Type	Coal	Oil	Natural Gas
CO_2 ton per TCE	2.611	2.028	1.541

Source: Author's calculation.

Table A5.3: Some Key Indicators of China's 29 Provinces in 2009, 2000 and 1990

		2009			2000			1990		
Province	**Size (1000 m²)**	**Population (million persons)**	**GRP per capita (yuan, at 1978 price)**	**Energy Consumption (million tce)**	**Population (million persons**	**GRP per capita (yuan, at 1978 price)**	**Energy Consumption (million tce)**	**Population (million persons)**	**GRP per capita (yuan, at 1978 price)**	**Energy Consumption (million tce)**
Coast al	**1061.7**	**527.52**	**7739.23**	**1428.76**	**487**	**2629.03**	**626.17**	**429.25**	**1027.11**	**393**
Beijing	16.8	17.55	13342.59	44.88	13.64	4188.49	31.66	10.86	2131.97	27.07
Tianjin	11.3	12.28	11802.09	43.91	10.01	3773.55	28.52	8.81	1583.81	18.88
Hebei	187.7	70.34	4721.21	212.18	66.74	1756.92	98.24	61.59	672.51	61.12
Liaoning	145.9	43.19	6786.57	172.04	41.35	2601.74	105.96	39.17	1253.72	74.33
Shanghai	6.3	19.12	15162.78	70.03	16.74	6264.35	51.16	13.37	2701.65	31.41
Jiangsu	102.6	77.25	8594.40	196.48	73.27	2667.53	82.34	67.67	967.32	49.12
Zhejiang	102	51.80	8551.62	133.20	46.80	2973.79	54.36	42.38	986.46	21.24
Fujian	121.3	36.27	6500.45	61.99	34.10	2631.30	20.55	30.37	794.70	12.34
Shandong	153.8	94.70	6896.67	320.22	89.97	2187.73	80.89	84.93	822.24	63.33
Guangdong	180	96.38	7893.16	165.48	86.50	2573.77	70.21	63.47	1135.05	34.41
Hainan	34.0	8.64	3689.01	8.35	7.88	1513.77	2.28	6.63	583.03	0.49
Central	**1669.9**	**421.69**	**3949.76**	**815.5**	**421.19**	**1351.72**	**376.11**	**385.53**	**617.89**	**279.95**
Shanxi	156.3	34.27	4137.11	142.99	32.48	1162.10	66.31	28.99	684.16	44.58
Jilin	187.4	27.40	5118.45	72.74	26.27	1626.50	36.24	24.40	805.36	34.10
Heilongjiang	454.8	38.26	4324.43	96.71	38.07	1942.50	60.33	35.43	932.82	52.45
Anhui	139.7	61.31	3162.43	85.40	62.78	1116.19	38.57	56.61	533.22	19.59
Jiangxi	167	44.32	3328.04	45.05	41.49	1100.93	22.37	38.11	519.78	16.97
Henan	167	94.87	3956.43	191.36	94.88	1247.67	72.54	86.49	499.37	48.18
Hubei	185.9	57.20	4365.95	95.01	59.60	1650.91	48.20	54.39	700.37	31.22
Hunan	211.8	64.06	3928.06	86.24	65.62	1296.34	31.55	61.11	562.95	32.86
Western	**5650.7**	**364.39**	**3518.01**	**758.5**	**354.97**	**1072.87**	**282.85**	**322.31**	**479.85**	**159.16**
Sichuan	563.7	110.44	3608.14	156.04	112.56	1147.90	68.53	108.13	380.74	55.36
Guizhou	176	37.98	1984.96	71.36	37.56	609.53	37.52	32.68	144.68	19.98
Yunnan	383.3	45.71	2600.69	94.07	42.41	1062.26	22.57	37.31	524.22	16.75
Shaanxi	205.6	37.72	4173.23	79.78	36.44	1050.22	25.24	33.16	624.74	20.37
Inner Mon.	1183	24.22	7748.70	144.68	23.72	1351.84	34.43	21.63	780.43	21.10
Gansu	454.4	26.35	2477.07	51.37	25.57	888.80	28.98	22.55	539.44	20.08
Qinghai	722.3	5.57	3740.34	13.80	5.17	1128.88	5.14	4.48	721.97	3.87
Ningxia	66.4	6.25	4172.05	33.65	5.54	1102.65	8.78	4.66	726.48	6.50
Xinjiang	1660	21.59	3817.02	74.13	18.49	1699.83	34.87	15.29	790.06	19.91
Guangxi	236	48.56	3078.71	39.62	47.51	994.28	16.79	42.42	489.19	11.24

Source: Author's calculation based on the *China Statistical Yearbook* (2010) and *China Energy Statistical Yearbook* (2010).

Table A5.4: CO_2 Emissions from Different Sectors (10^4 tons)

Year	Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	Industry	Construction	Transport, Post and Telecommunications	Wholesale, Retail Trade, Catering service	Other services industries	Total industries emission	Residential	Total emission
1980	2 914.55	92 220.91	1 234.37	3 767.23	848.97	2 236.88	103 231.89	21 585.94	124 817.83
1985	4 121.44	120 116.33	1 495.39	4 447.57	1 377.06	2 957.23	134 515.02	29 140.09	163 655.11
1986	4 285.54	129 557.17	1 404.57	4 301.81	1 341.25	3 130.75	144 021.09	29 508.62	173 529.71
1987	4 266.81	142 896.25	1 306.06	4 366.07	1 539.82	3 234.82	157 609.83	30 747.00	188 356.83
1988	4 437.02	152 068.09	1 172.66	4 378.50	1 832.05	3 567.16	167 455.48	32 684.78	200 140.25
1989	4 069.03	163 631.08	1 278.04	4 312.66	1 911.54	3 710.12	178 912.47	31 785.83	210 698.29
1990	3 908.21	168 814.11	1 193.32	4 220.04	1 974.64	3 719.85	183 830.17	31 145.56	214 975.73
1991	3 963.02	161 124.13	1 148.12	3 646.48	1 821.99	3 535.35	175 239.08	29 541.07	204 780.16
1992	3 297.95	183 935.47	1 203.72	3 420.82	1 766.77	3 375.51	197 000.24	26 150.25	223 150.49
1993	2 987.23	187 177.02	1 024.10	3 267.66	1 801.52	3 938.71	200 196.24	25 064.18	225 260.42
1994	3 333.56	204 796.63	961.82	2 828.74	1 870.75	4 474.09	218 265.59	22 834.04	241 099.63
1995	3 496.21	246 423.71	833.83	2 939.08	1 835.61	3 733.69	259 262.13	25 234.14	284 496.27
1996	3 575.84	261 083.00	870.82	3 298.25	2 025.26	3 453.02	274 303.20	26 855.23	301 158.43
1997	3 593.93	261 588.33	723.21	3 221.87	1 630.89	1 387.16	272 115.38	22 824.14	294 939.71
1998	3 587.03	249 151.92	1 149.49	3 158.69	1 819.13	1 476.41	260 342.66	16 568.99	276 911.65
1999	3 239.96	263 311.89	998.39	3 019.31	1 731.46	1 417.18	273 715.19	15 681.98	289 397.17
2000	1 740.83	282 735.06	1 027.52	2 333.13	2 522.88	2 179.60	292 539.02	15 772.55	308 311.56
2001	2 983.31	275 147.89	1 021.70	2 572.05	1 615.42	1 258.09	284 597.57	14 603.80	299 201.37
2002	3 026.77	291 917.89	1 059.00	2 614.20	1 634.31	1 247.93	301 500.10	14 179.13	315 679.24
2003	3 139.42	349 857.37	1 102.44	2 559.58	1 746.39	1 310.12	359 715.76	15 246.12	374 961.43
2004	4 198.57	406 259.74	1 150.51	2 140.12	1 814.50	1 652.33	417 215.76	15 243.32	432 459.08
2005	2 823.29	476 789.63	1 156.28	2 659.46	3 343.94	3 387.09	490 159.70	18 723.05	508 882.75
2006	2 802.41	526 996.35	1 250.01	2 878.32	3 610.85	3 624.20	541 162.14	18 718.15	559 880.29
2007	2 834.06	567 130.53	1 190.45	2 807.44	3 853.07	4 140.84	581 938.39	18 203.90	600 142.29
2008	2 839.71	589 916.30	1 145.28	3 187.40	3 704.80	3 770.09	604 563.58	17 060.63	621 624.29
2009	2 905.69	625 218.08	1 205.28	3 506.28	4 179.91	4 188.73	641 248.98	17 012.78	658 261.75

Note: China's material production sectors are primary sector, secondary sector and tertiary sector. Primary sector includes farming, forestry, animal husbandry, fishery and water conservancy; secondary sector includes industry and construction; the tertiary sector refers to transport, post and telecommunications, and wholesale, retail trade and catering service.

Source: Author's calculation.

Table A5.5: CO_2 Emissions from Different Provinces (10^4 tons)

Coast	Beijing	Tianjin	Hebei	Liaoning	Shanghai	Jiangsu	Zhejiang	Fujian	Shandong	Guangdong	Hainan	Total coast
1990	6 490.28	4 558.04	15 648.35	17 962.41	7 513.59	12 134.64	5 342.47	3 046.02	15 354.34	8 223.29	126.82	91 057.8
1995	6 941.14	6 023.79	22 069.17	20 423.54	10 183.49	19 598.36	9 556.92	3 779.56	20 504.42	12 790.78	313.36	122 627.6
2000	7 482.85	6 779.23	24 918.43	24 932.85	12 231.73	20 349.73	13 266.30	5 066.92	19 581.48	16 682.49	508.86	138 534.6
2003	7 526.74	8 301.89	30 287.08	25 578.88	14 494.56	25 213.86	17 682.20	7 152.37	34 895.74	20 848.34	1 665.01	175 964.5
2004	9 198.56	9 056.71	34 679.20	30 001.42	15 066.10	30 253.38	21 025.08	8 246.44	42 035.45	23 353.26	1 050.32	202 940.8
2005	8 697.07	9 791.76	41 405.66	31 898.44	15 978.35	38 842.79	24 223.44	9 817.22	56 643.47	25 346.83	1 070.99	239 492.6
2006	8 839.21	9 942.78	43 095.32	34 382.92	15 363.32	42 174.16	27 508.20	11 061.25	65 483.27	28 843.50	1 177.10	260 362.8
2007	9 278.01	10 369.22	49 536.64	38 177.54	15 296.08	45 766.17	31 176.03	12 439.04	71 423.43	32 636.90	1 510.61	286 433.6
2008	9 603.64	10 044.68	49 827.58	39 552.09	16 459.46	46 670.75	31 311.63	13 234.06	75 327.87	34 724.89	1 658.04	297 103.0
2009	9 761.94	10 502.42	53 922.56	40 627.24	16 193.42	48 182.12	32 415.60	15 478.01	78 753.68	38 512.26	1 758.04	313 689.7

Central	Shanxi	Jilin	Heilongjiang	Anhui	Jiangxi	Hubei	Henan	Hunan	Total central
1990	11 631.48	8 580.61	12 854.49	4 900.87	4 302.52	7 720.08	12 240.24	8 311.31	70 541.6
1995	20 553.02	9 785.99	13 406.34	7 824.51	5 844.03	11 575.75	16 202.30	11 438.17	96 630.1
2000	17 297.34	9 001.69	14 091.57	9 782.17	5 564.27	12 288.37	18 271.59	7 787.43	94 084.4
2003	27 077.51	11 377.32	15 069.89	12 699.55	6 671.02	15 364.33	23 488.30	10 766.60	122 514.5
2004	28 808.74	12 198.54	17 206.97	13 573.07	8 418.01	17 223.36	30 459.62	13 124.32	141 012.6
2005	31 533.31	13 166.33	19 228.55	14 502.94	8 981.84	19 158.05	36 867.16	18 312.61	161 750.8
2006	36 687.44	14 744.05	20 549.27	15 491.61	9 789.19	21 145.90	41 787.25	19 310.35	179.505.1
2007	40 510.35	15 547.56	22 322.30	17 365.37	10 814.08	22 975.82	44 113.85	21 269.54	194 918.9
2008	38 131.67	17 515.16	22 550.52	20 362.63	11 065.14	21 897.53	47 338.51	20 913.44	199 774.5
2009	37 138.88	18 145.13	23 186.82	21 781.44	11 350.63	23 782.99	48 718.07	21 899.83	206 003.8

Western	Sichuan	Guizhou	Yunnan	Inner Mon.	Shaanxi	Gansu	Qinghai	Ningxia	Xinjiang	Guangxi	Total western	National
1990	13 622.05	5 149.53	4 280.40	5 509.22	5 265.96	4 843.35	978.09	1 685.66	4 823.48	2 930.22	49 087.9	210 687.3
1995	18 116.81	7 463.55	5 346.54	6 631.35	7 356.89	6 424.13	1 118.01	2 212.05	6 619.21	4 468.49	65 757.0	285 014.8
2000	16 551.56	9 714.72	5 819.69	8 902.15	6 227.17	6 905.08	1 233.81	2 214.16	8 044.04	4 333.22	69 945.6	302 564.6
2003	20 803.89	12 782.76	8 720.32	14 951.03	9 123.25	8 442.48	1 557.78	4 977.16	9 635.10	5 100.31	96 094.1	394 573.1
2004	23 407.28	15 121.03	10 764.91	17 940.67	11 313.72	9 077.19	1 554.97	5 691.88	10 124.11	6 578.86	111 574.6	455 528.1
2005	26 679.38	14 316.95	12 587.81	26 478.87	11 662.28	10 174.89	2 271.16	6 358.58	12 186.12	7 055.61	129 771.7	531 015.0
2006	29 340.42	15 945.56	14 066.11	33 330.99	14 890.34	10 883.67	2 592.09	7 044.63	13 245.62	7 790.31	149 129.8	588 997.7
2007	32 405.59	17 399.84	14 324.42	28 199.71	16 109.15	11 882.83	3 019.97	7 705.10	14 463.88	9 182.27	154 692.8	636 045.3
2008	33 896.97	18 247.69	14 872.02	35 196.03	18 001.41	12 440.62	3 240.11	8 123.75	15 899.32	9 127.81	169 045.7	665 923.3
2009	37 967.47	18 571.92	16 665.56	36 986.67	19 393.05	12 203.08	3 184.22	8 500.60	16 975.69	10 193.46	180 641.7	700 336.2

Source: Author's calculation.

Dean (2002)'s Model

Income Equation

Assuming the perfect competitive market with fully employed factors, a small open economy[102] produces two types of goods, dirty (X_1) and clean (X_2). There is no trans-border pollution or consumption pollution. Thus, all emissions are generated by production. To consider the environment as a factor of production, Lopez (1994) and Dean (2002) point out that total industry output is also a function of the environment factor of production. Therefore, production in each sector is a function of the restrictiveness of the trade regime (T), the stock of conventional factors of production, capital (K_j) and labour force (L_j), and the ability to generate environmental damage (E_j), as follows:

$$X_i = A(T)h_j[F(L_j, K_j), E_j] \qquad (8.1A)$$

where $h(\cdot)$ is increasing and concave in $F(\cdot)$ and in E_j and is characterised by constant returns to scale in L_j, K_j, and E_j (j=1, 2). F(.) is an aggregator of the stock of conventional factors. Factor productivity (A) is assumed to be a function of the limit control of the trade regime (T). Increased openness is assumed to lead to higher total factor productivity ($A^{'} < 0$) (Dean, 2002).

The specification (8.1A) assumes weak separability between conventional factors of production and the environmental factors, which means, the marginal rate of technical substitution between capital and labour is assumed to be independent of the level of pollution. Weak separability is a condition for the production function defined only in terms of conventional factors of production to make sense when factors other than the

[102] In order to make the theoretical model simpler, we made this assumption. If thinking of China as large, the terms of trade will be affected by trade policy.

conventional ones change. Moreover, it simplifies the algebra substantially by allowing the consideration of the interactions between one aggregate conventional factor and the environmental resources (Lopez, 1994). Dirty goods are defined as those which are relatively pollution-intensive. Thus, production of X_1 uses a higher ratio of E_j to conventional factors at any given factor price ratio than production of X_2.

Assume this country is producing dirty goods using the abundant resources in which they have a comparative advantage. Emissions taxes (τ) are used to internalise the costs of environmental damage. And there exists some level of trade restrictions on imports of X_2. As in Jones (1965) and Dean (2002), the unit cost functions for each good can be used to derive changes in relative factor prices as a function of changes in relative goods prices:

$$(\hat{\tau} - \widehat{w}) = (1/|\theta|)(\widehat{p_1} - \widehat{p_2}) \tag{8.2A}$$

where ^ is proportional change in a variable, w is the wage paid to the factors of production, p_j are domestic prices of goods j; θ_{ij} is the share of input i (i=F, E) in unit cost of output j, and $|\theta| = |\theta_{E1} - \theta_{E2}| > 0$. Note that $(\widehat{p_1} - \widehat{p_2}) = (\widehat{p_1^*} - \widehat{p_2^*} - \widehat{T})$ (where * indicates world prices). Equation (8.2A) captures changes in the derived demand for inputs as a function of changes in relative goods prices.

With constant return to scale, Dean (2002) expresses the changes in the composition of output:

$$\widehat{X_1} - \widehat{X_2} = (1/|\lambda|)(\widehat{E} - \widehat{F}) + \sigma_s |\theta| (\hat{\tau} - \widehat{w}) \tag{8.3A}$$

where σ_s is the elasticity of substitution along the production possibility frontier; λ_{ij} is the share of total i used in producing j, and $|\lambda| = |\lambda_{E1} - \lambda_{E2}| > 0$.

Nominal income growth can be expressed as follow:

$$\widehat{Y_N} = \alpha_1 \widehat{p_1} + \alpha_2 \widehat{p_2} + \alpha_1 \widehat{X_1} + \alpha_2 \widehat{X_2} = \alpha_E \hat{\tau} + \alpha_F \hat{w} + \alpha_E \widehat{E} + \alpha_F \widehat{F} \qquad (8.4A)$$

where α_j is the share of sector j (j=1,2) in total output; α_i is the share of input i (i=E,F) in total output.

Using (8.2A) and (8.4A), real income growth is then:

$$\widehat{Y} = \alpha_E \widehat{E} + \alpha_F \widehat{F} + \widehat{A} \qquad (8.5A)$$

Dean (2002) supposes the technological change is Hicks-neutral, which means that changes in the technology do not affect the optimal choice of other factors, and it is identical across sectors. Assuming the world's stock of knowledge (N) grows at a rate ω, that $N_t = N_0 e^{\omega t}$, and a country's ability to access that knowledge is inhibited by its trade restrictions (T). Therefore, the world's knowledge accumulation occurs at rate $\beta(T)\omega$ ($0 < \beta < 1$, and $\beta' < 1$); the local knowledge is given, at rate δ for simplicity. Then (8.5) may be written as:

$$\widehat{Y} = \alpha_E \widehat{E} + \alpha_F \widehat{F} + \beta(T)\omega + \delta \qquad (8.6A)$$

Emission Equation

Following the standard labour supply model, where workers' utility is a function of both goods consumption and leisure, for the supply of environmental damage (E), let utility be a positive function of goods consumption and environment damage, $U=U(C_1,C_2,E)$

where C_j is consumption of good j, and E is environment damage. Given consumers value goods, and goods production generates some level of pollution, utility maximisation yields consumer demand for a level of clean environment and, a level of environmental damage they are willing to tolerate. Consumers will tolerate higher levels of E only if firms pay a higher charge. Assuming a clean environment is a normal good, an increase in income raises demand for a clean environment and hence reduces supply of E.

Referring to Martin and Neary (1980), Dean (2002) introduces a variable supply of environmental damage into the HO model. Write the supply of E as $E = \gamma(\tau, p_1, p_2, Y_N)$. Totally differentiating and writing in proportional change, we have

$$\widehat{E} = \varepsilon_\tau \hat{\tau} + \varepsilon_{E1} \widehat{p_1} + \varepsilon_{E2} \widehat{p_2} + \varepsilon_Y \widehat{Y_N} \qquad (8.7A)$$

Where ε_τ, $\varepsilon_{E1,}$ ε_{E2} are own price elasticity and ε_Y is income elasticity.

Assuming that a consumer's demand for a clean environment (supply of E) is homogeneous of degree zero in income and prices, which means if we scale income and price by the same proportion, the value of E does not change. Substituting for changes in commodity prices from (8.2A), equation (8.7A) can be written as:

$$\widehat{E} = \varepsilon_{\tau w} (\hat{\tau} - \widehat{w}) + \varepsilon_Y \widehat{Y} \qquad (8.8A)$$

where $\varepsilon_{\tau w}$ is a reduced-form environment supply elasticity with respect to changes in relative factor prices, assuming commodity prices adjust to a change in factor prices. Dean (2002) states that if the supply curve does not bend backward, $\varepsilon_{\tau w} > 0$; and since a clean environment is a normal good, ε_Y <1. Thus, a rise in income reduces the amount of environmental damage individuals are willing to allow at any price τ .

Substituting (8.2A) to (8.8A) yields emissions growth as a function of changes in relative goods prices and growth in real income:

$$\widehat{E} = (\varepsilon_{\tau w} / |\theta|)(\widehat{p_1^*} - \widehat{p_2^*} - \widehat{T}) + \varepsilon_Y \widehat{Y} \tag{8.9A}$$

Together, equations (8.6A) and (8.9A) form a simple simultaneous system describing income growth and emissions growth as functions of the level of trade restriction. In this system, trade liberalisation affects the growth of emissions in two ways. First, recall that changes in the domestic terms of trade is $(\widehat{p_1} - \widehat{p_2}) = (\widehat{p_1^*} - \widehat{p_2^*} - \widehat{T})$, thus a reduction in trade restrictions will raise the relative price of dirty goods (see equation 8.9A), leading to increased specialisation in these goods, then increase the growth of emissions. This is the direct effect of freer trade on the composition of output (composition effect), which is captured by the first term in equation (8.9A). Second, lower levels of restrictions will raise income growth (see equation 8.6A). This increase in income will reduce the growth of emissions since it reduces the willingness of individuals to supply the environment as a factor of production at any level of emissions change. This is the indirect effect of freer trade, via its effect on income growth (technique effect), which is captured by the second term in equation (8.9A).

List of Candidate's Publications

Jayanthakumaran, K., and Liu, Y., 2009. "Trade and Investment Liberalisation and Industry Per Capita Emissions in China: 1990-2007". *School of Economics, Working paper* series 09-13, University of Wollongong.

Jayanthakumaran, K., and Liu, Y., 2011. "Trends in Emissions across the States of Australia 1998/99 to 2007/08: A Shift-share Analysis". *Agenda: a journal of policy analysis and reform*, 18(1): 53-66. (ADBC rank = B)

Jayanthakumaran, K., and Liu, Y., 2012. "Openness and the Environmental Kuznets Curve: Evidence from China". *Economic Modelling*, 29: 566-576. (ERA rank = A)

Jayanthakumaran, K., Verma, R., and Liu, Y., 2012. "CO_2 Emissions, Energy Consumption, Trade and Income: A comparative analysis of China and India". *Energy Policy*, 42: 450-460. (ERA rank = B)

Liu, Y., 2009. "Economic Growth and the Environment: China, 1990-2007", paper presented to 2009 Melbourne Conference on China, Melbourne, Australia, July 13-14.

Liu, Y., 2010. "Evidence on EKC hypothesis in China: 1990 to 2007", *IABE-2010 Bangkok-Proceedings*, 7(1): 55-59. (with Jayanthakumaran, K.)

Liu, Y., 2012. "Economic Growth, Trade, Energy Consumption and Environment in China: A Panel Cointegration Analysis", paper presented to *the 5th Annual Joint Workshop, the Department of Economics, BK21 Project*, Seoul National University, Seoul, Korea

Liu, Y., and Jayanthakumaran, K 2013. "Economic Growth, Trade, Energy Consumption and Environment in China: A Panel Cointegration Analysis", paper presented to *the 8th Annual International Symposium on Economic Theory, Policy & Applications, the Economics Research Unit of ATINER*, Athens, Greece, July 22-25.

Liu, Y., Jayanthakumaran, K., and Neri, F., 2012. "Who is Responsible for the CO_2 Emissions that China Produces?", *School of Economics, Working paper* series 12-08, University of Wollongong.

Liu, Y., Jayanthakumaran, K., and Neri, F., 2012. "Who is Responsible for the CO_2 Emissions that China Produces?", *Energy Policy*, 62: 1412-1419.