# Statistical Analysis of Environmental Protection and Economic Growth in China

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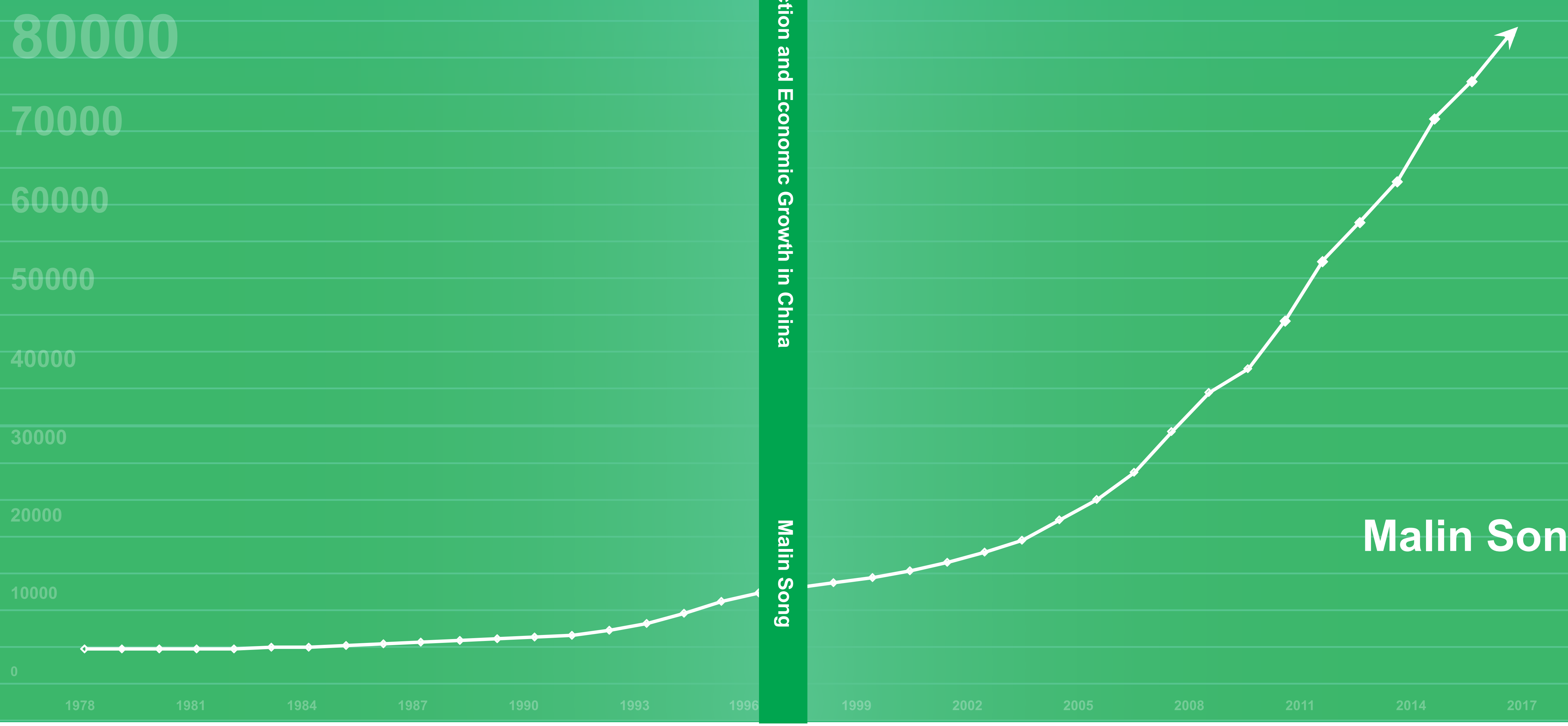

# Statistical Analysis of Environmental Protection and Economic Growth in China

Statistische analyse van milieubescherming en economische groei in China

Thesis

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# Contents

# 1

# *Introduction*

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# Chapter 1. Introduction

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In China, the past 30-plus years of reform and opening-up have enabled a rapid development of the economy. However, this growth has come at a devastating cost to the quality of the environment. As a result, developed countries are placing increasingly stringent requirements on the environmental attributes of Chinese exports. This chapter introduces the research topic of this thesis: how can China address its increasingly serious environmental challenges, and how does it manage the tradeoff between economic growth and environmental protection? Following this introduction, we conduct in the subsequent chapters a theoretical, methodological, and empirical analyses of the relevant research questions.

## 1.1 Study Motivation

Natural resources and a healthy environment are required for the survival and development of human society. However, these resources have been exploited to the point where environmental pollution has begun restricting economic growth, and people now realize that such resources are precious and limited. As a result, climate change, which refers to a dramatic change in the statistical distribution of weather patterns over a period (from decades to millions of years), has become a primary issue in many countries. The dominant cause of climate change is human activity, including increasing levels of greenhouse gases, deforestation, and increasing concentrations of aerosols. The global problems related to environmental pollution and the gradual depletion of natural resources have led to worldwide concern over how to develop the economy and sustain the environment (Meadows, 1972; Brown et al., 1993; World Commission on Environment and Development (WCED), 1987). The 15th National Congress of the Communist Party of China prioritized a sustainable development strategy as being necessary for the modernization of China, treating it as a guiding ideology for the future development of society. Sustainable development is based on the coordination and mutual development of society, the economy, the population, and energy, and focuses on protecting the environment. In its 2012 report, the 18th National Congress of the Communist Party of China emphasized the construction of an ecological civilization, given China's energy constraints, serious environment pollution, and degraded ecosystem. This included proposing a series of requirements, such as optimizing the spatial pattern of land development, promoting comprehensive energy conservation, increasing the intensity of ecological and environmental protection, and strengthening the system through which an ecological civilization can be constructed (Anshan et al., 2011; Zhu et al., 2015). Globalization has resulted in greater awareness of environmental pollution as a problem that must not be neglected.

By the end of 2006, China was the greatest producer of carbon dioxide emissions. Since then, China's economic dependence on fossil energy has not decreased. To achieve stable long-term economic development, China must adjust its model of economic development that currently operates at the expense of the environment. Economic growth has led to increased environmental pollution at the same time that social expectations related to environmental quality have increased. As a result, the environment has become an important economic and social resource. Conversely, as economic activities have brought about environmental changes, these changes have also influenced the economy.

In recent years, international climate negotiations (e.g., the Copenhagen Conference, the Cancun Conference, and Paris Conference) have resulted in many countries negotiating ways in which to address environmental problems. This has included establishing intergovernmental bodies, such as the Intergovernmental Panel on Climate Change (IPCC), which aim to provide objective scientific assessments of climate change that will have a significant impact on scientific research and policymaking worldwide (Stocker and Plattner, 2014).

As a result, the pressure on China to cut emissions has increased significantly, prompting the Chinese government to introduce environmental regulatory policies and to adopt several environmental regulations. China played an important role in the global climate agreement in Paris, having submitted an Intended Nationally Determined Contribution (INDC) to the Paris Agreement on June 30, 2015. As such, China committed to the following actions: reaching peak carbon dioxide emissions around 2030; reducing its carbon dioxide intensity by 60 to 65 percent from the 2005 level;

expanding the share of non-fossil fuels by 20 percent; and increasing the level of forest stock by 4.5 billion cubic meters from the 2005 level. However, implementing these policies and measures will increase the costs of pollution control in certain industries. Additionally, several researchers have claimed that tighter limits on emissions deter investment in new equipment and improvements in productivity (Nelson et al., 1993; Joshi et al., 1997). The increased costs to managing pollution mean some businesses may need to cut expenditures elsewhere, such as reducing the size of their workforce. Hence, a consequence of increased regulation may be an increase in unemployment. If companies are unable to meet the necessary discharge standards, the additional investment required for pollution management may be too high, increasing the risk of business failure and potentially resulting in greater unemployment. An alternative view is that stringent water and air pollution standards may spur innovation. This is known as the Porter hypothesis. According to this model, there is a mutually beneficial relationship in having a cleaner environment coexist with economic growth through innovation. Many empirical studies based on the United States (US) and Organization for Economic Co-operation and Development (OECD) data suggest that stringent environmental policies can stimulate environmental Research and Development (R&D) activities (Jaffe and Palmer, 1997; Arimura et al., 2007). Overall, the goals of economic development may not always be consistent with the goal of environmental protection. However, ideal strategies should increase efforts to both protect the environment and to improve the coordination of sustainable development in order to achieve economic growth.

## 1.2 Essential causes of environmental pollution

Environmental pollution describes the increasing decline of environmental quality due to the effects of harmful factors that are directly or indirectly discharged by humans into the environment during economic growth. There can be contributions of economic, social, and institutional factors to environmental pollution. In this section, essential causes of environmental pollution are discussed based on economic aspects.

### 1.2.1 Lagging economic development mode

The Chinese economy has developed rapidly over the past 40 years. Its current economic development pattern is extensive growth. This mode of expanding economic development is characterized by relying on resource inputs and causes, increasing deterioration of the environment in China and of the world. The conflicting goals of protecting the environment and achieving economic development continue to grow significantly as China enters the mid-and post-industrialization phase with a high proportion of heavy industries. Thus, meeting the challenge of how to best maintain and encourage scientific development will be a fundamental step for constructing an ecologically civilized society.

### 1.2.2 Gross Domestic Product-only theory

Countries will strive to increase the Gross Domestic Product (GDP) and growth rate to improve their overall competitiveness. However, this index essentially only measures the economic size of a country without consideration of economic quality and benefits. Thus, the use of the GDP index is limited because it does not measure resource allocation efficiency or environmental cost. Additionally, regional differences of economic development, local government officials' pursuit of political achievements, and the one-sided concept of acquiring economic benefits at the cost of the environment and resources will further accelerate environmental problems in a short period of time (Cumberland, 1979).

### 1.2.3 Economic globalization

With economic globalization, factors that cause environmental pollution in different countries become increasingly complex. Multinational corporations of developed countries may transfer industries with high pollution and emissions to underdeveloped areas not only to obtain greater labor cost benefits and market advantages but also to avoid the restrictions on economic growth designed to protect the environment in their own country (Unruh and Moomaw, 1998). However, this practice greatly affects the resources and the environment in the countries of capital inputs. The economy in different countries all over the world varies greatly, and some developing countries and areas are weaker participants in the global industrial chain. To shrink the gap, developing countries may choose to lower their standards of environmental regulations and blindly expand the scale of capital attraction, which may provide short-term economic benefits but further aggravates local environmental problems.

## 1.3 The topic: relationship between the environment and the economy

Development is the final goal of the environment and economy subsystems. Coordination includes the internal and external restriction to the development process that guarantees the proper allocation and harmonious development for each process to ensure continuous optimization of the whole system and to achieve advanced and well-organized objectives. Coordinated development between environment and economic growth means that every factor in environmental and economic systems is mutually consistent and coordinative.

The process of coordinated development emphasizes integrity and integrality rather than the unilateral growth of a subsystem. This can occur with different degrees of coordination, as shown in Figure 1-1. Before time T, coordinated development is low. Low coordination indicates that attainment of economic benefits occurs at the cost of resources and the environment. Though limits for resource consumption and environmental damage are not surpassed, ecological benefits and resource utilization efficiency are low in this situation. Conversely, high coordination after time T means that economic growth is disconnected from resources and the environment, which guarantees that resources can be fully utilized and environmental pollution be improved concurrently with fast, continuous, and stable economic growth.

Countries worldwide have different degrees of coordination reflecting their different stages of development. At the beginning of economic development, the marginal effect brought about by economic expansion is much larger than the influence resulting from improvement of the environment. Hence, people are more inclined to prioritize fast economic growth rather than the quality of the environment. Accordingly, the degree of coordination is at a low level between the two subsystems. Then, as the economic level improves and people's living standards increase, the marginal effect produced by the improvement of the eco-environment becomes larger than the influence due to economic expansion. In this case, the degree of coordination between the two subsystems is increased and economic effects keep pace with environmental effects.

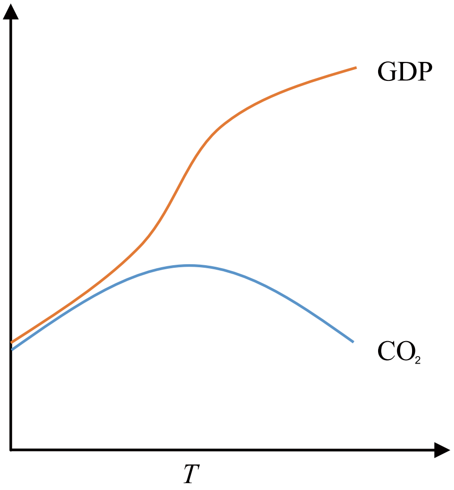


**Figure 1-1: Low and high coordination between the environment and the economy**

Note: Time T can be expected to be 2020, according to the Paris Climate Accord, which was signed by nearly every country to decrease greenhouse gas emissions. This new accord set the goal and direction to address climate change, adaptation, and finances starting in 2020. Developed countries have committed to provide 100 billion US Dollars to developing countries every year.

This study aims to characterize the relationship between economic growth and environmental protection. China is a country with a vast territory and abundant resources. Owing to varied economic structures, industrial policies, environmental policies, and natural environmental conditions in different regions, there are significant differences in environmental protection and pollution across regions. Meanwhile, different industries also demand different attention from the government for creating environmental policies. Therefore, we raise our first question:

*RQ1: What are the properties of pollution emissions at the regional and industrial levels?*

It is widely believed that economic growth would boost energy consumption. However, there is another effect associated with economic growth that should be considered. With the development of an economy, the demand for environmental quality increases over time. China's environmental protection standards and regulations are becoming stricter than before, efforts are being undertaken to minimize the negative environmental impacts of energy production, transportation, conversion, and utilization.

Since energy is the main source of pollution, this kind of environmental protection will inevitably have an impact on energy consumption. So far, relevant research on this topic is scant. Therefore, we raise our second question as follows:

*RQ2: How do economic growth and environmental total factor productivity affect energy consumption growth?*

A mutually dependent and mutually reinforcing relationship, often called coupling, may exist between the environmental protection and manufacturing industries during an economy's development process. From the perspective of policymakers, industry coupling is an important tool to upgrade the traditional manufacturing industry and boost the emerging environmental protection industry. Through industry coupling, governments can help to maximize resource utilization efficiency, promote the flow of resource elements, and build a new low-carbon, high-efficiency recycling industrial system. In this study, we will examine the relationship between the environmental protection and manufacturing industries and whether the coupling relationship exists between them:

*RQ3: What is the relationship between the environmental protection and manufacturing industries?*

It is commonly believed that intensifying environmental regulation would lead to industrial transfer or upgradation, which could subsequently reduce or inhibit employment. Environmental regulation is needed not only to achieve economic development but also for survival. However, employment generation is also one of the four major goals of the macroeconomy. The Chinese local government usually chose stable employment over environmental protection in the early stages of economic development. In recent years, however, the Chinese central government has begun to stress on environmental quality, and consequently, the problem of unemployment has become severe. How to deal with the relationship between environmental protection and stable employment has drawn increasing attention from both the government and society. Therefore, we also focus on the following concern:

*RQ4: Will environmental regulations affect employment?*

For the convenience of analysis, the above questions are sorted in the following order: phenomenon – mechanism – consequence. In the subsequent chapters, we extend our study in line with this order, where various methodologies and methods are used to answer these questions, including a Data Envelopment Analysis (DEA), the Slack-Based

Method (SBM), the Malmquist index, and regression analyses, among others. These methodologies and methods are proven to be effective using numerical examples and applications.

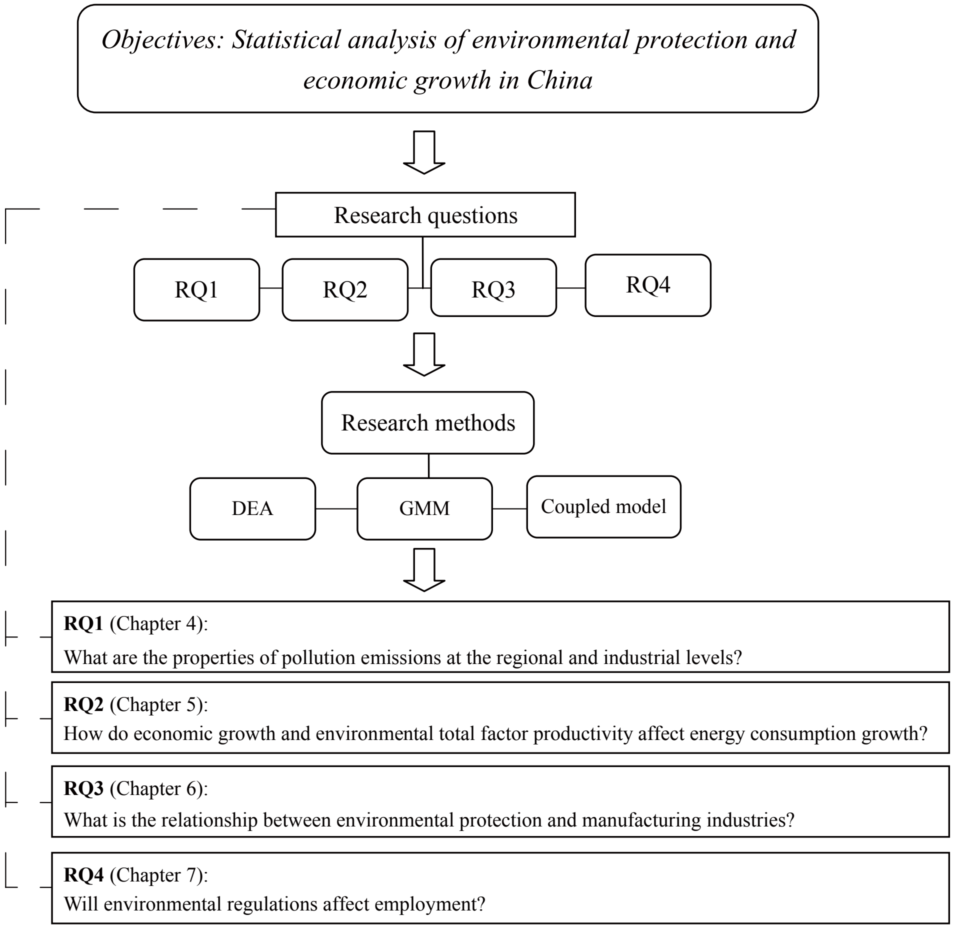


**Figure 1-2: Thesis roadmap**

## 1.4 Organization

This thesis comprises eight chapters. Chapter 1 introduces the research topic of the thesis, namely, how China can address the environmental challenges of, and the tradeoff between economic growth and environmental protection.

Chapter 2 reviews the relevant literature. This chapter offers a survey of the literature on the relationship between economic development and environmental protection, and includes the Environmental Kuznets Curve (EKC), environmental efficiency assessments, and environmental regulation practices. Related chapters are Chapters 4 and 7, which examine empirical studies on Chinese environmental regulation effects, and Chapter 5, which presents topics related to environmental efficiency evaluation.

Chapter 3 summarizes the relevant methods used in this thesis, namely, the DEA, Generalized Method of Moments (GMM), and coupling model. These methods are adopted in Chapters 4–7.

The aim of Chapter 4 is to explore the properties of pollutants in various regions in China. The chapter compares water, air, and solid waste pollution across 31 provinces and autonomous regions at the regional level, and then summarizes the pollution conditions for all types of regions.

In Chapter 5, DEA is used to simultaneously consider the desirable and undesirable outputs under environmental constraints, which includes calculating the efficiency and environmental total factor productivity. Here, it is concluded that China's early excessive emphasis on economic development caused the degradation of the environment, and explore the current state of pollution in different regions and industries in China. After the reform and opening up of the country's economy, the government has paid more attention to the relationship between environmental degradation and economic growth. The introduction of corresponding policy has, to an extent, controlled the deterioration of the environment, but further efforts are needed.

Chapter 6 uses enterprise survey data and a coupling evaluation model to examine the relationship between the production and environmental protection industries.

Chapter 7 analyzes the influence of environmental regulations on employment in terms of product demand and supply using GMM estimation. Here, from the perspective of open conditions, we test the mechanism of the relationship between FDI, environmental regulation, and employment.

The final Chapter 8 is a summary of the preceding chapters and proposes several areas for future research. This chapter also provides recommendations for the design of environmental protection policy.

## 1.5 Conclusion

In the face of increasingly serious environmental pollution, China have to change the current development pattern that operates at the expense of ecology and the environment. This chapter introduced the topics and structure of this thesis, including the theoretical, methodological, and empirical analyses. Specifically, the key research questions are as follows. What is the environmental situation facing China? What is the relationship between environmental degradation and economic growth? What effect does environment regulation have on economic activities, such as employment?

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# 2

# Environmental protection and economic development literature

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# Chapter 2. Environmental protection and economic development literature

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## 2.1 Introduction

The economic and social construction in China have made great achievements that amazed the world. Unfortunately, there are now problems including resource shortages and environmental pollution. Although governmental institutions have set different policies and taken actions to prevent and handle environmental problems, the results are still not satisfactory. In fact, the exhaustive exploitation of resources and environmental pollution have been serious problems around the world since the Industrial Revolution. Realization of sustainable development becomes a common human goal with the development of human society and economy. The idea of coordinated development is needed to address the contradiction between environment and economy, which requires nature's resources to be utilized in a sustainable, careful, and rational manner. At the same time, the environmental problems need to be solved in a process of balanced economic growth. This chapter will first explore the basic idea of coordinated development. Over time, the implications of coordinated development have varied dramatically due to preference changes of people. The environment and ecosystem are exploited more and more in modern societies.

This chapter provides a background to China's environmental pollution and discusses the relevant literature on the relationship between environmental protection and economic development, which presents a basis for the upcoming chapters, including chapters 4-7, which primarily involve the empirical aspect of environment and growth issues. First, we use descriptive statistics to explore the environmental pollution in China, including that of carbon dioxide, sulfur dioxide, and other pollutants. Second, we focus on the Jevons paradox and the Environmental Kuznets Curve (EKC). The former refers to the counterintuitive phenomenon in which technological progress is usually followed by greater energy consumption. The latter illustrates the relationship between economic development and environmental quality, which is sometimes described by an “inverted U-shaped” curve. The content of this chapter is closely related to the next several chapters. In this chapter, we also summarize the literature on the classification of environmental regulations and Chinese environmental regulations. In particular, we focus on the latter regulations and their effects, especially on sustainable development, Foreign Direct Investment (FDI), innovation, and employment. This chapter is closely related to Chapters 4 and 7, where we study the effects of China’s environmental regulations empirically. Here, we also discuss environmental efficiency, environmental policy, and its classifications as a preparation for Chapter 5, which evaluates the environmental efficiency of provinces and cities in China. The final section summarizes the chapter.

## 2.2 Status of China’s environment pollution

China is currently in a critical stage of rapid industrialization and urbanization, while facing serious problems with pollution, ecological fragility, and other external effects. The coal-dominated energy structure and labor-intensive industrial structure make it difficult to limit greenhouse gases and decrease environmental pollution. During the 12th Five-year Plan period (2011–2015), the conflict increased between China’s rising demand for energy resources and the constraints on the resource environment. The carbon dioxide is a major contributor to the greenhouse effect. Its emissions cannot be obtained directly from statistics, because such emissions are mainly the result of energy consumption during production. Therefore, in order to understand China’s carbon emission trends while ensuring data integrity and reliability, this chapter examines data on the three main energy consumption processes (raw coal, crude oil, and natural gas, measured in terms of standard coal) that contribute to the growth of carbon emissions in 31 Chinese provinces and autonomous regions. Here, we multiply the Intergovernmental Panel on Climate Change (IPCC) energy carbon emission coefficients (0.756 for raw coal, 0.586 for crude oil, and 0.448 for natural gas) by the consumption of each resource to determine the total carbon dioxide emissions in each case (unit: ten thousand tons).

Then, we use these results to determine the national carbon dioxide emissions for the years 1996–2012. We also calculate the carbon dioxide emissions per Gross Domestic Product (GDP) (i.e., carbon emission intensity). The latter indicator indicates the relationship between the economy and carbon dioxide emissions, and is used in the test of the low-carbon development model. A higher carbon emission intensity denotes greater pollution per unit of GDP. The carbon emissions and gross domestic product are shown in Table 2-1.

**Table 2-1: Carbon emissions and GDP data**

| Year | $CO_2$ (million ton) | GDP (billion yuan) | $CO_2$/GDP (ton/thousand yuan) |
|---|---|---|---|
| 1996 | 967.1 | 7117.7 | 0.136 |
| 1997 | 952.7 | 7897.3 | 0.121 |
| 1998 | 946.2 | 8440.2 | 0.112 |
| 1999 | 941.8 | 8967.7 | 0.105 |
| 2000 | 987.7 | 9921.5 | 0.100 |
| 2001 | 1031.9 | 10965.5 | 0.094 |
| 2002 | 1119.5 | 12033.3 | 0.093 |
| 2003 | 1274.5 | 13582.3 | 0.094 |
| 2004 | 1480.4 | 15987.8 | 0.093 |
| 2005 | 1723.5 | 18493.7 | 0.093 |
| 2006 | 1933.6 | 21631.4 | 0.089 |
| 2007 | 2071.8 | 26581.0 | 0.078 |
| 2008 | 2164.8 | 31404.5 | 0.069 |
| 2009 | 2294.0 | 34090.3 | 0.067 |
| 2010 | 2508.5 | 40151.3 | 0.063 |
| 2011 | 2751.7 | 47310.4 | 0.058 |
| 2012 | 2813.0 | 51894.2 | 0.054 |

Source: Calculated by author.

As shown in Table 2-1, China's overall carbon emissions rose from 967 million tons to 2813 million tons during the period 1996–2012, an increase of 190.88%. Total carbon emissions remained stable before 2002, increasing by only 6.7%, which is consistent with the preliminary effects of the "total amount control" environmental policy proposed in 1996. However, carbon emissions have exhibited significant growth since 2002, growing by 124% during the period spanning the 10th and 11th Five-Year Plans. This may be partly the result of the influx of polluting manufacturing enterprises funded by foreign capital after China joined the World Trade Organization (WTO) at the end of 2001. In the case of China's economic development, the "pollution haven" hypothesis applied. According to this hypothesis, foreign-owned enterprises relocate to new countries with less regulation and oversight in order to avoid the cost of domestic strong environmental regulation intensity. China's weak environmental regulations provided the necessary conditions for the entry of this type of enterprise.

Plotting the carbon emission intensity (Figure 2-1) shows the pattern of economic development and environmental pollution. Overall, carbon emissions per unit of GDP are decreasing, indicating that China has is ensuring economic growth while effectively controlling environmental degradation. Prior to 2001, the carbon emission intensity decreased significantly. In the period of the 10th Five-Year Plan, GDP grew with total carbon emissions, and the carbon emission intensity remained at around 0.93. In the 11th Five-Year Plan period, after the sixth Environmental Protection Conference, many environment, energy, and industry policies were introduced and the carbon emission intensity began to decline.

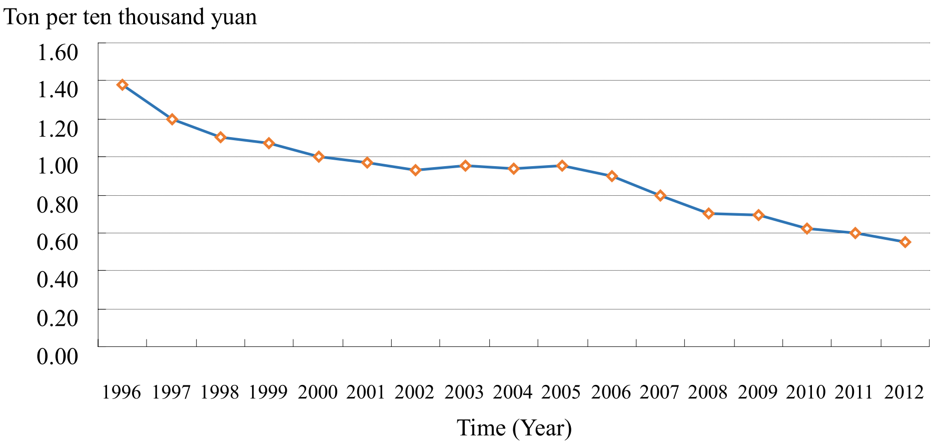


**Figure 2-1: The trend in carbon emission intensity in China from 1996 to 2012**

## 2.3 The relationship between environmental protection and economic development

### 2.3.1 The Jevons paradox

With continual technological advances and increased production efficiency, the economies of many developing countries have grown rapidly. However, this economic growth also leads to increased consumption of resources, which poses a threat to the ecological environment. Many countries have begun to realize the importance of environmental protection and have attempted to deal with environmental pollution issues by adopting modern technology that increases environmental efficiency. However, this introduces the so-called Jevons paradox, a well-known paradox in environmental economics, also called the rebound effect. In 1865, the English economist William Stanley Jevons observed that technological progress usually increases the efficiency of coal consumption, but that this then causes an increase in the consumption of coal, rather than a decrease.

With the rapid development of science and technology in the automotive field, the efficiency of gasoline use has improved, which may have led to a decrease in the consumption of gasoline. Instead, technological improvements led to a large increase in the demand for motor cars, which led to increased fuel consumption, greater air pollution from vehicle emissions, and an increased threat to the environment. Some researchers claim that this describes the situation in China. Despite the improvement in energy efficiency, China's gross carbon dioxide emissions show an upward trend (Fan et al., 2012).

Jevons (1906) introduced the "Jevons paradox" based on utility theory. This model is also described as the technical expansion paradox, in which the increased efficiency of using natural resources increases rather than decreases the demand for these resources, as well as the subsequent consumption of the resource. This is contrary to the goal of reducing resource consumption by improving the efficiency of resource utilization. Many scholars have sought to understand and interpret the rebound effect or Jevons paradox, despite it describing a development law for one thing or phenomenon rather than being a complete theoretical system or application method.

Polimeni and Polimeni (2006) constructed models based on the United States (US) energy data and found that the rebound effect or Jevons paradox did not hold at the macroeconomic level. Amado and Sauer (2012) conducted a comparative analysis between the neoclassical and ecological economics perspectives, finding that the persistent presence of the Jevons effect in the long run is an anomaly. Overall, the results on this topic are mixed, and further research is needed.

Since the industrial revolution, the consumption of energy has been an indispensable driver of economic growth. China is currently in the industrialization and urbanization development stage, and the resulting increase in the demand for polluting energy has had a negative impact on the environment. Over the period 1996 to 2012, China's GDP grew from 7.18 trillion yuan to 54.03 trillion yuan. Taking inflation into account, the real GDP growth rate is about 9.8%. With the rapidly increasing size of the economy, China's carbon dioxide emissions have exhibited a dramatic upward trend, from 1 Gt in 1996 to 2.8 Gt in 2012, representing an average increase of 6.6% per year. This rate is lower than the increase in GDP because of the development of technology. In this period, Research and Development (R&D) expenditure increased from 40 billion yuan to 1.5 trillion yuan. Thus, carbon dioxide emissions per GDP, or eco-efficiency, shows a downward trend, which is what is needed. Figure 2-2 shows the situation in China.

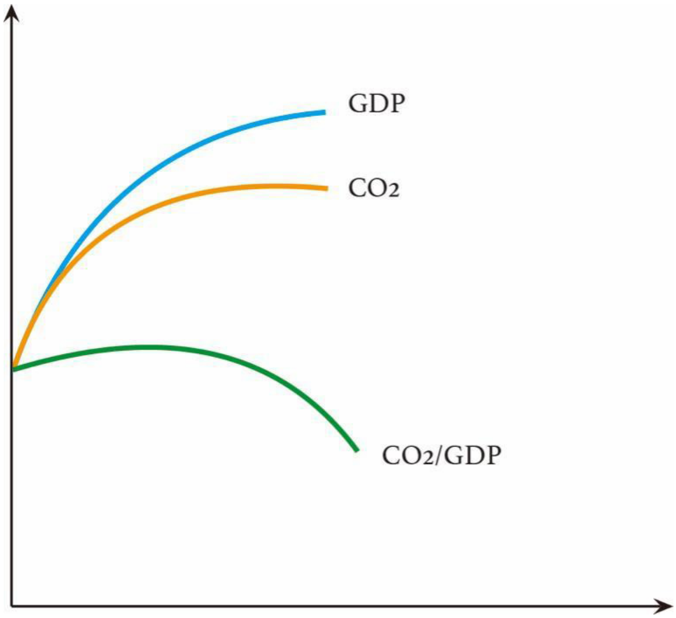


**Figure 2-2: The trend of GDP and carbon dioxide**

Nevertheless, the growth rate of carbon emissions is very high, particularly since China joined the WTO in 2001. Weak environmental regulations have stimulated the move of polluting manufacturing enterprises to China, funded by foreign capital. This is known as the "pollution haven" hypothesis.

No matter if the Jevons paradox is valid or not in the case of China, the country faces a serious problem of environmental pollution that accompanies rapid development. Environmental protection is now an important priority for Chinese citizens. The government is facing unprecedented pressure to balance economic development and environmental protection. Appropriate environmental–economic development policies need to be set that are specific to the needs of a region, based on the situation in that region.

### 2.3.2 Environmental quality and economic growth

The authors of "The Limits to Growth" proposed that environmental restrictions should be respected while pursuing economic benefits (Meadows et al., 1972). With the economic development, some scholars thought that economic growth would improve the environmental quality when the economic development level exceeded the value of a certain inflection point. This is the famous hypothesis of the EKC that was first proposed by the American environmental economists Grossman and Krueger in 1991 (Grossman and Krueger, 1991). Figure 2-3 depicts the EKC. This hypothesis reflects two trends. One trend is that the function form between pollution and growth depends on the economic structure. When the average personal income level is low, the industry dominates economic growth. Excessive reliance on the input of energy resources causes a high degree of environmental damage. This sage is referred to as the period before time T in Figure 2-3, corresponding to the low coordination mentioned in section 3.2. However, with the change of the economic development stage, the economic structure changes correspondingly. The output value of the manufacturing industry is transferred to the service industry with lower levels of consumption and pollution. Industries that relied heavily on raw materials are transferred to the production equipment industry with high levels of human resources and technology. All these changes will relieve the contradiction between growth and pollution. The second trend is that when the average personal income level is low, people will preferentially seek the satisfaction that results from economic growth and then gradually turn their attention to ecological benefits after basic life demands are satisfied (Grossman and Krueger, 1994 and 1995).

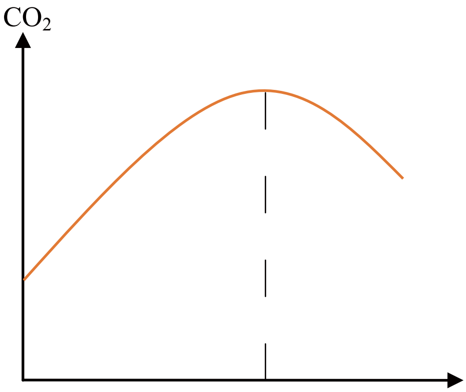


**Figure 2-3: KEC and coordinated development**

Many scholars have applied the EKC to assess China's development, finding that the economy shows an inverted U-shape curve (Peng and Bao, 2006a, 2006b; Wen and Cao, 2009; Diao et al., 2009; Han et al., 2011; He and Wang, 2013; Liu, 2012). The curve indicates that environmental conditions worsen with economic development, and then improve when economic development reaches a certain level. Sun and Deng (2014) analyzed the long-run dynamic relationship between the economy and changes in the environment in Jiangsu Province using a Vector Auto-Regressive (VAR) model. They found a positive correlation between economic development and environmental deterioration. Other scholars have performed analyses on data from China's provinces and cities and applied the EKC to different regions (Zhou et al., 2015).

In the EKC development model, development below the ecological balance line is considered "green development." However, the levels of development in developing and developed countries have already exceeded the ecological balance, and most regions have not yet reached a "turning point." Therefore, to make reasonable policies, it is crucial to increase environmental management efforts and to implement phased control objectives so that environmental resources can remain below the "limits to growth."

Based on the development levels of different countries, the basic features of an EKC include taking a long time to reach the turning point and a significant "inverted U shape." However, in developed countries such as the United States, the curve is flatter and can quickly reach the turning point. In addition, developed countries may transfer polluting enterprises to developing countries to decrease the time it takes them to reach the turning point. The existence of different turning points and lax environmental regulations in developing countries ultimately enables countries to absorb high-polluting enterprises and to delay the pace of their sustainable development because these companies bring positive effects to their economies. In China, there is significant variation in the economic development of industries between regions. This presents a challenge for the government in terms of enacting adaptable and widely applicable environmental policies. Thus, there is a strong need to use Chinese EKC theory to analyze the economy–environment development conditions in various regions and sectors.



The Chinese government claims it will not repeat the practice of “treatment after pollution,” which has often been standard in industrialized countries. However, the economic development in China shows it has not escaped “treatment after pollution.” The current environmental crisis shows that China is still in the upstream phase of the EKC, while the overall trend of deterioration of the environment has not changed. What China needs to do is to make this curve smoother in order to minimize environmental degradation while maintaining economic growth. China should not misinterpret the EKC, believing that the environment will improve if economic development continues, or use economic development as an excuse to destroy the environment. In the latter case, the “turning point” will never arrive for China.

There are many explanations about EKC, the following reasons are considered here:

*(1) Environmental regulation*

Government regulation is generally considered as a main factor affecting environmental pollution (Panayotou, 1997; Bhattarai and Hammig, 2001). During the initial stage of economic growth, the government cannot impose strong environmental regulation due to the low fiscal revenue. In addition, the focus of the government is on how to reduce poverty and achieve economic growth. Therefore, during this period, the situation of the environment would get worse with the development of the economy (Dasgupta et al., 2006). However, economic development does provide the necessary tools to enforce environment regulation activities. When the economy development reaches a certain level, the government has resources and the capability to implement stringent environmental regulations. Then, the degree of environmental pollution would reduce gradually. The empirical study of Bhattarai and Hammig (2001) shows governance and institutional factors play more significant roles than income or other macroeconomic conditions.

*(2) Market mechanism*

As the economic level increases, the degree of resource exploitation and utilization will also increase. The most direct indicator of the scarcity of natural resources on the market is the rapid increase of the market equilibrium price of a resource. This increases the input cost of enterprises, and the increased cost pressure will encourage enterprises to improve their resource utilization efficiencies and to reduce economic running costs. Thus, environmental pollution can be improved through the self-regulation of the market (Lanoie, 1998). However, there is little evidence that supports this mechanism. The oil crises of 1973/74 and 1978/79 did not result from this mechanism but from political conflict. Therefore, this mechanism still remains to be tested.

*(3) International trade*

In open economic systems, the degrees of environmental regulations among different countries are different, which allows for trade and investment between countries. The economic development level in developing countries lags behind that of more developed countries and they lack the capital and technology to support economic growth. In this context, the effect of industrial allocation of international trade will allow developing countries to produce pollution-intensive products while developed countries consume such products. Thus, through a multinational corporation strategy of industrial transfer, developed countries improve their environmental quality, and developing countries become the “refuge of pollution” due to relatively low environmental standards together with lower labor costs and market differences. Thus, the environmental quality in developing countries further deteriorates (Lopez, 1994; Copeland-Taylor, 2004).

*(4) Scale effect and structure effect*

With an increase of the per capita income, the economic scale is further enlarged. An increase in economic aggregate demand can, to some extent, aggravate the consumption of resource factors, but the expansion of economic scale will be accompanied by change and optimization of the economic structure. Specifically, when the economic scale is small, agriculture is the primary sector of the national economy and the reliance on resource factors is low. Accordingly, pressure on the environment is low. Along with the expansion of economic scale to satisfy the demands of production and living for infrastructure and housing, industrial sectors will replace agriculture sectors and become dominant in the national economy. The rate of resource exploitation and consumption will be much higher than that of resource regeneration. Pollutants that result from resource consumption will have certain effects on the environmental quality. Nevertheless, when the economic scale is expanding, the industrial structure will be upgraded and heavy industries that relied on high resource consumption will be gradually replaced by the technology-intensive information industry and the low-energy-consuming and low-emission service industry, which will improve the environmental quality (Panayotou, 1993).

*(5) Living demands of residents*

Demands for livable environment exhibit income elasticity. In countries at an earlier economic development level, the demands of people for environmental quality are low as the overall social income can only meet the demands of residents for adequate food and clothing. Therefore, during this early stage of economic development, there is relatively little damage to the environment and there is little attention to ecological quality. However, when income reaches and exceeds a certain point, the income elasticity of demands for ecological quality will increase and people's environmental expectations will increase as well. Thus, people will gradually turn their attention to ecological quality and demand improved ecological benefits. Residents will be willing to accept extra costs to improve the environmental quality (Neha, 2002; Manuelli, 1995).

## 2.4 Environmental regulations

### 2.4.1 Definition of environmental regulation and classifications

Earlier scholars considered environmental regulation solely as administrative measures that governments use to directly intervene with environmental problems in a way that is not related to the market, mainly with prohibitions and licenses. This definition reflects that the enaction and implementation of earlier environmental regulations was the sole responsibility of government agencies, and market and enterprises were not participants in the decision-making but were subject to the restrictions of environmental regulations. Later, with the application of economic measures such as environmental taxes, subsidies, and deposit/refund systems, scholars gradually found that multiple kinds of policies could produce the effects of environmental regulation. Thus, the meaning of environmental regulation was redefined and the concept of indirect intervention was added as a separate component from direct governmental intervention, expanding the concept of environmental regulation to include economic measures and market mechanisms. Additionally, the implementation of Eco-labels, environmental qualification, and voluntary agreements as new society-driven steps developed since the 1990s made scholars review and expand the meaning of environmental regulation again; therefore, voluntary environmental regulation is now included as a separate means of environmental regulation distinct from command-control environmental regulation and market-based incentive environmental regulation (Pargal and Wheeler, 1995; Kathuria and Sterner, 2006). In our opinion, environmental regulations constrain the behavior of individuals or organizations, irrespective of whether such restraints are voluntary or compulsory, to achieve the goal of harmonious development between humans and nature. Regulation is a form of social management that falls between governmental ownership and a laissez-faire market.

Scholars have different definitions of regulation. Spulber (1999) defines regulations as general rules by which administrative bodies directly or indirectly intervene in a market mechanism and that are formulated and executed by administrative bodies. Chang and Wang (2010) describe environmental regulations as a series of measures used by governments to protect the environment from further deterioration. These measures are indispensable to environmental treatment and control under the current situation of global warming. Overall, regulation refers to an intervention imposed by the government on micro individuals based on rules, which is a form of public policy for managing economic activities. The purpose of regulation is to achieve economic growth and development. There are two kinds of regulation widely used in the existing literature: economic regulation and social regulation. Economic regulation includes price control, investment approval, licenses grant, and so on. On the other hand, social regulation mainly concerns the individuals who are in a weak position. Such regulations aim to protect consumers from dangerous products, protect the environment from industrial hazards, and protect. The environmental regulation highlighted in this study is a typical social regulation.

Li and Tao (2012) study the effects of environmental regulation on the Chinese manufacturing sector using panel data. They find that for heavily polluting industries, the existing intensity level of environmental regulations is at an optimum level, and can provide continuous incentives for technical innovation and efficiency improvement, which will facilitate an increase in green total factor productivity. A further increase in regulation intensity will not encourage additional investments in environmental technology. For moderate and light polluting industries, the present environmental regulation intensity is not sufficient to stimulate enterprises to conduct technological innovation and management innovation. In this situation, the intensity of environmental regulation must increase to an appropriate level. Regulation intensity is used to measure the degree of regulation. Researchers have adopted various indices to denote this variable, such as the number of environmental laws, income from sewage charges, and the proportion of sewage investment in the total cost of the enterprise, among others.

Environmental regulation differs from environmental governance. Davidson and Frickel (2004) consider that environmental governance generally refers to administrative bodies or organizations that intend to relieve existing environmental problems. They identified six concepts related to environmental governance: pluralism, capture theory, ecological Marxism, ecological modernism, society constructionism, and global greenism. Lemos and Agrawal (2006) summarized relevant research on environmental governance and emphasized a new mixed governance model that includes nations, markets, and community sectors. They advocate joint operations, public–private partnerships, and society–individual relationships to connect social and natural systems.

There are several representative opinions, as discussed below, on how to classify environmental regulations. Iraldo et al. (2011) classify environmental regulations into three types: direct regulation, economic instruments, and soft instruments. Direct regulation is also called command-control regulation, which means regulating the process of input, treatment, and output by stipulating standards, commands, and prohibitions. Economic tools, or indirect regulation, include tariffs (taxes and fees), tradable emissions permits (such as the European Union (EU) carbon emissions trading plan), environmental pollution liability insurance, among others. Soft instruments include voluntary emission reduction agreements, information tools, and environmental certification schemes. The latter include both the process and product (e.g., the environmental management system certification International Standards Organization (ISO) 14001, EU Eco-label, and government green purchasing). Zhang (2005) divides Chinese environmental regulations into two types (formal and informal) based on restrictive modes for pollution emissions. Formal regulations contain command-control regulations and market-based stimulatory environmental regulations. Informal regulations consist primarily of environmental management certifications and auditing, Eco-labels, and environmental agreements. In conclusion, environmental regulations can be classified into three groups: direct, indirect, and social communicative. Direct regulation is used to regulate the activities of production, and depends on prohibition or command. Indirect regulation is based on economic incentives and market mechanisms, rather than on prohibition or command. Social communicative regulations are derived from public pressure. Rather than using administration orders or economic incentives, these regulations rely on voluntary participation. Examples of such regulations include information disclosure, environmental certification, and environmental agreements. In fact, the classifications of environmental regulation are not mutually exclusive. Furthermore, they are not exhaustible. Overall, most researchers consistently agree that environment regulation tools include command-control and market-based regulation. However, there is considerable debate regarding the definition and scope of information disclosure, environmental certification, public participation, and so on.

### 2.4.2 Influences of environmental regulations on enterprise competitiveness

After China joined the WTO, enterprises throughout China have faced the challenges of an increase in international trade friction. To adjust to the new form of global economy, it has been important to improve China's competitiveness and trade positions. At the same time, improvement of enterprise competitiveness has become key for a country or an area to seize market shares and gain economic benefits. In other words, improvement of competitiveness is necessary for the enhancement of economic strength. Differences in voluminous aspects such as labor cost, market size, and the degree of environmental regulations among different countries have led to varied competitive pressure on enterprises. Thus, it is meaningful to study the effects of regulations.

Some economists found an inconsistent linkage between regulation and enterprise competitiveness and considered enhancement of environmental regulations and improvement of enterprise performance mutually exclusive. For example, Gray (1987) studied the entire U.S. manufacturing sector, including 450 separate industries, from 1958 to 1978 and found that environmental regulations by the Environmental Protection Agency caused a 0.44% drop of productivity growth per year. In another study, Gray et al. (2003) analyzed the Longitudinal Research Database, including 116 pulp and paper mills, from 1979-1990. They found that pollution abatement has a negative influence on productivity levels. One standard deviation increases in abatement costs decreased productivity by 5.4%. This is because enterprises will have to pay extra expenditures for environmental treatment processes to satisfy environmental regulation standards, and these increased costs will limit the improvement of economic competitiveness. Similarly, improvement of economic competitiveness relies on the input of resources, which will inevitably fail to meet the environmental restrictions on enterprises' productions and operations. These influences of environmental regulations on competitiveness can usually be summarized as the effect of "compliance cost." Scholars with this viewpoint argued that enterprises incur expenses by utilizing resources under the restrictions of environmental regulations, which increases the operating costs of enterprises. Because the production technology level in an enterprise is generally static in the short term, production may decline, thus environmental regulations may hinder economic development. Meanwhile, to satisfy the requirements of regional regulations, the extra costs for environmental treatments may limit other productive investments, leading to a decline of the potential economic output capacity and to the suppression of economic improvement.

In a contrasting view, some modern economists reasoned that the previously assessed negative influence of environmental regulations on enterprises was erroneously based on the assumption of static technological levels in enterprises. Additionally, they pointed out that with the enhancement of environmental regulations, enterprises could benefit from both the improvement of environmental quality and an increase of economic benefits. Hence, the influence of environmental regulations on enterprise competitiveness is expressed as the effect of "innovation offsets." Specifically speaking, when an enterprise faces environmental regulations, the average product price will increase, but the amplitude of increase will not surpass the cost of environmental treatment promised by the enterprise. Otherwise, the enterprise may lose profits or even face a deficit. In the long run, new production facilities of enterprises will encumber the promised environmental treatment costs, and finally the amplitude of price increases of all products will exceed the amplitude of the average cost increase. The enhancement of regional environmental regulations will increase the standards for enterprises to enter into this area, which will reduce the impact of potential competitors on original local enterprises. To summarize, with enhancement of environmental regulations, enterprises will gain more benefits in the long run than they would under weak environmental regulations. The most representative hypothesis of this view is the “innovation offsets” theory proposed by Porter (1995). Porter first questioned the traditional viewpoint that environmental regulations are restrictive to the improvement of enterprise competitiveness. He pointed out that the biggest problem of this viewpoint is that the production capacity of enterprises, preferences of consumers, and modes of resource allocation are all considered as static. Porter stated that the advantage of enterprise competitiveness could not be evaluated in terms of static efficiency and static constraints, as technological innovation comes from dynamic situations. Therefore, the influence of environmental regulations on enterprise competitiveness should not be limited to the analysis of short-term effects because the enhancement of environmental regulation would have long-term stimulatory effects on the innovation of technology in enterprises, increasing their overall competitiveness (Porter and Linde, 1995). Speaking from this perspective, environmental regulation does not necessarily increase the operating costs of enterprises but may in fact effectively stimulate technological innovation to improve the competitive edges of enterprises and to further improve local economic benefits.

Three hypotheses can be extracted with regard to the consequences of environmental regulations: First, the industrial-flight hypothesis argues that stricter environmental regulations adopted in developed countries drive companies to less industrialized countries. Thus, environmental regulations lead to a reduction in traditional industries in developed industrial countries (Garrod, 1998). Second, the pollution-haven hypothesis states that developing countries with more lenient environmental policies can attract investment from transitional industrial enterprises. This hypothesis is inferred from the theory of comparative advantage by Eskeland and Harrison (2003). Pollution havens are created for developed countries because their economic activities involving pollution are transferred to developing countries. Leonard (1988) examined the industrial-flight hypothesis with trade and investment information from four industry groups and did not find industries had left America due to environment regulation. Dean et al. (2009) tested these hypotheses by estimating a Chinese industrial location choice model, and derive results that are consistent with the pollution-haven model. Third, the Porter hypothesis states that effective environmental regulations can stimulate enterprises to innovate, improve productivity, and increase competitiveness. Albrecht (1998) researched the export performance of enterprises in air conditioning, refrigerator, and similar industries under international chloro-fluorocarbon regulations, and found that environmental regulations can enhance enterprise competitiveness, supporting the Porter hypothesis. Jaffe and Palmer (1997) used panel data from US enterprises to analyze the relationship between environmental protection expenditure and corporate innovation. Their results showed that without considering the influence of specific industrial matters, there is a strong linkage between environmental protection expenditure and corporate innovation. Rennings et al. (2006) used survey data from 2270 German EMAS-validated manufacturing facilities, and found the effects of environmental protection measures were favorable for the innovation of environmental technologies and economic performance. Iraldo et al. (2011) presented different definitions and measurement modes for the influence of environmental regulations on competitiveness and market forces. They researched this issue from two aspects: 1) how well environmental regulations would positively or negatively affect competitiveness, and under what conditions; and 2) ways of enforcing environmental regulations, and the subsequent responses of the market. Kemp and Pontoglio (2011) studied the effect of different environment protection policies on environment innovation. They determined that different environment protection policies may exert varied influences on environmental innovation, called the “scale effect” and the “demand effect” of environmental regulations by Morgenstern et al. (2002). Lanoie et al. (2011) also found that taxes have the smallest environmental innovation effect, as measured by environmental R&D investment, when they are associated with a market. As mentioned previously, the well-known Porter hypothesis, based on data on Organization for Economic Co-operation and Development (OECD) countries’ environmental policies, R&D, and environment and business achievements, found that environmental regulations promote environmental innovation (Porter, 1991; Porter and Van der Linde, 1995). Horbach et al. (2012) divided environment protection policies into those related to energy, air, water, and land energy, and studied the effect of each on ecological innovation. Yabar et al. (2012) studied the incineration emissions of dioxin and the recycling of home appliances in Japan to analyze the impact of Japan’s environmental policies on technology innovation, measured using the number of environment-related patents. They found that environment regulations promote technology innovation, based on their quantitative analysis of patent application data for the period 1990 to 2008. Goodstein (1994) argued that environment regulations help to increase employment in green industries, a result that was validated by Becker and Shadbegian (2009). Other scholars have examined the choice of environment regulation tools. For example, Böcher (2012) focused on a selection of different types of environmental policies, and established a theoretical framework that serves as a powerful reference for the selection of environmental policy tools.

Many researchers have tried to determine the relationship between the environment and employment. Morgenstern et al. (2002) determined that, from a static perspective, the effect of environmental regulations on employment can be considered in terms of “scale effects” and “demand effects.” Under the condition of fixed technology, resource allocation, and consumer demand, environmental regulations are likely to cause polluting enterprises to utilize more labor to achieve the same level of output, thus increasing the cost burden on enterprises and forming a “scale effect.” At the same time, the increase in costs increases the price of the product, which reduces consumers’ demand and weakens the international competitiveness of enterprises (Denison, 1979), inducing the so-called “demand effect.” However, from a dynamic perspective, reasonable environmental regulations can be designed to promote enterprises’ technical progress over a longer period, improve the efficiency of their resource allocation, and cover their pollution control costs. Indeed, it is possible to enhance the international competitiveness of enterprises and stimulate employment while providing enterprises with a comparative advantage, thus encouraging enterprises to produce the innovation “offsets” effect (Porter, 1991; Porter and Van der Linde, 1995).

However, it remains unclear whether environmental regulations promote or reduce employment. Some international scholars believe that such regulations reduce employment. For example, Hazilla and Kopp (1990) proposed that employment is largely associated with the level of real wages, and that more stringent environmental regulations will improve the production costs of enterprises, thereby reducing wages and decreasing the number of people employed. Low and Yeats (1992) assumed rational enterprises, and pointed out that enterprises can employ more labor in areas with weak environmental regulations, but have smaller labor forces in areas with stronger environmental regulations. Greenstone (2001) found that environmental regulations caused the loss of 59,000 jobs in nonstandard states and counties in a study based on American data.

Other scholars have concluded that environmental regulations can promote employment. For example, Environmental Product Manufacturers (EPMs) may increase their number of employees, although this increase may be minimal. This thesis is verified by Becker and Shadbegian (2009), who proposed that both EPMs and similar general enterprises increase employment in response to environmental regulations. Morgenstern et al. (2002) proposed that reasonable regulations can stimulate enterprises to optimize the allocation of resources and improve their use of technology. Thus, workers in such enterprises will either not be affected or employment will increase. Based on research using UK data, Cole and Elliott (2007) found that the costs of environmental regulations, whether exogenous or endogenous, do not significantly affect employment. Bezdek et al. (2008) proposed that protecting the environment and increasing employment are compatible and complementary, because investments in environmental protection promote the employment of accountants, engineers, and workers. Sen and Acharyya (2012) found that environmental regulations affect production efficiency, and that improving environmental standards can increase the employment of unskilled workers.

### 2.4.3 Chinese environmental regulations and their effects

Prior research on Chinese environmental regulations has focused on two aspects: sustainable development and FDI.

Many scholars believe that environmental regulations are, in general, effective in addressing environmental issues in China and promoting the implementation of sustainable development strategies. The most important goal of regulation in China is to solve environmental problems. Chen and Cao (2013) point out that improving the performance of environmental regulations and achieving expected environmental objectives means governmental groups on every level must understand environmental issues sufficiently well to revise relevant policies and encourage sustainable development, while balancing economic growth and public demands. Shi and Zhang (2006) attempted to solve the problems of rapid industrialization by establishing a new mode of industrial environmental regulation. They note that Chinese environmental regulations have changed significantly owing to the modernization of existing environmental network surveillance, changes in environmental policies, the separation of power and the market, and the establishment of public social institutions and departments for environmental regulations. Tsang and Kolk (2010) found that tension and conflict can affect environmental regulations, to a certain extent, and that a harmonious society is required for the effective development of China's environmental regulation Mol (2009) pointed out that the Chinese environmental regulation system has changed rapidly and, hence, brought about new objectives. The government has continued to reform environmental regulations by changing laws and environmental policies, and both enterprises and the public have taken greater responsibility in environmental governance. An important issue in China's environmental protection is that many laws, regulations, and standards have not been implemented by the Ministry of Environmental Protection. New relationships between the state, companies, and the population have improved the efficiency of environmental governance. Innovation and an improvement in the efficiency of Chinese environmental regulations will continue to be a key topic for future environment-related research.

High levels of FDI have accompanied the rapid economic growth in China. However, this has resulted in serious environmental pollution problems. Hence, China has implemented a series of regulations to enhance environmental protection. Researchers have studied the linkage between environmental regulation and FDI in other countries. The results of such studies indicate three main conclusions. First, the effects of environmental regulation on FDI are not notable or are indefinite in direction. Focusing on United Kingdom (UK) manufacturing firms, Manderson and Kneller (2012) found that regulation is not a key factor in site selection decisions of FDI. Second, environmental regulations stimulate FDI. Kirkpatrick and Shimamoto (2008) show that, in Japan, FDI is preferred in areas with stringent environmental regulation. Third, environmental regulations hinder the development of FDI. For example, Xing and Kolstad (2002) find that FDI inflows from the United States are determined by the environmental regulation intensity in a host country. Lax environmental regulations facilitate the inflow of heavily polluting industries.

The empirical evidence related to China is mixed. Some scholars find that regulations have no influence on FDI. Peng et al. (2011) tested the association between environmental regulation and FDI using Value-At-Risk (VAR). Their results showed that the effects of environmental regulation on FDI decrease over time, which supports the pollution-haven hypothesis. They also find the evidence in an adverse direction. In other words, FDI could affect the environment and environmental regulation. They claim that FDI explains 6.89% of the variance in pollution charge payments, and 3.9% of the variance in investment in pollution abatement projects. The authors propose that China's government became aware of the decreasing quality of the environment brought about by FDI and, thus, began promoting environmental regulations. Ljungwall and Linde-Rahr (2005) propose that FDI in China is not sensitive to environmental regulations. However, Dean (2003) examined Chinese environmental regulations and found that strengthening regulations has different impacts on different industries. Industries that use low-polluting processes are less responsive to pollution taxes than are industries that use heavily polluting processes.



Some scholars propose that environmental regulations have stimulate FDI into China. Dean et al. (2009) analyzed data from nearly 3000 FDI projects in China and found that environmental regulations had notable effects. For example, weak environmental standards attract highly polluting equity joint ventures funded from Hong Kong, Macao, and Taiwan, where the top five industries are wire, cable, cable and electrical equipment manufacturing; iron making; motor manufacturing; commonly used nonferrous metal smelting; and battery manufacturing. Guo and Tao (2009) studied FDI for a selection of regions, taking into account environmental regulations, and found that such regulations can stimulate the economy. Yang et al. (2013) compared the influence of environmental regulations on FDI and domestic investment, and found fewer effects on some FDI enterprises than on domestic enterprises. FDI is more environmentally friendly compared with domestic investment. Therefore, China's policymakers should encourage FDI. Zeng and Eastin (2012) and List and Co (2000) drew similar conclusions, consistent with the potential benefits of environmental regulation on FDI.

However, other scholars have proposed that environmental regulations would hinder the development of FDI in China. He (2006) reported that strict environmental regulations hindered the inflow of FDI, to a certain extent. At the same time, the concentration of economic activities and the population caused by an inflow of FDI can deter enforcing environmental regulations. Chen et al. (2014) researched the relationship between Chinese environmental taxes and FDI privileges, and found that provinces with low environmental taxes and relaxed environmental regulations were more likely to attract FDI, suggesting that environmental regulations are not favorable to the inflow of FDI. Liu and Chen (2009) conducted a study on the linkage between regulations and

FDI in 192 areas in China, and found that environmental regulations were the primary reason for the unbalanced regional distribution of FDI. These studies show different effects of environmental regulations on FDI, likely reflecting differences due to the specific research objects and perspective of the studies.

However, few studies have examined the linkage between environmental regulations and employment in the context of China. Lu (2011) used data on 44 industries in China to conduct a vector autoregression analysis, and concluded that environmental protection will not cause a net employment loss. The impact of a carbon tax on China's employment would be negative, but not significant. The model suggested that a 10 yuan per ton carbon tax would decrease employment growth by 0.428% for high-carbon industries, and by 0.218% for low-carbon industries. The authors proposed that increased investment in environmental protection and the growth of EPMs would stimulate employment.

### 2.4.4 Conclusions of these studies

Chinese environmental regulations and their effects are central in existing research (see Chapters 4 and 7). Previous studies tend to have a narrow focus in terms of their analysis, for example, investigating the effect of regulations on the number of jobs, or limiting their studies to the effects of regulations on the number of jobs within an industry. Few have considered the impact of other factors on employment or conducted comprehensive studies across regions and industries. Overall, the empirical results of the reviewed studies are mixed. Thus, being able to consider more factors in a model would make the predicted impact on employment of environmental regulations clearer and more reliable. Especially in the case of China, there are significant differences in capital stock and technological progress between regions, requiring a comprehensive cross-regional analysis. Another concern is that most existing studies utilize data from the United States or other developed countries. Given the variation between developing countries, additional research is required to make better predictions for the economy of China. Given China's severe environmental pollution and the high inflows of FDI, we asked whether the "refuge of pollution" hypothesis applies to China under open conditions. If it does, how do environmental regulations affect FDI in different areas? Do such regulations also influence other economic variables associated with

FDI? Understanding the potential effects of environmental regulations has important theoretical and practical significance that can guide future regulations for different regions and industries in China. This will allow for the "offsets effect," while reducing the "scale effect," thus enhancing both environmental protection and employment. In Chapter 7, we reinvestigate these issues using the GMM discussed in Chapter 3.



## 2.5 An evaluation of environmental efficiency and policy

### 2.5.1 Environmental efficiency evaluations

Along with the increased attention on environment problems, there is ongoing research on theories and methods for evaluating environmental efficiency. In recent years, scholars have begun using the DEA method for estimations by treating the production process as a "black box" to avoid considering the production function and parameter settings. Some scholars have used the DEA–Malmquist evaluation method to calculate the technology level of Decision-Making Units (DMUs) by measuring the inputs and outputs of production functions. Caves et al. (1982) decomposed DMUs into technology changes relative to the frontier level. The model considers inputs and outputs of different periods. For a given technology level of a base period, the efficiency change is measured as the efficiency ratio between the base period input-output and the terminal stage's input-output. Similarly, with the input and output fixed, the efficiency value, considering the change of the production frontier level, serves as the technical change. Färe et al. (1989) assume that reducing undesirable outputs will impact normal outputs, and that in order to reduce undesirable outputs such as pollution, good outputs must be sacrificed. Since then, the DEA method has been widely applied to environmental efficiency evaluations (Zhou et al., 2008). However, there have been few statistical tests or factor analyses of evaluation results. The core of an environmental performance evaluation of a DEA is based on how to dispose of waste materials generated during production. The analysis strategies comprise four categories. The first considers the output of the strong discretionary assumption as a replacement for weak free disposability (Färe et al., 1989, 1993, 2005; Tone, 2004; Zhou et al., 2007, 2008). The second uses an undesirable output as an input (Liu and Sharp, 1999; Hailu and Veeman, 2001; Dyckhoff and Allen, 2001), which only requires determining which indicators are smaller or larger in a simple system (Seiford and Zhu, 2002). The third includes the nonlinear and linear monotone decline transformation method (Scheel, 2001; Seiford and Zhu, 2002). The fourth category is the scale model of You and Yan (2011), where a penalty factor is proposed as a substitute for the undesirable output. The output is obtained as the original expected output divided by the penalty factor in the new system.

The Malmquist index is built on the DEA method. As the basis of the DEA method, Färe et al. (1989) turned theoretical Malmquist productivity index into an empirical index. Yuan et al. (2009) focused on Total Factor Production (TFP) measurement of productive service industries, which provides service to producers instead consumers. To do so, they collected panel data for productive services of 27 provinces for the period 1997 to 2005, and then employed a Malmquist index approach. Their results showed extensive growth in China's productive service, with the TFP declining every year, which they attributed to reasons unique to each period. The rate of decrease varied between the eastern, middle and western areas.

### 2.5.2 Performance evaluations of environmental policies

The development of indices to monitor energy and emissions has been the focus of developed countries. In 1993, the United Nations Statistics Office began to construct a comprehensive System of Environmental Economic Accounting (SEEA) as a large data set for studying the connection between the environment and the economy, providing a significant impact on the design of ecological and environmental accounting systems in all countries. The focus of the agenda index system of the Baltic Sea in the 21st century is regional cooperation and environmental protection, mainly to provide guidance for the development direction of this region. On March 7, 2005, the British government released a new national sustainable development strategy, which included a sustainable development index system of 68 indicators. Clearly, the use of indices is an important component of the strategies of developed countries when setting quantitative energy consumption and pollution-reduction goals.

The full use of natural resources in China has a key role to play in an effective economic development strategy. However, not everyone is aware of the importance of the management of natural resources (Meadows et al., 2014). Many scholars have studied energy saving and emission reduction in terms of the carrying capacity of natural resources, including Liu and Borthwick (2011), who provided a new integrated measurement system for the Carrying Capacity of the Environment (CCE). The system includes a natural resources model and an environmental assimilation model, and includes the ecosystem service ability and social support ability. This system has been used to evaluate the basic index and the comprehensive index state of CCE in Ningbo, assuming that environmental pressure would continue unabated. Hua et al. (2011) evaluated the safety of land in Dali Bai Autonomous Prefecture. For energy index evaluations, Vera and Abdalla (2006) focused on Johannesburg for a systematic energy index evaluation, and Meyar-Naimi and Vaez-Zadeh (2012) explored an energy evaluation index system for 40 cases for the period 1994–2011. Geographical Information System (GIS) technology is increasingly being used in environmental science to evaluate the carrying capacity of resources. Giupponi and Vladimirova (2006) used an Ag-PIE screening model based on GIS technology to comprehensively evaluate the factors influencing agricultural pressure on water resources in Europe. Shi et al. (2013) focused on Shanghai and used GIS technology to evaluate the urban land population carrying capacity.

In 1992, the United Nations Development Agency helped China to establish an environmental Decision Support System (DSS) in three cities. the DSS project increased the role of the government and enhanced their ability to participate in comprehensive environmental and developmental decision-making. This is an important component of a strategy to make pollution-reduction monitoring and management scientific, legal, procedural, and quantitative. Liang et al. (2004) analyzed domestic and international regional sustainable development, using the analytic hierarchy process to design a comprehensive evaluation system of economic, social, and sustainable development, resources, and environmental security. Zhang and Lan (2013) established a comprehensive evaluation system based on urban sustainable development, which they used to construct an evaluation model. The system divided the Urban Ecological Sustainable Development Index (UESDI) into four subsystems: economic, social, natural, and civilization. Bina (2010) analyzed the reasons for the low efficiency of environmental policies in China, and found that it was due to inconsistent development among the norms, organizations, and procedures. The author suggested that environmental policy should be developed harmoniously in multiple dimensions to effectively solve environmental problems.

However, prior research does not consider interactive coupling properties in the evaluation, monitoring, or assessment of environment policies. Additionally, previous studies mostly use a single evaluation method and employ a static evaluation, without capturing the dynamic change of efficiency. There have been no scientific, complete studies on reducing energy consumption or pollution evaluation, monitoring, and assessment. In our study, we adopt a coupling model (see Chapter 3) to construct a collaborative, multi-directional, coupling system in combination with an improved DEA. This analysis will contribute to the existing literature on industrial economics and environmental and ecological statistics, as well as provide technical support for economic development in China.

## 2.6 Conclusions

In this chapter, we reviewed existing literature from three aspects. First, we investigated the connection between the environment protection and the economy, including studies on the rebound effect or Jevons paradox. We found that the paradox appears to be valid in China, according to existing studies. China's gross carbon dioxide emissions grew rapidly, even as the carbon dioxide emissions intensity dropped, from 1996 to 2012. We have surveyed the well-known EKC theory and its causes. The EKC theory argues that in the earlier stage of economic growth, there is a positive correlation between development and pollution. After the income level reaches a point, development is negatively correlated with pollution. Therefore, the contradiction between economic activities and the environment may be solved. This curve is a result of environmental regulations, the market mechanism, international trade, the scale effect, and a change of residents' demands. Particularly, environmental regulations are the most important factor among all these factors.

Second, we discussed research on environmental regulations and its impacts, including issues related to Chinese environmental regulations. Overall, the existing empirical results are mixed. For instance, some researchers claim that environmental regulations can foster FDI, while others argue that there is no such effect, or that the effect is negative. We found that part of the researchers believe that environmental regulations and economic growth are mutually exclusive, which includes Gray (1987) and Gray et al (2003). The intuition behind this is that environmental regulations could lead to costs for corporations, which could then make them uncompetitive. However, from a more modern perspective, environmental regulations can stimulate technological innovation and then boost economic growth (Porter, 1991; Porter and Linde, 1995). Environmental regulation could push up the product price to offset the environmental treatment costs. In addition, environmental regulations may block off potential competitors and allow incumbents to gain benefits to invest into technological innovation, which can facilitate the overall economy in the end.

Lastly, considering the increasing amount of research on the evaluation of environmental efficiency and the performance of environmental policies, we surveyed relevant studies in this field. We found that the DEA method has been employed widely to assess environmental performance (Hailu and Veeman, 2001; Dyckhoff and Allen, 2001), but that most prior studies fail to consider both desirable and undesirable outputs in their evaluations. To address this problem, we reevaluate environmental efficiency by employing a super-efficiency SBM model. The ultimate purpose of the evaluation is to detect relationships between the energy consumption growth rate and environmental efficiency.

This section presents a theory and insights for the upcoming chapters. In the following chapters, we will study the relevant issues utilizing China's data set. In chapter 5, we employ the DEA to measure the efficiency where pollution is considered an undesirable output. The GMM and a coupling model will be adopted to explore the effect of regulations and coordinated development between different industries. The lack of analysis for a specific industry is a shortcoming of the current literature. Energy consumption and pollution emission varied significantly across all industries. For example, the secondary industry is the largest energy consumer among the three industries. Within the secondary industry, there are significant disparities for various sectors. In China, sectors such as mining, textile, petroleum processing, chemical manufacturing, smelting, and electricity production account for half of the total energy consumption. If we add the energy consumption of all the sectors for Jevons, EKC, and other analyses, we would obtain a result that would reflect the dominant industry. However, the dominant industry changes with the development of the economy. This may give us an impression that the energy consumption would vary according to the level of economic development. However, the real cause is the upgradation of the industrial structure in effect. We will conduct an industry-specific analysis in Chapter 5 to overcome this issue.

The aforementioned literature indicates that scholars have made some progress in terms of environmental protection and economic development. In the next chapter, we continue our main research based on existing literature, including several aspects. First is an empirical study of resource consumption and the cost of economic development in China (Chapter 4). Second is an empirical calculation of China's environmental efficiency (Chapter 5). Third is an empirical study of the coupling development of an environment-friendly industry and the production industry in China (Chapter 6). Forth is an empirical test of environmental regulations and employment under open conditions (Chapter 7). The last is a policy study on environmental protection (Chapter 8). The methodological section (Chapter 4) introduces DEA, GMM, and Coupling Model methods, which are respectively adopted in the above studies.

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# 3

# *Methodology*

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# Chapter 3. Methodology

3

## 3.1 Introduction

The previous chapters reviewed the development process of regulations on the environment, including the relationships between regulation and some aspects of regional economic development. In addition, the basic idea of coordinated development between the environment and economy was introduced, as well as the theoretical analysis of how to realize such coordinated development. Coordinated development, just as its name implies, means factors in environment and economic systems are coordinative. In some sense, coordinated development is green growth, a pattern characterized by balance of economic growth and environmental sustainability. Green growth has been a comprehensive consensus across the globe. An international organization, The Global Green Growth Institute (GGGI), launched by Korea in 2010 highlights achievement of a resilient world through sustainable, green growth. Both coordinated development and green growth seek integrity and integrality rather than the unilateral growth of a subsystem.

This chapter presents a comprehensive overview of relevant methods. First, we introduce the Data Envelopment Analysis (DEA), which treats the production process as a “black box” and avoids consideration of the production function and parameter settings. In recent years, along with the increased interest in environment problems, there is ongoing research using the DEA to evaluate environment efficiency. Second, we discuss the application of the Generalized Method of Moments (GMM) in an empirical study on environmental regulations and employment. Third, we introduce the coupling model method, an ideal tool for the analysis of the interaction mechanism of the two industries.

### 3.2 Data Envelopment Analysis (DEA)

In the next few chapters, we will calculate environmental efficiency using the DEA framework. For specific, super-efficiency Slack-Based Method (SBM) model, a DEA variant method, will be employed to compute 30 provinces and cities of China (not including Tibet) from 2002 to 2012. The variables include the number of employees, investments in fixed assets, disposable energy (standard coal) consumption, Gross Domestic Product (GDP), and $SO_2$. Our goal is to determine the relationship between energy consumption growth rate and environment efficiency.

The DEA method does not require a function of form and is a non-parametric way to measure productivity. The following figure 3-1 illustrates the idea of DEA and performance measurement. The production possibility set is bounded by the axes and the frontier. Points A, B, and D are inefficient because there is a distance from them to frontier. Only the point C is efficient, which is on the frontier. The DEA method uses the distance of observation point to frontier to measure the productive performance. For example, the radial DEA evaluates the point A, B, D by OA/OE, OB/OF, and OD/OE, respectively. It is easy to see that the efficiency of A is much higher than that of D. The C is higher than the rest of points in productive performance.

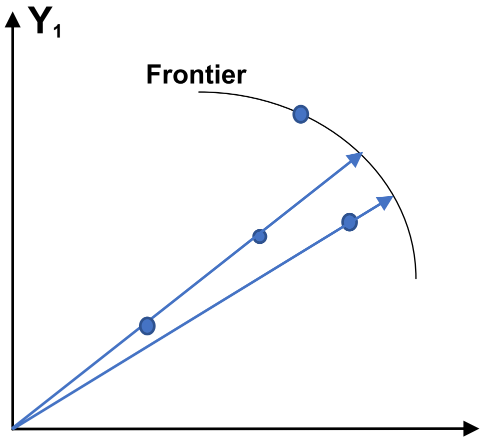


**Figure 3-1: The idea of DEA (radial)**

When there is excessive input or insufficient output, or say, there are non-zero input and output slacks, radial DEA models may overestimate the efficiency of the evaluation objects. However, an oriented DEA model ignores certain aspects of input or output, so the calculation results may not be accurate. In order to overcome these two defects, based on Tone's model (2001), Rayeni and Saljooghi (2010) and Fukuyama and Weber (2009) proposed a new model, which treats resources as input for the production possibility set. However, it is difficult to put environment factors into the feasible production set. Hence, we have built a feasible production set, including desirable output and undesirable output, to describe environmental technology. If each Decision Making Unit (DMU) uses *N* inputs $x=(x_1,\cdots,x_N)\in R_N^+$, and produces *M* good outp ts $y=(y_1,\cdots,y_M)\in R_M^+$, with *I* bad outputs $b=(b_1,\cdots,b_I)\in R_I^+$, in each period *t*=1..., *T*, the input and output of nation *K* is $(x^{k,t},y^{k,t},z^{k,t})$ . The DEA model can describe environmental technology as follows:

$$\max z_k$$

$$s.t.\begin{cases}\sum_{k=1}^{K} z_k x_{km} \geq x_{km},\ m=1,\cdots,M\\ \sum_{k=1}^{K} z_k b_{ki} \geq b_{km},\ i=1,\cdots,I\\ \sum_{k=1}^{K} z_k y_{kn} \leq y_{km},\ n=1,\cdots,N\\ \sum_{k=1}^{K} z_k =1,\ z_k \geq 0\end{cases} \tag{3-1}$$

$z_k$ is the weight of each cross section, and the sum of $z_k$ is 1. The constraint condition means the production technology returned to scale; if this constraint is removed, it means the constant returned to scale. Referring to the model of Tone (2004) and Fukuyama and Weber (2009), we constructed a model that includes resources and the environment as SBM directional distance functions:

$$\max \theta$$

$$s.t.\begin{cases}\theta+\omega X_0-\mu Y_0-\delta B_0=1\\ \omega x_j-\mu y_j-\delta b_j\geq 0,\ j=1,2,\cdots,n\\ \omega\geq 1/m(1/X_0)\\ \mu\geq \theta/s(1/Y_0)\\ \delta\geq \theta/p(1/B_0)\end{cases} \tag{3-2}$$

Where $X$ denotes the output, $Y$ denotes the desirable output, $B$ denotes the final pollution, and $(1-\mu)N$ are estimated parameters.

Model (3-2) can be rearranged into the following form:

$$\min \rho = \frac{1-\frac{1}{m}\left(\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}\right)}{1+\frac{1}{s+p}\left(\sum_{r=1}^{s}\frac{s_n^+}{y_{n0}}+\sum_{r=1}^{p}\frac{s_r^+}{b_{r0}}\right)}$$

$$\begin{aligned} \text{s.t.} &\sum_{j=1}^{n}\lambda_j x_{mj}+s_i^- = X_0,\ m=1,2,\cdots,M \\ &\sum_{j=1}^{n}\lambda_j y_{nj}-s_n^+ = Y_0,\ n=1,2,\cdots,s \\ &\sum_{j=1}^{n}\lambda_j b_{rj}-s_r^+ = B_0,\ r=1,2,\cdots,I \\ &\lambda \geq 0,\ s_i^-,\ s_n^+,\ s_r^+ \geq 0 \end{aligned} \tag{3-3}$$

Where $s_i^-$ is the slacks of inputs; $x_{mj}$ represents the inputs; $y_{nj}$ represents the outputs; $b_{rj}$ represents the undesirable outputs; $s_n^+$ , $s_r^+$ represents the slacks; $m$ represents the number of inputs; and $n$ and $r$ represent the number of good and bad outputs, respectively. Based on Charnes, Cooper, and Rhodes (1978), model (3-3) can be rewritten as follows:

$$\min \tau = \varphi - \frac{1}{m}\left(\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}\right)$$

$$s.t.\begin{cases} \sum_{j=1}^{n}\lambda_j x_{mj}+s_i^- = X_0,\ m=1,2,\cdots,M \\ \sum_{j=1}^{n}\lambda_j y_{nj}-s_n^+ = Y_0,\ n=1,2,\cdots,s \\ \sum_{j=1}^{n}\lambda_j b_{rj}-s_r^+ = B_0,\ r=1,2,\cdots,I \\ 1=\varphi+\frac{1}{s+p}\left(\sum_{r=1}^{s}\frac{s_r^+}{y_{r0}}+\sum_{r=1}^{p}\frac{s_r^+}{b_{r0}}\right) \\ \lambda,\ s_i^-,\ s_n^+,\ s_r^+ \geq 0 \end{cases}$$

In order to include the radial, added-structure Directional Distance Function (DDF), Chambers et al. (1996) proposed an indicator as a productive measure of the additional structure method. The values of environment total factor productivity are equal to the product of comprehensive technological efficiency and technological progress rate. Comprehensive technological efficiency is obtained by multiplying pure technical efficiency and scale efficiency, which is:

$$\begin{aligned} M_{\mathrm{st}} &= \left[ \frac{D_i^s(x^t, y^t)}{D_i^s(x^s, y^s)} \times \frac{D_i^t(x^t, y^t)}{D_i^t(x^s, y^s)} \right]^{1/2} \\ &= \frac{D_i^t(x^t, y^t)}{D_i^s(x^s, y^s)} \times \left[ \frac{D_i^s(x^t, y^t)}{D_i^t(x^t, y^t)} \times \frac{D_i^s(x^s, y^s)}{D_i^t(x^s, y^s)} \right]^{1/2} \\ &= E\mathrm{ffch} \times Techch \end{aligned} \tag{3-4}$$

Where $Effch = \frac{D_i^t(x^t, y^t)}{D_i^s(x^s, y^s)}$ is the relative technology efficiency change index from time s to time t. $\mathrm{T}echch = \left[ \frac{D_i^s(x^t, y^t)}{D_i^t(x^t, y^t)} \times \frac{D_i^s(x^s, y^s)}{D_i^t(x^s, y^s)} \right]^{1/2}$ is the technology progress index from time $s$ to time $t$ . The technology efficiency change index is mainly used to measure the distance between the unit inspected and production function and reflects the maximum output obtained under a certain sum of input. When the values of these two indices are greater than one, the total factor productivity of environment will be improved and is increased. If it is lower than one, it will reduce the Total Factor Production (TFP) of the environment.

### 3.3 Generalized Method of Moments (GMM) estimator

We employ the GMM estimator introduced by Arellano and Bover (1995) and Blundell and Bond (1998) in an empirical study about environmental regulation and employment. The equation is as follows:

$$d_{it} = \alpha d_{it-1} + \gamma y_{it-1} + X_{it-1}^{'}\beta + \mu_t + \delta_i + \varepsilon_{it} \tag{3-5}$$

Where $d_{\mathrm{it}}$ is the explained variable for country $i$ in period $t$; $\mathrm{y}_{\mathrm{it-1}}$ is the main explanatory variable; $X_{\mathrm{it-1}}$ are control variables; and $u_{\mathrm{t}}$ denotes the unobserved time effect. This model specification reflects the following facts. Currently, China's government is implementing a series of vigorous environmental regulation policies, which may cause other unexpected economic effects such as unemployment. As a country with a large population, a good employment rate is an important goal pursued by the Chinese government. Model (3-5) can be adopted to capture the relationship between regulation and jobs.

To deal with the correlation between $\delta_i$ and $d_{it-1}$ in (3-5), a rearrangement was employed to reflect the fixed effect $\delta_i$:

$$\Delta d_{it} = \alpha \Delta d_{it-1} + \gamma \Delta y_{it-1} + \Delta X'_{it-1}\beta + \Delta\mu_t + \Delta\varepsilon_{it} \quad (3\text{-}6)$$

Since $d_{it-1}$ is correlated with $\varepsilon_{it-1}$,(3-6) gives a biased estimate of *d*, and so do other main- explanatory variables. To get the consistent estimation of (3-6), Arellano and Bond (1991) used $d_{it-2}$ and all its lags as instruments for $\Delta d_{it-1}$ assuming no second-order serial correlation in $\Delta\varepsilon_{it}$ . The instruments' validity can be attributed to the assumption of $E(\varepsilon_{it}) = E(\varepsilon_{it} d_{it-j}) = 0$ for $j = 1,2,\cdots,t-1$ ,which is the equivalent to the following condition for (3-6):

$$E\left[A'_i \Delta\Gamma_i\right] = 0 \quad (3\text{-}7)$$

Where $\Delta\Gamma_i = (\Delta\varepsilon_{i3}, \Delta\varepsilon_{i4}, \cdots, \Delta\varepsilon_{iT})'$ and

$$A_i = \begin{bmatrix} d_{i1} & 0 & 0 & \ldots & 0 & \ldots & 0 \\ 0 & d_{i1} & d_{i2} & \ldots & 0 & \ldots & 0 \\ . & . & . & \ldots & . & \ldots & . \\ 0 & 0 & 0 & \ldots & d_{i1} & \ldots & d_{iT-2} \end{bmatrix} \quad (3\text{-}8)$$

The AR(2) and Hansen J test is recommended by Arellano and Bond (1991) to check the serial correlation of and the validity of condition (3-7), respectively. However, if the dependent variable is highly persistent, the severe weak instrument problem will make estimates and hypothesis tests misleading (Striger and Stock, 1997; Stock and Wright, 2000; Stock et al., 2002).

Arellano and Bover (1995) and Blundell and Bond (1998)

suggested augmenting the difference-GMM method with the original level Eq. (3-5).

This leads to the following additional orthogonality conditions:

$$E\left[\Delta d_{it-1}\left(\delta_i + \varepsilon_{it}\right)\right] = 0$$

Arellano and Bover (1995) and Blundell and Bond (1998) recommended checking the validity of the above conditions with the Difference-In-Hansen J-tests. This method is called "system-GMM" Considering the high persistence of the dependent variable in a country over time, we plan to use the system-GMM method.

## 3.4. Establishment of the coupling model

In what follows, we introduce coupling model methods used in coupling development analyses of the two industries, the environmental protection industry and the general production industry. It is important to understand that the interaction mechanisms of the two industries is in policy-making, policy effect evaluation, and policy optimization. The environmental protection industry is the industry that aims to conduct technological product development, commercial circulation, resource utilization, information services, project contracting, and other activities for the purpose of preventing and controlling environmental pollution, improving the ecological environment, and protecting natural resources in the national economic structure. The pollution industry is the industry that emits pollutants, such as waste gas, waste water, and solid emissions. Most production industries are classified as pollution industries, especially heavy chemical production industries. Generally speaking, the environmental protection industry and the pollution industry are distinct types of industries. The environmental protection industry serves the environmental pollution industry. However, some environmental pollution companies may provide some pollution control, so some of their plants or sectors may be part of the environmental protection industry. Nevertheless, there is also some case that no sharp and clear distinction can be found between the environmental protection industry and the general production industry. For example, owing to the backwardness of China's production technology for solar panel, a substantial amount of toxic substances, including waste water, waste gas, and waste solid, is produced in the production process. Although solar energy is one of the greenest energy sources currently meeting human energy needs, its upstream, the manufacturing of solar panel, is more likely a general production industry rather than an environmental protection industry. Similar is the case with nuclear power. Therefore, it is important to capture comprehensive differences in the development modes of the environmental protection industry and general production industry. In what follows, the Weaver-Thomas model, which was introduced by Weaver and improved by Thomas (Atkinson and Unwin, 2002; Fang, et al., 2012), will be adopted to identify the two types of industry objectively.

### 3.4.1 Industry-coup ling level index system construction

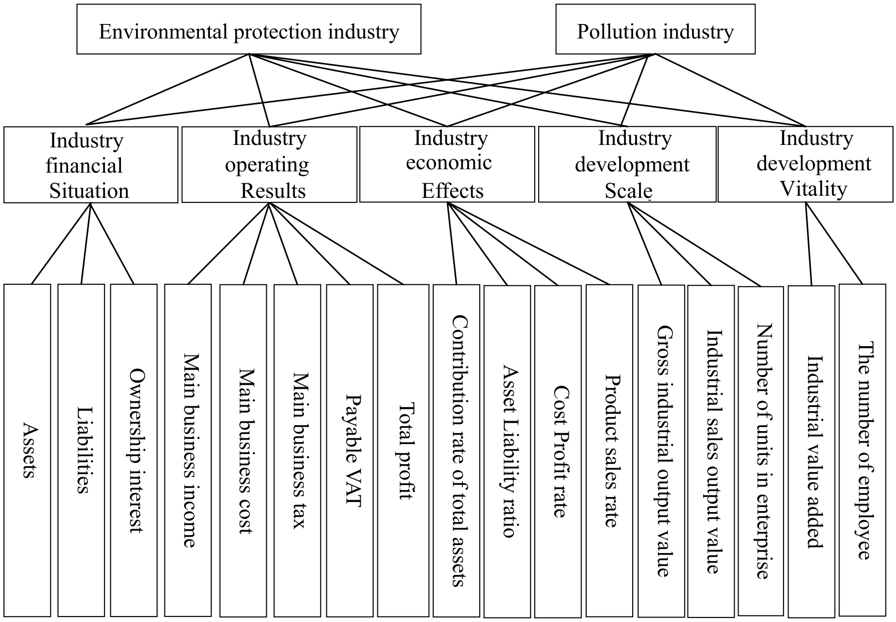


**Figure 3-2: Industry coupling index system**

Note: the classification of the first-level indicators is based on a broad classification and is different from that used in general accounting.

Weaver-Thomas model uses comprehensiveness and correlation between industries and solves the problem of industrial optimization under the multi-index. Five first-class indexes were screened for the industries: “1. industry financial situation,” “2. industry operating results,” “3. industry economic efficiency,” “4. industry development scale,” and “5. industry development vitality.” For the second-class indexes, a total of 17 factors were considered: “1. industry financial situation,” including assets, liabilities, and owner’s equity, expressing the economic activities and the results of enterprises during a period of time; “2. industry operating results,” including income, cost, profit and taxes, major income, main costs, main taxes and added value, value-added tax payable, and total profits, representing the sum of the income and expenses resulting from the production and operation activities; “3. industry economic efficiency,” including the total asset contribution rate, the asset liability ratio, the cost of industry profit margins, and the product sales rate, reflecting the relationship between the internal operation of the industry and external production; “4. industry development scale,” including gross industrial output, industrial sales output, and enterprise unit number, reflecting the industry major output size and external scale; “5. industry development vitality,” including industrial added value and the number of workers, reflecting the future potential of the industry. The industry-coupling level index system diagram is shown in Figure 3-2.

### 3.4.2 Index-weight determination

In the coupling evaluation model, the calculation of the index weight is a key step, and the reasonable weight calculation method directly affects the calculated coupling evaluation. The KPCA-LINMAP coupling weight model is associated with the Kernel Principal-Component Analysis (KPCA) method based on kernel function and the Linear Programming Technique for Multidimensional Analysis of Preference (LINMAP) method to weigh indicators. The method uses KPCA to give the order of the original sample that is then used as the input for the LINMAP to determine the multi-index weight. This order reflects the true state of the sample, and thus the index weights obtained by the method are more reasonable and scientific than the subjective weight and the objective weight.

**Sub-model 1 (kernel principal-component model):**

We set the original data $X_k \in R^p, (k = 1,2,\cdots,n)$ for the column vector, deal with the data with the standard treatment, and eliminate the indices' differences in the dimension and quantity level. To represent the data, we use the data matrix $X = (X_1, X_2, \cdots, X_n)$ . *p* represents a number of indicators and *n* is the sample size.

Compared with the traditional principal-component model, the model based on the kernel function is mainly characterized by projection of the original data into a new feature space $\phi$ by nonlinear transformation. Linear principal-component analysis is performed in the new space, which bypasses the shortcomings of the traditional model that can only consider two-order linear correlations between the indices.

Assuming that the feature space $\phi = (\phi(X_1), \phi(X_2), \cdots, \phi(X_n))$ meets the condition $\sum_{i=1}^{n} \phi(X_i) = 0$. Then, the sample co-variance matrix can be expressed as $A = \frac{1}{n-1}\sum_{j=1}^{n} \phi(X_j)\phi(X_j)^T$ and this is transformed to solve the characteristic equation $\lambda\alpha = A\alpha$ (where *a* is a feature vector corresponding to the eigenvalues $\lambda$) . Because *a* belongs to space $\phi$, we have $\lambda\phi(X_k)\alpha = \phi(X_k)A\alpha, k = 1,2,\cdots,n$, and there exists a set of nonzero vector $\alpha = \sum_{i=1}^{n} \beta\phi(X_i)\ \beta = (\beta_1, \beta_2, \cdots, \beta_n)^T$, so and allows the two equations to be used in the characteristic equation. At the same time, define the matrix $K_{ij} = \phi(X_i)\phi(X_j)$ ,and the equivalent expression of the characteristic equation is obtained as $n\lambda\beta = K\beta$ . This solution should meet the above-mentioned $\sum_{i=1}^{n} \phi(X_i) = 0$ conditions, but generally this does not happen. In this case, it is necessary to center the matrix *K*, make $\phi_i = \phi(X_i)$ and $\phi_i^c = \phi_i - \overline{\phi_i}$ , then:

$$K_{ij}^c = \phi_i^c \phi_j^c = (\phi_i - \frac{1}{n}\sum_k \phi_k)^T (\phi_j - \frac{1}{n}\sum_l \phi_l)$$

$$= \phi_i^T \phi_j - \frac{1}{n}\sum_l \phi_i^T \phi_l - \frac{1}{n}\sum_k \phi_k^T \phi_j + \frac{1}{n^2}\sum_k \sum_l \phi_k^T \phi_l$$

$$= K_{ij} - \frac{1}{n}\sum_l K_{il} - \frac{1}{n}\sum_k K_{kj} + \frac{1}{n^2}\sum_k \sum_l K_{kl}$$

For $C = (1/n)_{n\times n}$ , $K$ can be centered as: $\hat{K} = K - CK - KC + CKC$

**Sub-model 2 (multidimensional linear programming model):**

The kernel principal component above offered the order of the original sample. Here, it will be used by the multidimensional linear programming model to get the multi-index weight. We used the original data of the decision-making matrix $Y = (y_{ij})_{n\times p}$,with *p* as the number of indicators and *n* as the sample capacity. We performed standardized processing to eliminate the differences of the index at the level of dimension and quantity. To simplify the data representation, we will use the data matrix $y^* = (y_1^*, y_2^*, \cdots, y_p^*)^T$ to represent the ideal sample point of the decision maker's preference in the index space, and then the squares of weighted Euclidean distance of any sample point $Y_j$ to the ideal point can be expressed as:

$$D_j = \sum_{i=1}^{p} \omega_i (y_{ij} - y^*)^2 \tag{3-9}$$

If all of the programs in the sample space are directly-neighboring comparatives,then the preference scheme can be compared to the number of sets of $\Theta = \{(k,l) | k,l = 1,2,\cdots,n\}$, where *k* is not less than *l*. Then, the squares of the weighted Euclidean distance between different samples (schemes) and the ideal points can be expressed as:

$$D_k = \sum_{i=1}^{p} \omega_i (y_{ik} - y^*)^2 \tag{3-10}$$

$$D_l = \sum_{i=1}^{p} \omega_i (y_{il} - y^*)^2 \tag{3-11}$$

For sample (*k,l*), if $D_k \le D_l$ , then sample *k* is closer to the ideal point than sample *l,* which is consistent with the preference of decision-making. In contrast, if $D_k > D_l$ , $(k,l)$ $(D_l - D_k)^-$ . When not in agreement, then $D_l - D_k$ . Conversely $(D_l - D_k)^-$ is 0. Hence:

$$(D_l - D_k)^- = \begin{cases} D_k - D_l, & D_l < D_k \\ 0, & D_l \ge D_k \end{cases} \\ = \max(0, D_k - D_l) \tag{3-12}$$

When we sum $\Theta$ all of the ordinal pairs $(k,l)$, we can get the total degree of inconsistency of the weighted distance squared comparison and $(k,l)$ with ordinal pairs:

$$B = \sum_{(k,l)\in\Theta} (D_l - D_k)^- \tag{3-13}$$

In the same way, we can define the overall consistency of the decision preferences as:

$$G = \sum_{(k,l)\in\Theta} (D_l - D_k)^+ \tag{3-14}$$

Where,

$$(D_l - D_k)^+ = \begin{cases} D_l - D_k, & D_l \ge D_k \\ 0, & D_l < D_k \end{cases} \\ = \max(0, D_l - D_k) \tag{3-15}$$

We hope that the consistency is not less than the degree of inconsistency, according to the definition such that:

$$\begin{aligned} G - B &= \sum_{(k,l)\in\Theta} (D_l - D_k)^+ - \sum_{(k,l)\in\Theta} (D_l - D_k)^- \\ &= \sum_{(k,l)\in\Theta} [(D_l - D_k)^+ - (D_l - D_k)^-] \\ &= \sum_{(k,l)\in\Theta} (D_l - D_k) = h \end{aligned} \tag{3-16}$$

The decision-maker gives an upper $h$ , and we can obtain one of the constraints in the programming $G - B \ge h$.

Based on this, this study establishes a multi-dimensional linear programming model with the objective of minimizing the degree of inconsistency.

Recorded as $\lambda_{kl} = \max(0, D_k - D_l), (k,l) \in \Theta$ , then there is: $\min\{\sum_{(k,l)\in\Theta} \lambda_{kl}\}$

$$s.t. \begin{cases} D_l - D_k + \lambda_{kl} \ge 0, \ (k,l) \in \Theta \\ G - B \ge h \\ \sum_{j=1}^{p} \omega_j = 1 \\ \omega_j \ge 0, \ j = 1, 2, \cdots, p \\ \lambda_{kl} \ge 0, \ (k,l) \in \Theta \end{cases} \tag{3-17}$$

The distance formulas (3-10) and (3-11), the consistent degree formula (3-16), the inconsistent degree formula (3-17), and substitution planning (3-18) can be rearranged as:

$$\min\{\sum_{(k,l)\in\Theta}\lambda_{kl}\}$$

$$s.t.\begin{cases}\sum_{j=1}^{p}\omega_j(y_{lj}^2-y_{kj}^2)-2\sum_{j=1}^{p}\upsilon_j(y_{lj}-y_{kj})+\lambda_{kl}\ge 0,\ (k,l)\in\Theta\\ \sum_{j=1}^{p}\omega_j\sum_{(k,l)\in\Theta}(y_{lj}^2-y_{kj}^2)-2\sum_{j=1}^{p}\upsilon_j\sum_{(k,l)\in\Theta}(y_{lj}-y_{kj})\ge h\\ \sum_{j=1}^{p}\omega_j=1\\ \upsilon_j=\omega_j y^*\\ \omega_j\ge 0,\ j=1,2,\cdots,p\\ \lambda_{kl}\ge 0,\ (k,l)\in\Theta\end{cases} \quad (3\text{-}18)$$

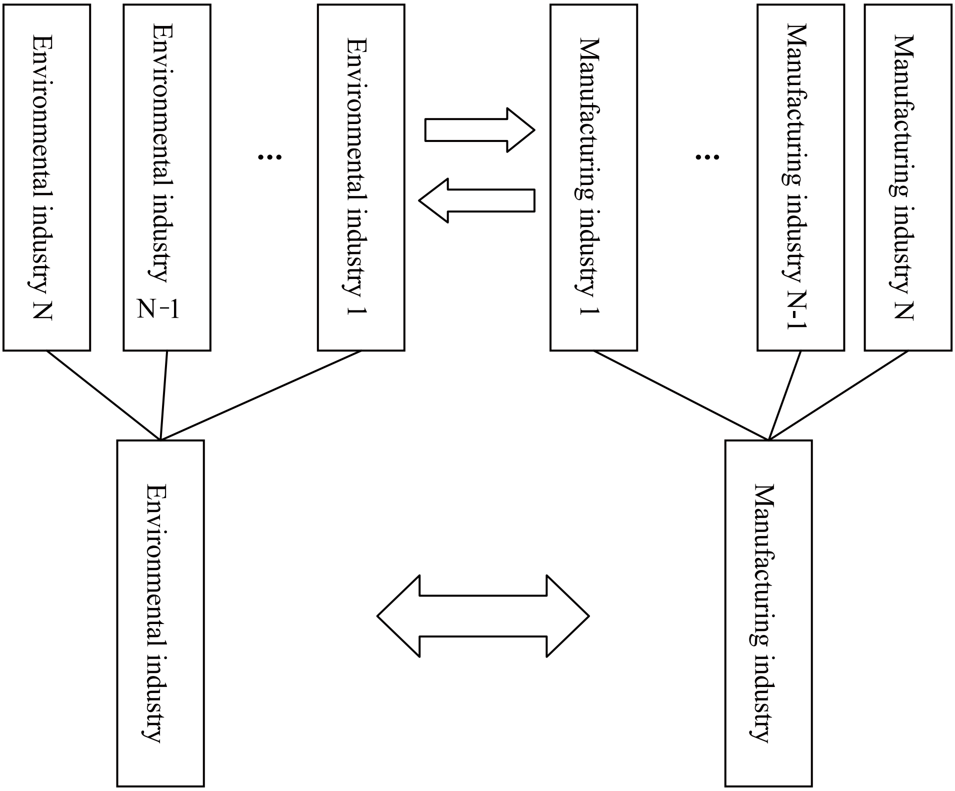


**Figure 3-3: Coupling interactions between the environment industry and the manufacturing industry**

### 3.4.3 Establishment of the coupling model

**Model one (coupling correlation degree model):** For subdivided industries included in the sub-systems of the environmental protection industry and the production industry, the optimal strategy to evaluate multiple coupling effects or how to merge the subdivided industries and then perform the coupling calculation must be determined. The link between industry couplings is presented in Figure 3-3, and in this section, we focus on the quantitative methods to measure the coupling effect and the construction of the model.

**Definition 1***:* $s$ is set as the subsystem order parameter for the environment industry and is a comprehensive contribution value for the system, $s_i$ is the contribution value for the first-class index of $i$, $s_{ij}$ is the $j$ variable parameter for the first-level index of $i$, and its index value is $x_{ij}$. Where, $i$=1,2,...,$n_1$ , and $j$=1,2,..., $m_1$; $n_1$ and $m_1$ denote the number of the first two level indicators, respectively of the environmental protection industry. Similarly, we set $t$ as the order parameter of the subsystem for the manufacturing industry, as acompre -hensive contribution value for the system, $t_i$ is the contribution value for the first-class index of $i$, $t_{ij}$ is the $j$ variable parameter for the first-level index of $i$,and its index value is $y_{ij}$ .Where $i$=1,2,...,$n_2$ , $j$=1,2,..., $m_2$; $n_2$ and $m_2$ respectively represent the number of the first-level and second-level indicators of the industry.

**Definition 2:** $d_{ij}$ and $\beta_{ij}$ are the two bounds of the upper-order parameter in the stability-critical point of the environmental protection industry's subsystem; $\eta_{ij}$ and $\gamma_{ij}$ are the upper and lower limits of the upper-order parameter in the stable critical value of the production industry's subsystem, and the ordinal efficacy models for the evaluation index layer for both industries are described as:

$$s_{ij} = \frac{x_{ij} - \beta_{ij}}{\alpha_{ij} - \beta_{ij}} \quad t_{ij} = \frac{y_{ij} - \gamma_{ij}}{\eta_{ij} - \gamma_{ij}}$$

Where, $\beta_{ij} \le x_{ij} \le \alpha_{ij}$ and $\lambda_{ij} \le y_{ij} \le \eta_{ij}$ , $s_{ij}$ and $t_{ij}$ values are in the interval [0,1], and the closer these values are to 1, the greater the contribution of the subsystem. The determination of $\alpha_{ij}, \beta_{ij}, \eta_{ij}, \gamma_{ij}$ is based on the period value, the standard value, and the ideal value of the regional reference period.

**Definition 3:** For the environmental protection industry, $\lambda_i$ represents the corresponding weight of the $i$ first-grade index, $\lambda_{ij}$ expresses the corresponding weight of the $j$ second level index included in the first level indicators. Similarly, for the production industry, $\mu_i$ represents the corresponding weight of the $i$ $\mu_{ij}$ first-grade index, $\mu_{ij}$ expresses the corresponding weight of the $j$ second-level index included in the $i$ first-level indicators.

Based on these definitions and using a model based on the concept of capacity coupling in physics, for the condition of a multi-system, we construct the following industry coupling-correlation degree model:

$$C = \sqrt[n]{\frac{O_1 \cdot O_2 \cdots O_n}{\prod(O_i + O_j)}} \tag{3-19}$$

Where, C is the coupling correlation degree, $O_i$ and $O_j$ represent the values of the order parameter of any two pairs of systems, and $n$ is the number of the order parameter of the system.

For the model of the environmental protection and manufacturing industry coupling, the coupling-correlation degree C can be expressed as:

$$C = \sqrt{\frac{s \cdot t}{(s+t)^2}} \tag{3-20}$$

Where, $s = \sum_{i=1}^{n_1} \lambda_i s_i$ , $s_i = \sum_{j=1}^{m_1} \lambda_{ij} s_{ij}$ , $t = \sum_{i=1}^{n_2} \mu_i t_i$ , $t_i = \sum_{j=1}^{m_2} \mu_{ij} t_{ij}$ .

**Model 1 (coupling sustainable development model):** The coupling model of sustainable development or coupling-system coordination model is different from the coupling-correlation degree model because it shows the dynamic and imbalance between the environment and the manufacturing industries. This modified model can effectively reduce the errors caused by the selection of the two bounds of the order parameter, reflecting the interaction degree of two systems.

$$D = \sqrt{\sqrt{\frac{s \cdot t}{(s+t)^2}}(\rho_1 s + \rho_2 t)} \tag{3-21}$$

We set $C = \sqrt{\frac{s \cdot t}{(s+t)^2}}$ to represent the industry-coupling correlation degree,

$D$ is the coupling-sustainable development degree, and $I = \rho_1 s + \rho_2 t$ expresses the integration index for the environment and the production industries. $\rho_1$ and $\rho_2$ represent contribution coefficients for the two industries as unknown parameters, and $\rho_1 + \rho_2 = 1$. In the coupling model of sustainable development, $D \in [0,1]$ ,if $D \to 1$, then the degree of coordinated development of the system is improving; conversely, if $D \to 0$ , the degree of coordinated development is declining.

### 3.4.4 Coupling-evaluation criterion

On the basis of model construction, we need a unified evaluation standard to measure the coupling between the environment and the manufacturing industries. We would establish evaluation criteria for a coupling-correlation degree model and a coupling model of sustainable development on the basis of the features of the two industries.

Theoretically, the value of the industry-coupling correlation degree C should be in the closed interval of $[0,1]$ , and the internal mechanism of industrial development shows there must be a relationship between the environment and the manufacturing industries. This relationship will maintain a dynamic balance at some time and some space Thus, we cannot save the coupling relationship of extreme values, that is $C \in [0,1]$ . However, to completely express the industry-coupling evaluation criteria and type, we include the extreme values in our analysis. The industry-coupling correlation degree standard is shown in Table 3-1 and includes the stage and the degree of coupling for the two industries. The coupling degree is divided into six classes from $C=0$ to $C=1$ ranging from no coupling to fully coupling. These industry-coupling stages are budding, running, growing, mature, and stable. According to this, we can evaluate the coupling development status between the environment and production industries. For a detailed discussion of overall development level and status, this study constructs an evaluation criterion for coupling sustainable development in Table 3-2 and explores the relationship of the two industries.

**Table 3-1: Industry-coupling correlation degree evaluation standard**

| Coupling correlation degree C | Stage | Coupling degree |
|---|---|---|
| $C=0$ | - | No coupling |
| $0<C<0.3$ | Budding | Low degree of coupling |
| $0.3<C<0.5$ | Running | Medium and low degree of coupling |
| $0.5<C<0.8$ | Growing | Moderate coupling |
| $0.8<C<1$ | Mature | Highly coupling |
| $C=1$ | Stable | Fully coupling |

Based on $D$ , the degree of coupling for sustainable development, we divided the standard into 4 categories: "offset recession," "barely coordinated," "moderate coordination," and "coordination development." Of these classifications, "offset recession" includes "serious disorder development," "disorder development," and "mild disorder development;" "barely coordinated" contains "endangered development" and "barely coordinated development;" "moderate coordination" includes "transitional coordinated development" and "low degree of coordinated development;" and "coordination development" includes "moderate coordinated development," "good coordinated development," and "high-quality coordinated development."

**Table 3-2: Coupling-evaluation criteria for sustainable development**

| Category | Coupling sustainable development degree D | Subdivision class |
|---|---|---|
| Offset recession | 0-0.09 | Serious disorder development |
| | 0.1-0.19 | Disorder developmental |
| | 0.2-0.29 | Mild disorder development |
| Barely coordinated | 0.3-0.39 | Endangered development |
| | 0.4-0.49 | Barely coordinated development |
| Moderate coordination | 0.5-0.59 | Transitional coordinated development |
| | 0.6-0.69 | Low degree of coordinated development |
| Coordination development | 0.7-0.79 | Moderate coordinated development |
| | 0.8-0.89 | Good coordinated development |
| | 0.9-1 | High-quality coordinated development |

### 3.5 Conclusions

This chapter introduces three methods, namely, DEA, GMM, and Coupling Model method, which are respectively adopted in Chapter 5, Chapter 7, and Chapter 6. The method framework of the following chapters is presented in Figure 3-4. For more advanced and detailed information on these methods, see Stock (2000), Cooper et al. (2007), Tone (2004), and Bentley and Whitten (2007). The weakness of any single method above is obvious. For example, the DEA is suitable for performance evaluation, but lacks causality-relationship detection. The GMM is helpful for estimating the causality relationship but cannot be used for performance evaluation. The Coupling Model method is ideal for the analysis of the interaction mechanism of the two industries but not for causality-relationship detection and performance evaluation. To overcome the limitations of each single method above, we will combine the above three methods in this thesis.

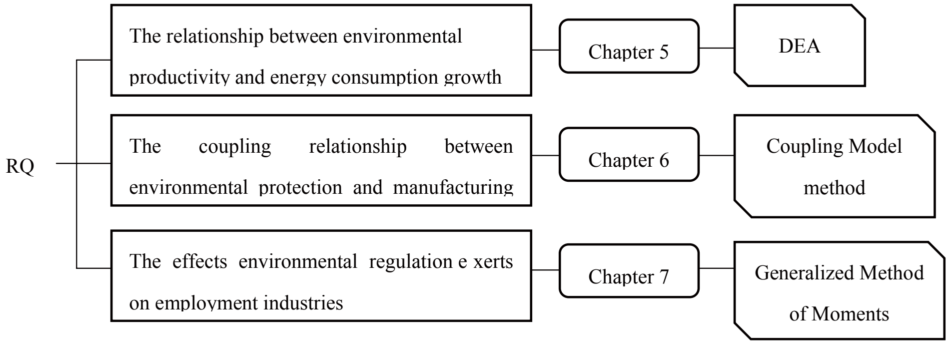


**Figure 3-4: Method framework of the upcoming chapters**

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# 4

# A descriptive statistical analysis of pollution emission at the regional and industrial level

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# Chapter 4. A descriptive statistical analysis of pollution emission at the regional and industrial level

## 4.1 Introduction

Technological advances and production efficiency brought sustained and rapid growth to the Chinese economy. However, the early policies concentrated on development and led to a massive growth of resource consumption with an increased negative impact on the environment. For this reason, environmental policies have become more important. China is a country of vast land resources, and the regional administrative division makes it difficult to formulate environmental policies for the entire country. Inevitably, there are differences in the response to policies due to varying regional environment and levels of economic development that influence policy implementation. At the same time, different industries also require more attention from the government for the development of environmental policies. In Chapter 1, we raised the question: What are the properties of pollution emissions at the regional and industrial levels? This chapter analyzes the index data for sulfur dioxide and other pollutants, and presents the current properties of environment pollution using descriptive statistical analysis.

There are three main types of pollution. The first is land-based pollution. Waste removal has become a serious problem in major cities, which are finding it difficult to dispose of the many tons of plastics, rubber, and glass waste generated every day. The second type is marine pollution, which results from leaking oil tankers and oil wells, agricultural pesticides, fertilizer emissions, wastewater from factories, and acid solutions from mining. This contamination of seas and lakes is not only harmful to marine life, but is also a threat to human health. The third type, air pollution, is perhaps the most direct and serious type of environmental pollution. This pollution results from emissions from factories, automobiles, power plants, and other sources, causing illnesses related to respiratory or visual exposure to contaminated air. We conduct comparisons of water, air, and solid waste pollution in different regions and industries.

## 4.2 Regional comparison of China's environmental regulation effects

Chinese government took numerous measures and passed laws to address environmental governance and formulated regulations for different types of pollution. As per the planning methods used by the research institute of China's central government, China is comprised of eight comprehensive economic areas. The specific divisions are shown in Table 4-1.

**Table 4-1: China's regional divisions**

| Region | Provinces included |
|---|---|
| Northeast | Liaoning, Jilin, Heilongjiang |
| Northern coastal | Beijing, Tianjin, Hebei, Shandong |
| Eastern coastal | Shanghai, Jiangsu, Zhejiang |
| Southern coastal | Fujian, Guangdong, Hainan |
| Middle reaches of the Yellow River | Shaanxi, Shanxi, Henan, Inner Mongolia |
| Middle reaches of the Yangtze River | Hubei, Hunan, Jiangxi, Anhui |
| Southwest | Yunnan, Guizhou, Sichuan, Chongqing, Guangxi |
| Northwest | Gansu, Qinghai, Ningxia, Tibet, Xinjiang |

Based on the regional division, the overall pollution indicators in these eight regions were analyzed and the differences in the effects of environmental policy were compared. This section collected the emissions data of waste water, industrial sulfur dioxide, and solid waste from the "China Statistical Yearbook", as shown in Figure 4-1 to Figure 4-3.

As shown in Figure 4-1, the industrial water pollution in the eastern region was significantly more severe than in other regions. This is due to the introduction and development of contaminating large-scale foreign capital enterprises liked to an increase in the domestic sewage due to the high population concentration, causing water pollution in the main area as a consequence of economic development. The degree of water pollution in the three northeastern provinces was decreasing before 2010 by about 19.7% in 14 years. China's environment policies have generated notable effects on the provinces, and as shown in the data, the water pollution situation has improved in most areas since the State Council enacted the "Water Pollution Protection Act" at the third national environmental protection conference in 1989. Since this act was amended in 2008, the water pollution in the southwest region fell from 4261.63 million tons to 2774.76 million tons in 2012, which is the most significant regional improvement. The water pollution in the northeastern region, northern region, and the middle reaches of the Yellow River and Yangtze River showed no improvement since the act was passed, and instead it appears to have worsened. Water pollution in China results mainly from the industrial waste water and domestic sewage. Since 1998, the emissions of the latter have exceeded that of the former, which is now the major source of water pollution. Thus, China's large population combined with an uncoordinated economic development has resulted in the extreme variation in the geographic distribution of water pollution.

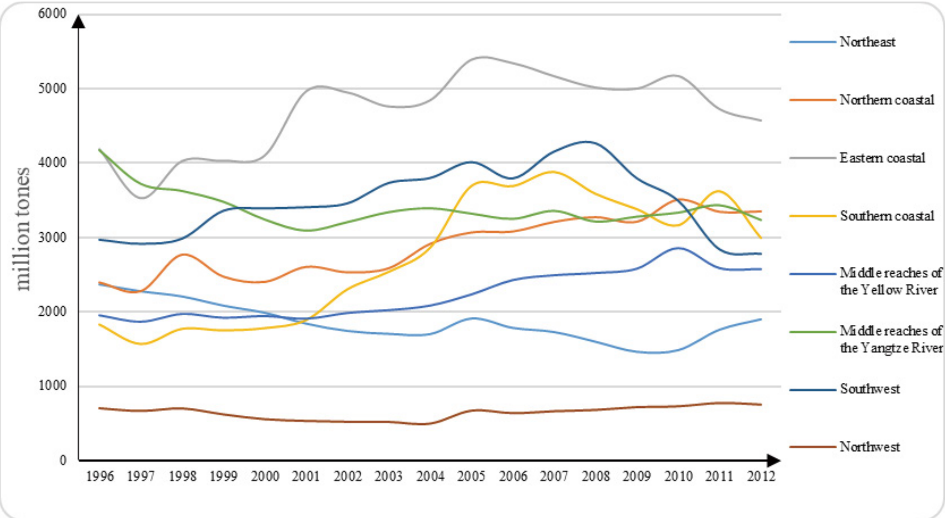


**Figure 4-1: Industrial water pollution in the eight main regions**

Source: The data is collected from China Statistical Yearbook.

Industrial sulfur dioxide emissions were also examined as the main indicator of air pollution. Prior to the "Ninth Five-Year" Plan period, the air pollution levels in Beijing, Tianjin and other northern coastal provinces were higher than in all other regions, and the overall levels were constantly high without significant fluctuations. Since China joined World Trade Organization (WTO) in 2001, the northern coastal region, the national political and economic center, has gradually adjusted its approach to economic development. As seen in Figure 4-2, since 2002, the growth rate of industrial

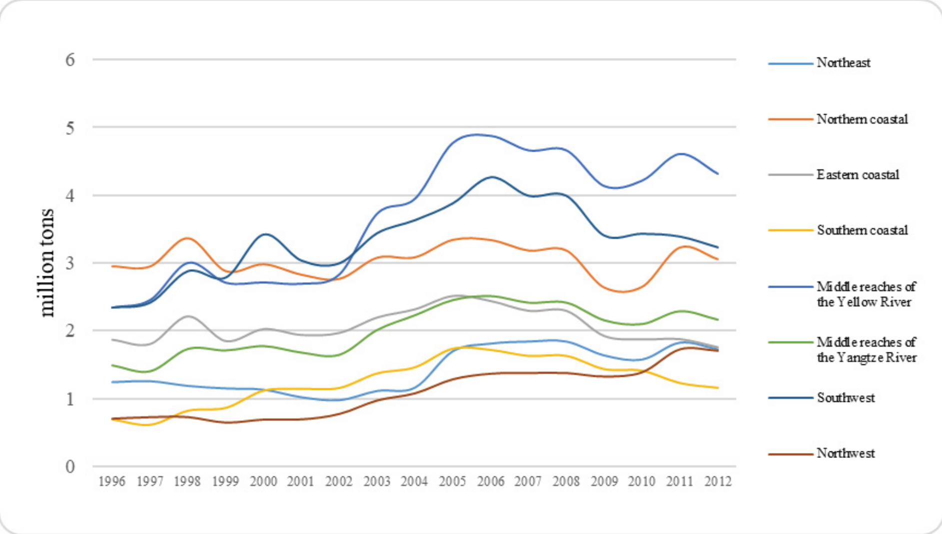


**Figure 4-2: Industrial sulfur dioxide pollution in the eight main regions**

Source: The data is collected from China Statistical Yearbook.

sulfur dioxide emissions has obviously slowed down in most areas, despite a continued increase in the total amount of emissions. The trend indicates that the environmental policies formulated during the "Tenth Five-Year" Plan period did have effects in these regions. However, the air pollution in the middle reaches of the Yellow River actually worsened with an increase of emission by approximately 72.3%. One of the possible reasons is that many heavy pollution enterprises have been transferred to this region from Beijing or other cities in the northern coastal region due to the proximity of the two regions. Moreover, special climate factors may contribute to the worsening of the air pollution. After the Sixth Conference on Environmental Protection was convened, the air pollution situation has improved in the eight main regions. The regions that appear to be influenced by the policies the most include the eastern coastal region, the northern coastal region, and the southwest region with respective decreasing rates of industrial sulfur dioxide emissions of 23.17%, 20.6%, and 17.9% during the Plan period. There was a 13.6% reduction in the industrial sulfur dioxide emissions in the regions near Yellow River and in the Northeast, indicating some response to policy changes. The air pollution emissions rose in the remote northwest region, but only by less than 2 percent, which may be viewed as an acceptable level, considering that this region is scarcely populated. Overall, China's atmospheric environmental regulation policies have had significant effects and played a positive role in controlling regional industrial waste gas emissions and dealing with air pollution.

From Figure 4-3, which displays emissions of solid waste, we can see that these emissions are increasing in all areas. Although the overall level was not high in the northwest region, its rate of increase was the most pronounced. Its rate of increase was approximately 10.23, which is four times greater than that of the northeast region, the eastern region, and regions along Yangtze River. By the end of 2012, regions near Yellow River and the northern coastal region were the two regions with the highest solid waste emissions of respectively 757.23 and 668.43 million tons. The emissions were far higher in Hebei, Liaoning, Shanxi, and other nearby places, which are the areas where population and industry are relatively more concentrated. However, there was a significant increase in solid waste in all regions, suggesting that relevant environmental regulation policies on solid waste emissions enacted in 1995 did not work.

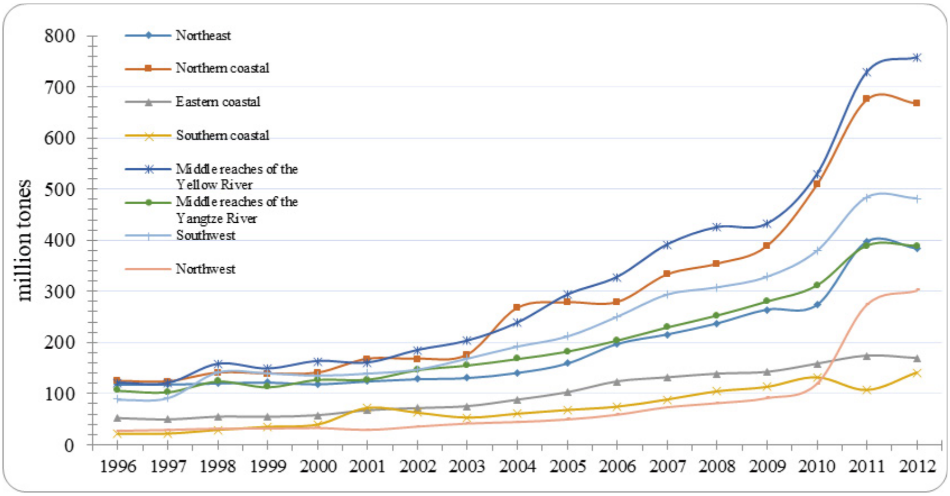


**Figure 4-3: Solid waste pollution in the eight main regions**

Source: The data is collected from China Statistical Yearbook.

The levels of sulfur dioxide in China's eight main regions since the adoption of the "Ninth Five-Year Plan" are shown in Table 4-2. The pollution level is the highest in Shandong, Hebei and other provinces and is the lowest in the northwest region. From 1996 to 2000, in the northeast region and the northwest region the pollution dropped by 9.05% and 1.83%. This indicates the success of the "total amount control" and "green project" policies promoted by the Chinese government. Although the government issued various regulations to control the environment pollution from 2001 to 2005, these regulations seem to have had little effect as the pollution levels in all regions increased to some extent, and especially in the northwest region, where the pollution level increased by about 83.94%. By the end of 2005, the overall amount of pollution in the regions near Yellow River exceeded 4.767 million tons, the highest level ever recorded. From 2006 to 2010, the government strengthened efforts to control pollution. After the Sixth Conference on Environmental Protection held in 2006, the government has been introducing environment regulation policies almost every year and has achieved remarkable results. The environmental quality changed at the end of the period in the four regions with leading levels of economic development, including the eastern and the southern coastal areas except for a slight rise in pollution in the northwestern regions.

**Table 4-2: Industrial Sulfur dioxide pollution in the eight main regions in China (million tons)**

| Region | Start of the Ninth Five-Year Plan | End of the Ninth Five-Year Plan | Start of the Tenth Five-Year Plan | End of the Tenth Five-Year Plan | Start of the Eleventh Five-Year Plan | End of the Eleventh Five-Year Plan |
|---|---|---|---|---|---|---|
| Northeast | 1.241 | 1.129 | 1.017 | 1.700 | 1.813 | 1.577 |
| Northern coastal | 2.952 | 2.983 | 2.830 | 3.342 | 3.339 | 2.652 |
| Eastern coastal | 1.874 | 2.030 | 1.943 | 2.518 | 2.444 | 1.878 |
| Southern coastal | 0.691 | 1.116 | 1.140 | 1.735 | 1.716 | 1.408 |
| Middle reaches of the Yellow River | 2.337 | 2.710 | 2.689 | 4.767 | 4.871 | 4.210 |
| Middle reaches of the Yangtze River | 1.490 | 1.773 | 1.679 | 2.451 | 2.509 | 2.098 |
| Southwest | 2.342 | 3.425 | 3.039 | 3.887 | 4.273 | 3.436 |
| Northwest | 0.708 | 0.695 | 0.698 | 1.283 | 1.364 | 1.385 |

Source: China Environmental Statistical Yearbook.

### 4.3 Industrial comparison of China's environmental regulation effects

We collected the emissions data on pollution by industry from the "China Statistical Yearbook" and "Chinese Industrial Statistics Yearbook" for corresponding years. The limitation of our data is the number of missing values for some industries in specific years, which may affect the subsequent analysis. We use averages of their nearest two values to replace these missing values.

To separate various types of industries by their different pollution emission levels during production and by the environmental regulations affecting these industries, the industries are classified into three types: labor-intensive, capital-intensive and technology-intensive. Representative industries were selected as research objects based on the extent of contribution of that industry to the national economy. The labor-intensive sector includes agricultural byproduct processing, food and beverage manufacturing, tobacco products, textiles, furniture manufacturing, and paper and paper production; the capital-intensive sector includes ferrous metals, etc. The "Eleventh Five-Year" Plan was divided into three periods: the beginning, the middle, and the end. The data is shown in Table 4-3 (units: ten thousand ton).

**Table 4-3: Pollution data for different industries**

| **Industry** | **Beginning of the Eleventh Five-Year Plan** | | **Middle of the Eleventh Five-Year Plan** | | **End of the Eleventh Five-Year Plan** | |
|---|---|---|---|---|---|---|
| Type of industry | Waste gas | Solid waste | Waste gas | Solid waste | Waste gas | Solid waste |
| agriculture byproduct processing | 5122 | 3182 | 7140 | 4096 | 9627 | 4106 |
| food processing | 2427 | 823 | 5011 | 1065 | 5621 | 1279 |
| beverage processing | 4416 | 1619 | 3615 | 1811 | 5315 | 1935 |
| tobacco products | 681 | 87 | 1025 | 91 | 1047 | 98 |
| Textiles | 7360 | 1339 | 6816 | 1522 | 7600 | 1427 |
| furniture processing | 397 | 54 | 346 | 34 | 419 | 31 |
| paper and paper products | 11283 | 3393 | 11425 | 3739 | 24791 | 4804 |
| ferrous metal smelting and rolling processing | 160613 | 58946 | 214176 | 65353 | 296143 | 80352 |
| non-ferrous metal smelting and rolling processing | 35370 | 11853 | 40019 | 14284 | 56191 | 19095 |
| metal products | 3739 | 630 | 4094 | 828 | 10948 | 836 |
| general equipment manufacturing | 2417 | 422 | 4174 | 881 | 4061 | 784 |
| special equipment manufacturing | 1235 | 268 | 4835 | 311 | 5010 | 362 |
| transportation equipment manufacturing | 6878 | 962 | 7701 | 1030 | 10130 | 1136 |
| pharmaceutical manufacturing | 1925 | 575 | 2738 | 699 | 5207 | 715 |
| electrical machinery manufacturing | 1324 | 101 | 1403 | 140 | 2586 | 148 |
| electronic equipment manufacturing | 4422 | 237 | 3767 | 333 | 12522 | 263 |
| instrumentation and others manufacturing | 1241 | 79 | 573 | 67 | 656 | 35 |
| crafts and others manufacturing | 348 | 25 | 148 | 29 | 822 | 148 |

Source: China Environmental Statistical Yearbook.

As it can be seen from Table 4-2, waste gas and solid waste pollution increased year by year for all types of industries during the "Eleventh Five-Year" Plan period, but the growth rates varied due to various responses to environmental regulations in different sectors. Labor-intensive industries increased air pollution by 6.29% and decreased solid waste pollution by 18.32%, which suggests that pollution control measures mainly focused on reducing solid waste pollution during this time period. In capital-intensive industries, both pollutants increased significantly: by 12.90% (waste gas) and by 11.21% (solid waste). This shows almost no effect that can be attributed to the regulation policy, possibly because of the larger “contribution degree” of ferrous and nonferrous metal smelting and the rolling processing industry. Technology-intensive industries had lower emissions of polluting gases at the beginning of the period, but it is notable that the emissions exponentially increased at the end of the period. This may be due to the transition from labor-intensive to technology-intensive production, caused by the upgrading of the industrial structure, and the resulting large increase in the technology-intensive industries. Solid waste pollution decreased by about 21.56% in the technology-intensive industry, which is a bigger decrease than in the labor-intensive industries. We used the arithmetic means of waste gas and solid waste emissions for all years in 2006-2010 and investigated the proportions under various pollution indicators for the three types of industries (Figure 4-4 and Figure 4-5). For both air and solid waste pollution, capital-intensive industries account for more than 80% of the total pollution, indicating that most pollution generated by China’s manufacturing industry originates from the capital-intensive sector. We can also determine that the labor-intensive industry ranks second after the capital-intensive industry, and its share of both pollution indices remains unchanged. At the same time, its contribution to the air pollution exceeds that of the solid waste pollution from the technology-intensive industries.

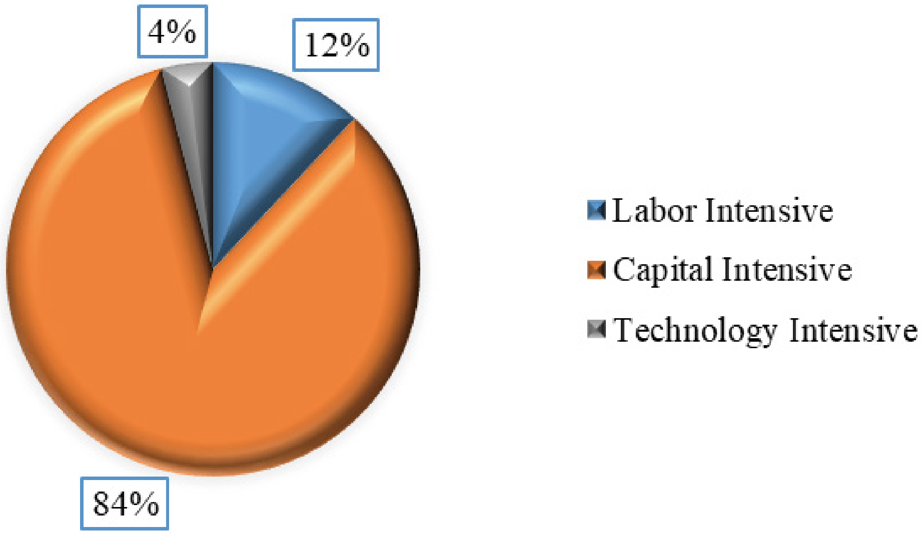


**Figure 4-4: The distribution of air pollution for labor-, capital-, and technology-intensive industries**

Source: Calculated by author.



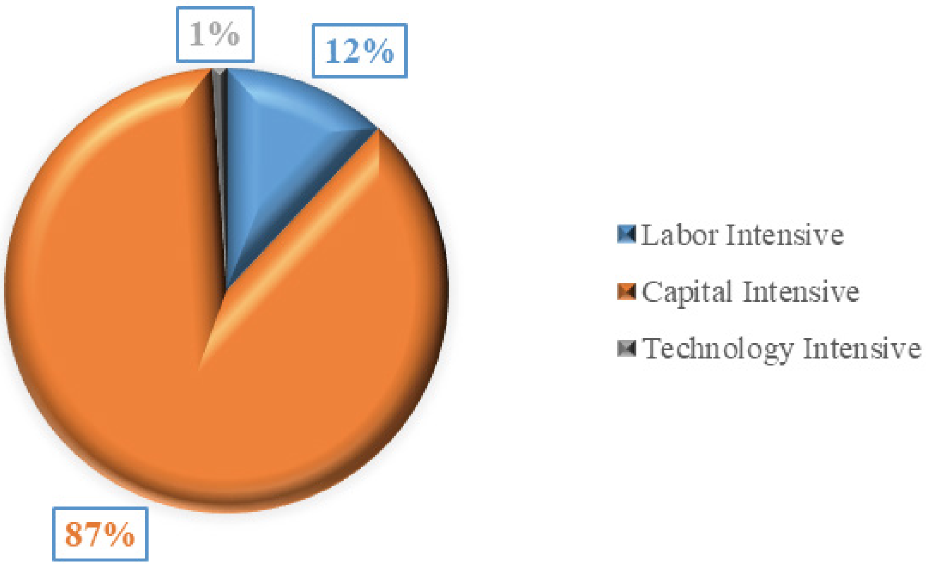


**Figure 4-5: The distribution of solid waste pollution for labor-, capital-, and technology-intensive industries**

Source: Calculated by author.

To calculate contamination, we defined the "contamination level" index of an industry as the pollution emissions per year compared with the pollution emissions in 2005 as a reference value. The index represents the change in the amount of pollution in the current year with respect to the base year and is given as a ratio. The index helps to observe the effects caused by environmental policies. Larger index values indicate more substantial pollution and small effect of policies compared with that in the base year. Conversely, smaller index values indicate that policies have curbed pollution. Since the index is a ratio of data points, we can take the geometric mean of contamination levels for all years to represent the overall pollution level as shown in Equation 4-1:

$$E = \sqrt[k]{\prod_{i=1}^{k} \frac{PO_i}{PO_c}} \tag{4-1}$$

$E$ Stands for the contamination level, $PO_c$ represents pollution emissions in the base year, $PO_i$ represents the corresponding pollution emissions in the $i$ target year, and $k$ stands for the number of years surveyed. We define the "contamination level" values of [0, 1), [1, 2), [2, 3) and greater than 3 as "slight," "light," "moderate," and "heavy pollution," respectively. Industrial contamination levels and ranks are presented in Table 4-4. As mentioned in the table, in most industries, the atmosphere and solid waste pollution contamination levels are in the [1, 2) range of light pollution. Solid waste pollution index indicating the heavy pollution level is only in the metal industry. The lowest pollution level (slight pollution) was in furniture, instrumentation and culture, and office product manufacturing. Overall, the pollution level of technology-intensive industries was the lowest, with the arithmetic average of pollution levels for all sectors in this category reaching 1.23. The pollution level of labor-intensive industries ranks second and approaches 2 in the capital-intensive industries, which are the main source of pollution.

**Table 4-4: Pollution level and rank for industries**

| Industries | Atmosphere | | Solid waste | |
|---|---|---|---|---|
| | Pollution level | Pollution rank | Pollution level | Pollution rank |
| Agriculture byproduct processing | 1.43 | Light | 1.43 | Light |
| Food manufacturing | 2.15 | Moderate | 1.20 | Light |
| Bverage manufacturing | 2.60 | Moderate | 1.32 | Light |
| Tobacco products | 1.75 | Light | 0.42 | Slight |
| Textiles | 1.20 | Light | 1.03 | Light |
| Furniture manufacturing | 0.52 | Slight | 0.45 | Slight |
| Paper and paper products | 1.58 | Light | 1.58 | Light |
| Ferrous metal smelting and rolling processing | 1.92 | Light | 1.44 | Light |
| Non-ferrous metal smelting and rolling processing | 1.63 | Light | 1.54 | Light |
| Metal products | 2.98 | Moderate | 3.06 | Heavy |
| General equipment manufacturing | 1.38 | Light | 0.66 | Slight |
| Special equipment manufacturing | 1.84 | Light | 0.92 | Slight |
| Transportation equipment manufacturing | 2.07 | Moderate | 1.53 | Light |
| Pharmaceutical manufacturing | 1.29 | Light | 1.35 | Light |
| Electrical machinery and equipment manufacturing | 1.26 | Light | 1.51 | Light |
| Communication devices, computer and other electronic equipment manufacturing | 1.62 | Light | 1.38 | Light |
| Instrumentation and culture, office machinery manufacturing | 0.51 | Slight | 0.44 | Slight |
| Crafts and other manufacturing | 0.52 | Slight | 2.41 | Moderate |

Source: China Environmental Statistical Yearbook.

## 4.4 Conclusions and recommendations

This chapter collected and organized Chinese data for several pollution indices and performed statistical analysis to explore the current environmental status and changes in the overall pollution emission levels. The results showed that the pollution and emissions have significantly increased with the rapid economic development. Meanwhile, the government began to notice the conflict between environment pollution and economic development and introduced policies in an attempt to control the deterioration of the environment. In addition, we carried out the analysis of water, air, and solid waste pollution in 31 provinces and autonomous regions at the regional level, summarized the pollution indicators from various industries, and illustrated varying effectiveness of China's environment policies for different regions and industries.

China's environmental pollution problems resulted from the excessive emphasis on the economic growth in the initial period, following Reform and Opening, and only recently environmental regulation and pollution control have become important issues addressed by public policies. There was an obvious increase in carbon emissions after China joined the WTO. One possible reason for this increase is the entry of Foreign Direct Investment (FDI), which are attracted by lax environmental regulations and which produce high amounts of pollution. For example, Chen et al. (2014) found that in China, provinces with low environmental taxes were more likely to attract FDI. Another reason is that industries' production design maximizes profits and neglects the environment. There is a dramatic variation in the degree of pollution across the country, and the most severe pollution conditions are in the eastern coastal provinces such as Shanghai and Jiangsu, where water pollution is a significant problem. Because of the relatively uneven degree of development and different environmental management practices, the more highly developed regions have higher overall pollution levels, and regions such as the ones in the northwest have lower pollution levels. From an industrial perspective, environmental degradation mainly stems from the capital-intensive industries, where metal manufacturing contributes the biggest share of pollution. Pollution generated by labor-intensive industries mainly consists of solid waste emissions. Pollution produced by technology-intensive industries is increased partially due to the upgrading of the industrial structure. On the whole, the effectiveness of environmental policies in China varies by different regions and industrial sectors.

From the above analysis, this chapter gives the following recommendations: (1) First of all, China needs to allocate differential reduction targets while controlling for the total amount of pollutants. Specifically, China must formulate appropriate environmental policies based on the differences in the degree of industrialization, the natural resources conditions, industrial structure, and population structure. In doing so, they should consider efficiency and fairness in maximizing the effects of environment policies. (2) China should rationally adjust industrial layout, guide enterprises to improve technology through policies, achieve optimal allocation of resources, improve energy efficiency, and then seek emission reduction targets. At the same time, the nation does not need to force the acceleration of the industrial structure upgrade from labor-based to capital-based industries, because appropriate adjustments in relations within the industrial structure can alleviate the deterioration of the environment to some extent. (3) China should formulate environmental regulation policies of varying intensity to cope with the influx of foreign or domestic polluting enterprises according to characteristics of different regions. In developed regions, environmental policies should be tightened and the cost of access for polluting businesses must be significantly increased. In under-developed regions, these businesses should still be encouraged to enter to spur energy development. Through rational implementation of tax abatement polices economic growth will be stimulated and pollution concentration will be dispersed.

This chapter has introduced the characteristics of Chinese environmental issues without applying formal analysis techniques. Our aim is to provide material in an intuitive and understandable form for those readers, who maybe have no necessary knowledge. In what follows, Chapters 4-7 will present more advanced and detailed analysis using econometric, linear programming, or other optimization techniques.

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# 5

# *Exploratory research on the economic and environment system of China*

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# Chapter 5. Exploratory research on the economic and environment system of China

5

## 5.1 Introduction

The China's Communist Party and the government in 2012 stated the urgency to promote energy conservation, to increase the intensity of environment protection, to strengthen the construction of an ecological civilization system, and to improve the efficiency of the environment protection alongside the adoption of an environment protection policy that allows coordinated economic and environmental development. In this chapter, we collected panel data from 30 provinces and cities of China from 2002 to 2012 and used the Data Envelopment Analysis (DEA) method, mentioned in Chapter 3, to consider both desirable and undesirable output under the environmental constraints and to compute the environmental efficiency and the decomposed Total Factor Production (TFP) of the environment. Through the analysis in this chapter, we can answer the question raised in Chapter 1: How do economic growth and environmental TFP affect the energy consumption growth?

## 5.2 Sustainable development requires sound environment protection policy

Since the opening up and reforms of 1978, there has always been a contradiction between the rapid economic development of China and its increasingly serious environment degradation. This conflict is the focus of studies of many scholars who analyze the environmental economics and determine the best approach to solve this problem. Global environmental problems, including air pollution, water pollution, and solid waste pollution, not only impede social and economic development but also threaten the ability of people to lead healthy lives. In recent years, the episodes of smog have occurred in more and more cities, making people realize that environmental problems are increasingly serious in China and that we must strengthen the enforcement of environmental protection policies. In addition, because China is the world's most populous country and the world's largest economy, China should take more responsibility in solving the global environmental issues.

China has made significant efforts to protect the environment and cope with the global climate change. These efforts are expressed in China's undertaking of the international environmental obligations (Chang and Wang, 2010). China aims for an economic growth and industrial development and, as a result, needs to constantly improve its environmental governance system. Command-control environmental policies of the "planned economy" period is no longer applicable to the existing state of economic development. During the transition period, China reformed and diversified its environmental policies, including environmental protection methods, tools, and laws (Mol and Carter, 2006). In this chapter, we use the DEA method to calculate the environmental efficiency and then decompose the TFP of the environment, which strengthens the reliability of the conclusions.

## 5.3 Developments and changes in Chinese environmental policy

Confronted by an unprecedented economic growth and industrial development, China is constantly trying to improve its environmental governance system. Command-control environmental policies of the "planned economy" period is no longer applicable to the existing state of economic development. During the transition period, China reformed and diversified its environmental policies, including environmental protection methods, tools, and laws (Mol and Carter, 2006). Compared with developed countries, the emergence of Chinese environmental protection laws was late, weak, and otherwise ineffective. Chinese environmental laws and regulations began to be enacted after the environmental conference held by the United Nations in Sweden in 1972 (Palmer, 1998). In the following, the development of pollution control policies will be examined starting from the period when the environmental protection first became part of the government's agenda and until now. There are four phases in the formation of the environmental protection in China. The starting phase refers to the early 1980's in China when legislative procedures for environmental protection laws were initiated. The developing stage is the period during which the Chinese government implemented policies for the harmonious development of the economy and environment. The deep developing stage is when Chinese government initiated a clear sustainable development strategy, and when society as a whole began to be concerned with environmental pollution. Finally, in the mature stage, a scientific outlook on development is utilized and efforts are made to build a sustainable society.

### 5.3.1 Starting stage

**Table 5-1: Environmental policies during the initial stage**

| Date | Policies and milestones |
|---|---|
| August 1973 | Chinese government issued the document "Several Provisions on the Protection and Improvement of Environment." |
| Nov-73 | Tentative Emissions for Industrial Wastes was published. |
| 1974 | The State Council of China set up the Steering Group on Environmental Protection. |
| February 1978 | China's Constitution specifically addressed its intent to regulate environmental pollution: "China protects the environment and natural resources and prevents and remedies pollution and other public hazards." |
| December 1978 | Report on the Primary Aspects of Environmental Protection Work is released. |
| 1979 | Environmental Protection Law (tentative) adopts the "polluter pays" policy. |

Source: Collected by author from related news announcements.

The later period of Chairman Mao's leadership was an important time when China participated in the environmental conference held by the United Nations in 1972. In addition, the enactment of environmental protection laws and regulations became part of the government's agenda. The environmental protection system in this period reflected China's notable attention to environmental protection as a developing country. The Environmental Protection Law (tentative) published in 1979 is one of the seven laws that China passed as a part of the development of an environmental legal framework and further reflected China's determination to take environment-related responsibilities (Chen, 2013). Policies issued in this period were formulated by addressing China's own environmental conditions and by utilizing advanced international environmental protection concepts and effective environmental policies. In the starting stage, China focused on the harm from industrial waste and made its treatment the primary objective. However, the effects of Chinese environmental policies during this period were not significant due to strong pressure to raise the national living standards, excessive pollution, shortage of natural resources. During this stage, the country was focused on economic growth and did not thoroughly understand the concept of sustainable development.

### 5.3.2 Developing stage

**Table 5-2: Environmental policies during the developing stage**

| Date | Policies and milestones |
|---|---|
| 1981 | Release of "Decisions on Enhancing Environmental Protection During the National Economic Adjustment Period by the State Council." |
| 1982 | Environmental protection bureaus in construction and environmental protection sectors were set up in rural areas. |
| 1983 | Policy on the "Synchronization of economic construction, town and city construction and environment construction; unification of economic, social, and environmental benefits." |
| 1984 | The Environmental Protection Committee of the State Council was founded. |
| 1986 | The first Environmental Statistical Bulletin was compiled. |
| 1987 | The Atmospheric Pollution Prevention Law was issued. |
| 1989 | The State Council of China released "Five New Systems," "Three Major Policies," and the "Marine Protection Law." |

Source: Collected by author from related news announcements.

Environmental policies in the developing stage considered prevention first and are guided by the government. Compared with the starting stage, environmental policies in this stage were more specific and detailed. Due to economic reforms and opening up to the global economy, industrialization in rural areas developed rapidly and local governments played increasingly important roles in economic growth (Skinner et al., 2003). Hence, the critical regions for implementation of environmental policies were no longer limited to urban areas but were expanded to include the entire country. The primary mode of pollution abatement changed from the end treatment only to process control. Environmental policy mainly developed during this stage and was defined by the Chinese government as a single basic state policy, which indicated the growing importance of the environmental policy in China. However, as a developing country, China still emphasized economic growth without sufficient understanding of the concept of sustainable development. Environmental protection was considered an economic issue rather than a social issue, resulting in a short-sighted approach to environmental degradation problems (Chen, 2013).

### 5.3.3 Deep developing stage

**Table 5-3: Environmental policies during the deep developing stage**

| Date | Policies and milestones |
|---|---|
| 1992 | Initiation of the Top Ten Countermeasures for Chinese Environment and Development. |
| 1994 | China's Agenda 21 – White Paper |
| 1995 | Release of interim regulations on prevention of solid waste pollution. |
| 1996 | The State Council of China issued measures on "Total Quantity Control" and "Green Engineering." |

Source: Collected by author from related news announcements.

During this stage, China's economic system transformed from a planned economy to a market economy. Environmental policy was elevated from a basic stage policy to a national strategy. In the "Top Ten Countermeasures for Chinese Environment and Development" initiated in 1992, China made it clear that a "sustainable development strategy" should be established and emphasized the control and prevention of industrial pollution and the improvement of the urban environment and energy utilization ratio. It also stressed that ecological agriculture and greening projects must be introduced and biodiversity protection should be enhanced. Environmental policy in this stage turned gradually from the government-oriented to the market-oriented one. Various economic incentives were provided to stimulate environmental protection, and for the first time, China considered that economic incentive tools such as education on environmental protection issues and relevant economic policies could be used to protect the environment (Hills and Man, 1998).

### 5.3.4 Mature stage

**Table 5-4: Environmental policies during the mature stage**

| Date | Policies and milestones |
|---|---|
| 2001 | Release of Regulations on Livestock Pollution Prevention. |
| 2002 | The State Council of China held the Fifth National Environmental Protection Conference. |
| 2003 | Release of the Cleaner Production Promotion Law. |
| 2005 | Basic stage policy on "Resource Saving and Environmental Protection." |
| 2006 | The State Council of China held the Sixth National Environmental Protection Conference. |
| 2008 | The Water Pollution Prevention Law was revised. |
| 2009 | Preferential catalogue of corporate income tax incentives for environment-friendly, energy-saving, and water-saving projects (tentative); environmental protection coordination groups were set up in rural areas. |
| 2010 | National Environmental Protection Standards were issued. The State Council issued "Opinions on Enhancing Waste Oil Regulation and Kitchen Waste Management," "Regulations on Environmental Emergency Response by the Environmental Protection Department," and "Cleaner Production Standards for the Copper Smelting Industry." |
| 2011 | Technical Specifications for On-site Investigation of Industrial Pollution Sources, General Guidelines for Environmental Impact Assessment, and Air Pollutant Release Standards for Thermal Power Plants were issued. |
| 2012 | The 208th Executive Meeting of the State Council passed the "Barrier-free Environment Construction Regulations," "Air Pollutant Release Standards for Steel Sintering and Pelletizing Industries," and the "Environmental Protection Regulations on Meteorological Facilities and Meteorological Sounding," and other policies. |
| 2013 | "Technical Requirements and Testing Methods for Continuous and Automated Monitoring System of Air Particulate Matters" (inhalable particulate matter (PM10) and fine particulate matter (PM2.5)); "Air Pollutant Release Standards for the Tile Industry," and other measures were released. |
| 2014 | The amendment of "Environmental Protection Law" and the "Standards for Household Waste Burning for Pollution Control." |

Source: Collected by author from related news announcements.

During this current stage, the environmental policy in China has incorporated the scientific outlook on development and emphasized energy conservation, emission reduction, and green industry. The acceleration of the Chinese economy slowed and the environmental policy gradually improved after 2011. The Chinese government has realized that environmental protection efforts must keep pace with economic growth and command-control policies should be transformed to market-incentive policies. Additionally, there is a growing awareness that government should play an important but supplemental role instead of acting as a direct controller in the implementation of environmental protection plans. Environmental policy during this stage should emphasize paths to new industrialization, optimization of industrial structures, and the development of a cyclic economy to save resources and protect the environment.

## 5.4 Empirical analysis

We intend to employ the provincial panel data of China as the basis for analysis in this chapter. However, we face several limitations in the data processing. Firstly, most of the data for Tibet are unavailable. Therefore, the Tibet sample was removed by us. Secondly, some variables (such as sulfur dioxide emissions and energy consumption) for the remaining 30 provinces and cities before 2002 contain missing values. Therefore, the samples before 2002 and after 2012 are excluded. China Statistical Yearbook (1990-2013) provides the data and guarantees its accuracy and comparability. The fixed assets investment and the Gross Domestic Product (GDP) data were deflated by the GDP deflator index. Unless there is an additional special description, all the results presented in this study were derived from the analysis of the data described above.

Firstly, we calculated the value of environment efficiency. According to the commonly used environment efficiency measurement index selection methods, we chose the number of employees, investment in fixed assets, and disposable energy (standard coal) consumption as input variables and GDP and sulfur dioxide emissions as output variables. The main fossil fuel used in China is coal, which is the source of sulfur dioxide – the biggest component of pollution and emissions. Although many dimensions are considered in calculating the environmental efficiency, the efficiency outcome is a one-dimensional variable without any measurement unit. Basically, the environmental efficiency is a ratio of the target amount and the actual amount, measuring the potential amount available for further exploitation.

The results of the super efficiency Slack-Based Method (SBM) model calculations are shown in Table 5-5.

The results show that Beijing, Liaoning, Shanghai and Fujian's environment efficiency values are greater than one in all years. The environmental efficiency values of Beijing increased year after year, indicating that the environmental utilization efficiency was significantly improved when there was economic growth. Since 2005, the Beijing government has made great efforts to control air pollution, including upgrading coal-fired boilers, using electricity as a substitute for coal, banning high-emission cars, relocating heavily polluting enterprises, and strengthening dust pollution management. These results reflect the successful efforts made by the Beijing government for environmental improvement. Guangdong is similar to Beijing except for the rate of progress, as the environmental policies in Guangdong were effective between 2005 and 2011. Since Guangdong is China's richest province, the Guangdong provincial government is able to invest heavily in environmental protection. Particularly, as the financial capital resources increased year by year after 2000, the Guangdong government also developed a "Blue Sky Project Plan" in 2000, encouraged enterprises to carry out technological transformation, and shut down many small businesses producing cement, glass, small oil refineries as well as small thermal power plants. Except for 2010 and 2011, the environmental efficiency in Hainan also increased. Most provinces in the North West, including Gansu, Qinghai, Ningxia, and Xinjiang, have made no progress in environmental efficiency with economic development. This can be attributed to the lack of financial resources for environmental protection in the region. In addition, many high-polluting enterprises' relocation to the North West led to this phenomenon. For example, investment in the coal-fired power production has been growing in the coal-rich western region during these years. The other provinces' environment efficiency values show different degrees of diversity and complexity.

**Table 5-5: Environmental efficiency of China's provinces and cities, 2002-2011**

| Region | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Beijing | 1.023 | 1.073 | 1.058 | 1.073 | 1.101 | 1.112 | 1.168 | 1.152 | 1.175 | 1.150 | 1.147 |
| Tianjin | 0.817 | 0.825 | 0.882 | 0.888 | 0.890 | 0.873 | 0.843 | 0.821 | 1.014 | 0.776 | 0.783 |
| Hebei | 0.680 | 0.706 | 0.718 | 0.750 | 0.738 | 0.728 | 0.724 | 0.725 | 0.724 | 0.687 | 0.677 |
| Shanxi | 0.602 | 0.608 | 0.611 | 0.620 | 0.605 | 0.603 | 0.601 | 0.603 | 0.600 | 0.580 | 0.580 |
| Inner Mongolia | 0.669 | 0.640 | 0.606 | 0.554 | 0.530 | 0.508 | 0.482 | 0.446 | 0.434 | 0.421 | 0.406 |
| Liaoning | 1.015 | 1.046 | 1.071 | 1.118 | 1.128 | 1.136 | 1.124 | 1.140 | 1.139 | 1.137 | 1.129 |
| Jilin | 0.718 | 0.772 | 0.776 | 0.779 | 0.742 | 0.723 | 0.690 | 0.665 | 0.646 | 0.614 | 0.629 |
| Heilongjiang | 0.814 | 0.869 | 0.916 | 0.916 | 0.890 | 0.853 | 0.843 | 0.831 | 0.825 | 0.779 | 0.758 |
| Shanghai | 1.195 | 1.203 | 1.169 | 1.172 | 1.225 | 1.256 | 1.165 | 1.158 | 1.086 | 1.187 | 1.182 |
| Jiangsu | 0.780 | 0.801 | 0.826 | 0.879 | 0.889 | 0.883 | 0.878 | 0.876 | 0.874 | 0.798 | 0.795 |
| Zhejiang | 0.792 | 0.850 | 0.851 | 0.913 | 0.906 | 0.903 | 0.890 | 0.887 | 0.896 | 0.827 | 0.810 |
| Anhui | 0.749 | 0.790 | 0.794 | 0.827 | 0.810 | 0.799 | 0.789 | 0.787 | 0.786 | 0.751 | 0.743 |
| Fujian | 1.161 | 1.098 | 1.109 | 1.025 | 1.027 | 1.030 | 1.027 | 1.017 | 1.023 | 1.004 | 1.001 |
| Jiangxi | 0.740 | 0.738 | 0.723 | 0.735 | 0.719 | 0.713 | 0.719 | 0.718 | 0.719 | 0.695 | 0.688 |
| Shandong | 0.694 | 0.729 | 0.746 | 0.792 | 0.788 | 0.790 | 0.782 | 0.775 | 0.765 | 0.719 | 0.711 |
| Henan | 0.720 | 0.750 | 0.743 | 0.746 | 0.731 | 0.714 | 0.704 | 0.695 | 0.683 | 0.649 | 0.634 |
| Hubei | 0.751 | 0.798 | 0.790 | 0.854 | 0.833 | 0.831 | 0.831 | 0.835 | 0.838 | 0.787 | 0.769 |
| Hunan | 1.014 | 0.777 | 0.774 | 0.802 | 0.789 | 0.782 | 0.785 | 0.790 | 0.788 | 0.779 | 0.773 |
| Guangdong | 1.004 | 0.943 | 0.949 | 1.021 | 1.032 | 1.044 | 1.053 | 1.029 | 1.015 | 1.016 | 0.976 |
| Guangxi | 0.681 | 0.688 | 0.687 | 0.693 | 0.681 | 0.667 | 0.658 | 0.645 | 0.633 | 0.631 | 0.627 |
| Hainan | 1.073 | 1.229 | 1.234 | 1.248 | 1.169 | 1.071 | 1.053 | 1.035 | 1.015 | 0.844 | 0.825 |
| Chongqing | 0.627 | 0.626 | 0.619 | 0.629 | 0.607 | 0.605 | 0.604 | 0.618 | 0.631 | 0.647 | 0.651 |
| Sichuan | 0.684 | 0.702 | 0.708 | 0.735 | 0.729 | 0.729 | 0.720 | 0.726 | 0.731 | 0.732 | 0.729 |
| Guizhou | 0.565 | 0.557 | 0.540 | 0.534 | 0.530 | 0.535 | 0.549 | 0.539 | 0.537 | 0.544 | 0.541 |
| Yunnan | 0.672 | 0.687 | 0.691 | 0.708 | 0.685 | 0.672 | 0.677 | 0.678 | 0.663 | 0.612 | 0.606 |
| Shaanxi | 0.602 | 0.608 | 0.611 | 0.620 | 0.605 | 0.603 | 0.601 | 0.603 | 0.600 | 0.580 | 0.580 |
| Gansu | 0.641 | 0.645 | 0.647 | 0.647 | 0.644 | 0.637 | 0.626 | 0.607 | 0.594 | 0.590 | 0.595 |
| Qinghai | 0.649 | 0.615 | 0.599 | 0.576 | 0.569 | 0.563 | 0.568 | 0.544 | 0.533 | 0.524 | 0.504 |
| Ningxia | 0.509 | 0.501 | 0.473 | 0.451 | 0.439 | 0.431 | 0.436 | 0.412 | 0.397 | 0.386 | 0.381 |
| Xinjiang | 0.658 | 0.670 | 0.639 | 0.644 | 0.627 | 0.608 | 0.603 | 0.581 | 0.574 | 0.562 | 0.549 |

Sources: Calculated by author using the super efficiency SBM model.

Malmquist index is employed to decompose the environmental TFP after considering energy consumption and sulfur dioxide emissions. These results are shown in Table 5-6. The Malmquist index measures how the performance changes for a Decision-Making Units (DMU) over time. Further, we can derive Technology Progress Rate, Pure Technology Efficiency, and Scale Efficiency. Technology Progress Rate is used to measure the general technological progress affecting every DMU. Pure Technology Efficiency is referred to as the catch-up relative to the present technology, measuring how close the DMU is to the frontier. Scale Efficiency measures the change in efficiency associated with returns to scale. Malmquist index can be decomposed into three parts in the following manner:

Malmquist index = Technology Progress Rate* Pure Technology Efficiency* Scale Efficiency

**Table 5-6: Decomposition of each province and city's environment TFP**

| Province | Technology Progress Rate | Pure Technology Efficiency | Scale Efficiency | Malmquist index |
|---|---|---|---|---|
| Beijing | 1.071 | 1.000 | 1.005 | 1.076 |
| Tianjin | 1.051 | 1.019 | 1.000 | 1.071 |
| Hebei | 1.021 | 0.996 | 0.986 | 1.003 |
| Shanxi | 1.018 | 1.006 | 0.972 | 0.995 |
| Inner Mongolia | 1.020 | 1.009 | 0.943 | 0.969 |
| Liaoning | 1.047 | 0.976 | 1.028 | 1.050 |
| Jilin | 1.029 | 1.005 | 0.968 | 1.001 |
| Heilongjiang | 1.022 | 1.000 | 0.990 | 1.012 |
| Shanghai | 1.087 | 1.003 | 0.972 | 1.060 |
| Jiangsu | 1.034 | 0.963 | 1.035 | 1.029 |
| Zhejiang | 1.033 | 0.985 | 1.019 | 1.037 |
| Anhui | 1.012 | 0.999 | 0.990 | 1.001 |
| Fujian | 1.031 | 1.001 | 0.978 | 1.009 |
| Jiangxi | 1.011 | 1.006 | 0.982 | 0.999 |
| Shandong | 1.026 | 0.922 | 1.075 | 1.017 |
| Henan | 1.020 | 0.987 | 0.977 | 0.984 |
| Hubei | 1.016 | 0.999 | 0.996 | 1.010 |
| Hunan | 1.018 | 1.003 | 0.978 | 0.998 |
| Guangdong | 1.032 | 0.970 | 1.029 | 1.030 |
| Guangxi | 1.020 | 1.007 | 0.962 | 0.988 |
| Hainan | 1.054 | 1.009 | 0.971 | 1.031 |
| Chongqing | 1.011 | 1.007 | 0.984 | 1.002 |
| Sichuan | 1.017 | 0.994 | 0.998 | 1.009 |
| Guizhou | 1.009 | 1.012 | 0.981 | 1.000 |
| Yunnan | 1.010 | 1.003 | 0.977 | 0.988 |
| Shaanxi | 1.011 | 1.004 | 0.986 | 1.000 |
| Gansu | 1.013 | 1.019 | 0.959 | 0.989 |
| Qinghai | 1.010 | 0.995 | 1.009 | 0.986 |
| Ningxia | 1.004 | 1.030 | 0.970 | 1.001 |
| Xinjiang | 1.021 | 1.006 | 0.976 | 1.002 |

Sources: Calculated by author using the super efficiency SBM model.

From Table 5-6, we can see that most provinces have an increasing trend in the environmental performance. Specifically, Malmquist indexes for all eastern and northeastern provinces are beyond 1. For two central provinces, Anhui and Hubei, Malmquist indexes are more than 1. Besides, Malmquist indexes for four provinces in Western China, Chongqing, Sichuan, Ningxia, and Xinjiang, are also above 1. The fact that Malmquist indexes exceeded 1 implies that improvements in the TFP occurred in these regions. The situation in other provinces is as follows. Three provinces in central China, Jiangxi, Henan, and Hunan, show regress in the environmental performance. Similar cases also occur in the four western provinces, namely, Guangxi, Yunnan, Gansu, and Qinghai, whose Malmquist indexes are less than 1. There is no change in the environmental performance for Guizhou and Shaanxi with Malmquist indexes of 1.

These improvements or regresses may be associated with the technological progress, the efficiency progress, or scale adjustment. All values of the Technology Progress Rate in the first column are greater than 1, indicating that technological frontier is moving forward in all provinces. However, not all provinces experienced improvements in efficiency. There are 12 provinces with the Pure Technology Efficiency score less than 1, as shown in the second column of Table 5-6. It means that these provinces are moving away from the frontier and are more backward relative to the present technology. Regarding the scale efficiency, only seven provinces have scores of more than 1. Therefore, most provinces were not operating at the most productive scale size.

## 5.5 Statistical test

### 5.5.1 Introduction



The following section begins with the unit root test with an eye toward avoiding spurious regression in equation estimation. Then the panel data model is estimated to explore the association between economic development and energy input. At last, TFP is incorporated into the model to detect its impact on the energy consumption growth rate.

### 5.5.2 Panel unit root test

Given the non-stationary panel data and to avoid spurious regression, we performed a unit root test before constructing the model. In view of the robustness of the test results, we used the test of Levin-Lin-Chu (LLC), the Projection Pursnit–Fisher (PP-Fisher), and the Fisher-Automatic Direction Finder (Fisher-ADF) and ran the unit root test on the data and variables using Eviews 6.0. The results are shown in Table 5-7. The level series of TFP of Environment and GDP Growth Rate variables are stationary. The other variables, Environment Efficiency and Energy Consumption Growth Rate, are all non-stationary. After the first-order differencing was performed, the Environment Efficiency and Energy Consumption Growth Rate showed no unit root. According to the test results, two stationary variables, TFP of Environment and GDP Growth Rate, can be employed directly in the subsequent analysis. However, the two other variables must be in the form of first-order differences to avoid spurious regression.

**Table 5-7: Stationarity test**

| Test Method | Value | | | Difference Value of First Order | | |
|---|---|---|---|---|---|---|
| | LLC | Fisher-ADF | PP-Fisher chi-square | LLC | Fisher-ADF | PP-Fisher chi-square |
| Environment Efficiency (*eeff*) | -3.57*** (0.0002) | 63.19 (0.3645) | 84.01** (0.02) | -12.29*** (0.00) | 146.75*** (0.00) | 183.67*** (0.00) |
| TFP of Environment (*tfpch*) | -8.33143*** (0.00) | 120.665*** (0.00) | 187.49*** (0.00) | -20.67*** (0.00) | 210.57*** (0.00) | 297.58*** (0.00) |
| Energy Consumption Growth Rate (*econrate*) | -3.57*** (0.0002) | 63.19 (0.36) | 84.01 (0.022)** | -12.29*** (0.00) | 146.75*** (0.00) | 183.67*** (0.00) |
| GDP Growth Rate (*gdprate*) | -5.35*** (0.00) | 83.89** (0.02) | 93.62*** (0.004) | -16.02*** (0.00) | 165.79*** (0.00) | 231.31*** (0.00) |

### 5.5.3 Fixed effects model

There are two kinds of panel data models: Fixed Effects and Random Effects models. The difference between the fixed and random effects model are embodied by the group means. Generally, group means are fixed in fixed effects model and random in random effects model. To reduce the error as much as possible, both models are used. We use the Fixed Effects model for estimation, because the selected time span is less than the section number and the research purpose is to conduct testing and inference under the conditions of inherent effects of the samples. In view of the linkages between energy and economy, we introduce the GDP Growth Rate as an explanatory variable, represented by $gdprate$. The model is assumed to be as below:

$$econrate_{it} = c_{it} + \alpha_1 gdprate_{it} + \alpha_2 tfpch_{it} + u_{it} \tag{5-1}$$

In (5-8), *econrate* , *gdprate* , represent the growth rates of energy consumption and GDP, respectively; *tfpch* is the environmental TFP change; *i* is the data of the section; and *t* represents the year between 2002 and 2012. *c* is the individual effect of provinces and cities. $a_1$ and $a_2$ are the slope coefficients. $u_{it}$ is the random disturbance term. We used the weighted least squares method to implement the regression analysis using Eviews 6.0 with coefficients of the independent variables as constants and the fixed effect represented by the variable intercept in the model. The test results are shown below.

### Table 5-8: Tests of unweight fixed effects and variable intercept model

| Explanatory Variable | Regression Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| *Gdprate* | 1.09 | 0.11 | 9.78 | 0.00 |
| *Tfpch* | -0.04 | 0.01 | -3.18 | 0.002 |

### Table 5-9: Fixed effects of different areas (sections)

| Area | Value of Fixed Effect | P-Statistic | Area | Value of Fixed Effect | P-Statistic |
|---|---|---|---|---|---|
| Ningxia | 0.410 | 0.00 | Shanghai | 0.065 | 0.00 |
| Inner Mongolia | 0.409 | 0.00 | Sichuan | 0.062 | 0.00 |
| Xinjiang | 0.405 | 0.00 | Beijing | 0.065 | 0.00 |
| Hainan | 0.388 | 0.00 | Hebei | 0.061 | 0.00 |
| Hunan | 0.387 | 0.00 | Henan | 0.061 | 0.00 |
| Qinghai | 0.386 | 0.00 | Jiangxi | 0.060 | 0.00 |
| Jiangsu | 0.383 | 0.00 | Shandong | 0.063 | 0.00 |
| Fujian | 0.383 | 0.00 | Gansu | 0.060 | 0.00 |
| Guangdong | 0.374 | 0.00 | Tianjin | 0.065 | 0.00 |
| Chongqing | 0.372 | 0.00 | Guizhou | 0.064 | 0.00 |
| Guangxi | 0.372 | 0.00 | Anhui | 0.060 | 0.00 |
| Yunnan | 0.366 | 0.00 | Jilin | 0.064 | 0.00 |
| Zhejiang | 0.365 | 0.00 | Heilongjiang | 0.069 | 0.00 |
| Hubei | 0.364 | 0.00 | Shanxi | 0.060 | 0.00 |
| Shaanxi | 0.364 | 0.00 | Liaoning | 0.064 | 0.00 |

From the results in Tables 5-8 and 5-9, all explanatory variables, including *gdprate*, *tfpch* and all individual effects across 30 provinces in the model passed the statistical significance test at 1% level, which shows the presence of a statistical correlation between the energy consumption and the TFP of environment. Removing the TFP of environment on energy consumption, we tested the above model again with the results presented in Tables 5-6 and 5-7.

Tables 5-10 and 5-11 show that the impact of economic growth is statistically significant at 1% level. The quantitative estimate indicates that the growth rate of energy consumption will correspondingly increase by 0.73% when economic growth rate is 1%. As seen from the sequenced P-Statistic (ascending), all provinces and cities except

Heilongjiang pass the statistical significance test at 5% level. From the standpoint of distributional effects, the positive effect of economic growth is statistically significant nationwide at 1% level, without considering the impact of the TFP of environment. The fixed effects in different areas are not the same with great differences across different regions. The fixed effect of Inner Mongolia is the highest (1.32), and the fixed effect of Beijing is the lowest (0.4548). Inner Mongolia, Ningxia, Xinjiang and Qinghai have fixed effects of more than 100%. These fixed effects reflect the level of the energy consumption growth rate.

Table 5-11 shows that the bigger the fixed effects are, the faster is the growth in the energy consumption; and smaller fixed effects indicate that energy consumption is growing more slowly. From a regional perspective, the provinces and cities with the highest values are mostly located in the West of China and far away from the eastern coastal areas, which supports the viewpoint that the technological level of economic development is lagging and that these areas are highly dependent on energy consumption. The results of the fixed effects model do not pass the statistical significance test at 1%, 5% or 10%. As the fixed effects model cannot be used to test the extent of the above-mentioned impact under different economic development levels, we use the varying-coefficient model test to conduct further analysis.

**Table 5-10: Tests of the fixed effects variable intercept model without consideration of the TFP of environment**

| Explanatory Variable | Regression coefficient | Std. Error | *t*-Statistic | Prob. |
|---|---|---|---|---|
| *gdprate* | 0.740 | 0.020 | 37.669 | 0.000 |

**Table 5-11: Tests of fixed effect variable intercept model without consideration of the TFP of environment-fixed effect (by section)**

| Region | Value of Fixed Effect | *P*-Statistic | Region | Value of Fixed Effect | *P*-Statistic |
|---|---|---|---|---|---|
| Inner Mongolia | 1.316 | 0.000 | Hubei | 0.775 | 0.000 |
| Ningxia | 1.194 | 0.0005 | Hebei | 0.752 | 0.000 |
| Xinjiang | 1.160 | 0.000 | Jiangxi | 0.743 | 0.000 |
| Qinghai | 1.047 | 0.000 | Zhejiang | 0.732 | 0.000 |
| Hunan | 0.972 | 0.000 | Gansu | 0.723 | 0.000 |
| Fujian | 0.933 | 0.000 | Shandong | 0.716 | 0.000 |
| Jiangsu | 0.928 | 0.000 | Tianjin | 0.678 | 0.000 |
| Guangxi | 0.913 | 0.000 | Guizhou | 0.650 | 0.0008 |
| Hainan | 0.904 | 0.000 | Anhui | 0.633 | 0.000 |
| Chongqing | 0.879 | 0.0004 | Jilin | 0.619 | 0.001 |
| Guangdong | 0.847 | 0.000 | Shanghai | 0.602 | 0.000 |
| Shaanxi | 0.842 | 0.000 | Shanxi | 0.587 | 0.000 |
| Yunnan | 0.829 | 0.000 | Heilongjiang | 0.501 | 0.102 |
| Henan | 0.828 | 0.000 | Beijing | 0.462 | 0.000 |
| Sichuan | 0.787 | 0.000 | Liaoning | 0.455 | 0.000 |

### 5.5.4 Varying-Coefficient Model

We introduced TFP as an explanatory variable and assume the varying-coefficient model as below:

$$econrate_{it} = c_{it} + \theta^{it} tfpch + \beta gdprate_{it} + \mu_{it} \tag{5-2}$$

Where $c$ is a constant term and $\theta$ is the influence coefficient of the TFP of environment, which captures the extent of influence of the TFP of the environment on the energy consumption growth rate. When we have a positive coefficient, it gives us positive correlation between the TFP of environment and the energy consumption growth rate. Thus, the improvement of the TFP of environment can increase energy consumption. If the coefficient is negative, the opposite is true, and the environmental TFP will reduce energy consumption. If the improvement in the energy utilization rate can reduce energy consumption, this will improve environment efficiency. If the coefficient is not statistically significant, the TFP of environment has no significant influence on energy consumption. We used Eviews 6.0 to estimate the model with results presented in Tables 5-12 and 5-13.

From the test results shown in Tables 5-12 and 5-13, the P-statistic of the GDP growth rate was 1.1801, which is greater than 100%, and its regression coefficient is statistically significant at 1% level. Additionally, calculation results show that all coefficients are statistically significant at 1% level for all regions. Coefficients were negative with different values. This phenomenon was seen for all regions. It means that the environmental TFP facilitates conservation of energy. Combined with the changes in the environmental efficiency estimated in this chapter, we draw two conclusions: the environment efficiency values for China may have long-term fluctuations and show no statistically significant increasing trend, and the rigid demands of the rapid economic development led to an increase in China's energy consumption. These results indicate that the change in the environment efficiency has significant influence on energy consumption. It may be associated with a phenomenon called "rebound effect," which states that the adoption of an energy conservation technology allows consumers to spend less money to get the same amount of energy, and the resulting reduction in financial pressure may lead to more consumption of energy. Therefore, the theory of rebound effect still needs to be verified, while taking measures to promote energy efficiency is necessary and useful. Even if the rebound effect exists, the promotion of energy efficiency can save the amount of used energy and improve the quality of life.

### Table 5-12: TFP of environment's influence on population model

| Explanatory Variable | Regression coefficient | Std. Error | *t*-Statistic | Prob. |
|---|---|---|---|---|
| *c* | 0.374 | 0.063 | 5.969 | 0.000 |
| *gdprate* | 1.180 | 0.109 | 10.847 | 0.000 |

**Table 5-13: The influence extent of TFP of environment on the energy consumption growth rate**

| Region | Variable Coefficient | *P*-Statistic | Region | Variable Coefficient | *P*-Statistic |
|---|---|---|---|---|---|
| Liaoning | -0.478 | 0.000 | Hubei | -0.419 | 0.000 |
| Shanxi | -0.452 | 0.000 | Yunnan | -0.417 | 0.000 |
| Jilin | -0.452 | 0.000 | Zhejiang | -0.417 | 0.000 |
| Heilongjiang | -0.451 | 0.000 | Shanghai | -0.416 | 0.000 |
| Anhui | -0.444 | 0.000 | Chongqing | -0.412 | 0.000 |
| Guizhou | -0.439 | 0.000 | Guangxi | -0.411 | 0.000 |
| Tianjin | -0.433 | 0.000 | Guangdong | -0.408 | 0.000 |
| Gansu | -0.432 | 0.000 | Fujian | -0.402 | 0.000 |
| Jiangxi | -0.431 | 0.000 | Jiangsu | -0.400 | 0.000 |
| Shandong | -0.431 | 0.000 | Qinghai | -0.397 | 0.000 |
| Henan | -0.427 | 0.000 | Hunan | -0.397 | 0.000 |
| Hebei | -0.426 | 0.000 | Hainan | -0.394 | 0.000 |
| Beijing | -0.423 | 0.000 | Xinjiang | -0.378 | 0.000 |
| Sichuan | -0.421 | 0.000 | Inner Mongolia | -0.374 | 0.000 |
| Shaanxi | -0.419 | 0.000 | Ningxia | -0.373 | 0.000 |

## 5.6 Conclusions and recommendations

Rapid economic growth will cause the rapid growth in the energy consumption, eventually leading to a conflict between energy supply and demand. Although people advocate for efficiency and energy saving, they also desire high quality of life, resulting in the development of energy-intensive products. Therefore, the improvement in efficiency leads to an increase in energy consumption. However, our results indicate that this phenomenon is not obvious at the current stage of economic development in China.

The relationship between energy consumption growth rate and environmental efficiency is significant. According to the results of the variable coefficient model, there are regional differences, when it comes to the effect of TFP of the environment on the energy consumption growth rate. One possible conclusion is that the production technology in some areas in China is still at a relatively early stage of development, the energy utilization is still at the stage of simple processing with low utilization rate, and the critical point where the improvement of efficiency accelerates energy consumption has not been reached. It would be useful to determine this critical point to guide future analysis.

We identified two notable problems in this chapter. Firstly, the economic development of China is highly dependent on energy consumption. The ratio of GDP growth rate to energy consumption growth rate is 1:1.81. Secondly, the influence of coefficients of the TFP of environment on the energy consumption growth rate is negative, which means that we have to limit energy consumption to achieve environment protection, reflecting the contradictions between economy, energy, and the environment. Improvements in production efficiency to enhance the utilization of resources can solve the problems of environment pollution.

Although we have obtained meaningful conclusions by detecting the relationship between different variables, such as the environmental efficiency, growth, etc., this chapter's analysis has some limitations. A noticeable problem is the lack of research on the relationship within industries by using enterprise level data. Nowadays, it is a popular trend to coordinate development for different industries, including manufacturing industries and the environmental protection industries. In addition, from the methodological point, regression analysis alone cannot reveal the type of industrial interaction. The new method, coupling evaluation model, is needed to study the process of industrial interaction. We will move to this topic in Chapter 6.

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# 6

# *The coupling development of environmental protection and manufacturing industries in Anhui Province*

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# Chapter 6. The coupling development of environmental protection and manufacturing industries in Anhui Province

## 6.1 Introduction

Chapter 4 employed descriptive statistical analysis techniques to explore China's current situations of environmental pollution, with lack of a formal detection of relationship between different production and environmental protection industries. Chapter 5 did the same, mainly concentrating on the regional environmental issues in China. In the post-crisis era, for China to achieve industrial strategic transformation and continue economic development, the plan to restructure and upgrade the industrial infrastructure must be considered together with effective regulation for different types of industry. Production industries promote the economy, and environment protection industries promote environmental quality. Based on previous chapters, this chapter uses enterprise survey data and an evaluation model to study the coupling development of production and environmental protection industries.

Since the 2008 financial crisis, the global economic growth pattern has been challenged. To continue to grow, the original international division of labor system needs to be adjusted and improved. To successfully continue economic development, most developed and developing countries must strategically adjust their economic and industrial structure, for example, by increasing investment in scientific and technological innovation, to achieve stable industrial transformation. From a regulatory perspective, governments need strategies to expand the industrial policy system and to plan and optimize the industrial layout. To do this, the goal is the cultivation of more emerging industries, such as ones that conserve energy, protect the environment, and/or develop new energy technology or biological medicine.

However, as industrial development brings economic growth, it can inevitably cause environmental problems. For China, the development of traditional industry, including heavy production, ensures a stable economic base and the development of new industries, including environmental protection. The focus of this section is the determination of environmental effects for different industries and analysis of the best strategies to coordinate development of production and environmental protection industries. From the perspective of regional heterogeneity, midwestern Chinese lacks a complete industrial support system, and the ability of this region to develop environmental protection industry is weak relative to the eastern part of the country with its more advantageous industrial scale. The development field of environmental protection industries in the three areas is consistent with the strategic objective at the national level. The cognitive differences of industrial concept and development model in all areas, combined with various policy-biased degrees, cause all areas to consider their own resources and environment to develop environmental protection industry and control production industry in different measures. We need to determine the interaction mechanism between environmental protection industry and production industry and analyze the merging mode, evolution path, and importance of key links. This plays a key role in policymaking, policy effect evaluation, and policy optimization, and guides regional economy transformation, structural optimization, and industrial upgrade.

Here, we present a research on the development of environmental protection and production industries, focusing on regional (Anhui) coupling development of the two industries and giving policy suggestions to guide future development. Anhui Province has not just production but also environmental protection industries, which is suitable for coupling analysis. Its industrial output accounts for about half of its GDP, of which highly polluting industries achieve 10% output share. Meanwhile, the environmental protection industries in Anhui Province have enjoyed a strong momentum of development. Many competitive environmental protection enterprises have emerged. The output of province’s environmental protection industries in 2015 reached 162.33 billion yuan, which makes it a promising new industry. In addition, Anhui can be seen as a representative and typical province both in geographical location and economic condition. It sits in the center of China, bounded by western inland and eastern coast, and has the features of western and eastern provinces. Anhui is moderate in the size of its economy, with Gross Domestic Product (GDP) ranking 13th of 31 provincial units. We then present our analysis of the mechanism of industrial coupling, establish the coupling model, perform empirical analysis, and finally present our conclusions and policy recommendations.

## 6.2 Coupling mechanism analysis

There are many studies on the relationship between or within industries, such as industrial complex (Isard and Schooler, 1959; Sivacoumar et al., 2001), industries clustering (Rui and Swann, 1999; Pinch and Henry, 1999; Voyer, 1998), and agglomeration economies (Duranton and Puga, 2003; Brülhart and Mathys, 2008; Glaeser and Gottlieb, 2009). Industrial coupling refers to a comprehensive interaction of technology, market, product development, technological innovation, and other factors between different industries. Coupling is a physical concept originally meaning the phenomenon that two or more systems interact with each other. Some Chinese researchers borrowed this concept and applied it to study the relationship between different industries (Li, 2012; Xiong and Li, 2010). This section argues there is narrow and broad industrial coupling. Narrow industrial coupling describes the process of dynamic interaction between industries. It has a positive relationship of interdependence and mutual promotion. Broad industry coupling emphasizes the natural process of industrial interaction rather than the direction of the coupling effect. Here, we discuss and analyze the coupling logic structure for generalized industry coupling.

### 6.2.1 Coupling process life cycle

As per the coupling life cycle, in a situation without the interference of external factors, the coupling process must meet the inherent evolvement law of the industry development. Specifically, the development can be divided into four stages: coupling formation stage or sprout stage, coupling growth stage, coupling maturity stage, and coupling recession stage (as shown in Figure 6-1).

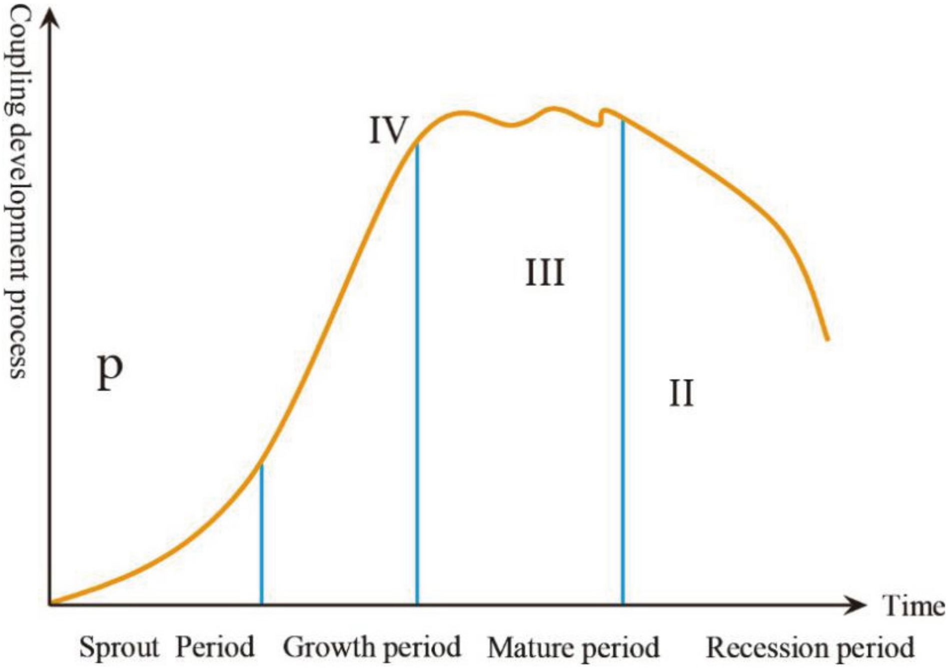


**Figure 6-1: Inherent law of industry coupling life cycle**

In the sprout period, environmental protection industry and production industry from an uncoupled state gradually form a coupling relationship. The coupling rate at this time is relatively flat but gradually increases. At this time, due to the characteristics of the environment-friendly industry, interaction with the production-type industry is not obvious, and the whole coupling system is in a state of disorder. At this point, the discrimination of coupling is happening spontaneously in the system, gradually eliminating the factors that influence the development direction of coupling positive effects, to form a more stable development of the system. Subsequently, the coupling system moves into the high-speed growth period, during which time the environmental protection industry and other emerging industries skillfully use advantages that traditional or production industries can provide (for example, resources or markets). Traditional industry benefits from the vigorous development of the emerging industry (for example, emerging technology and improved management experience). Thus, the two industries complement each other to promote coupling. With a limited role of internal resources, the two industries begin to exhibit exclusion phenomenon and the coupling development speed slows and enters a mature period. The coupling of the period is stable, and fluctuation of the system is generated during the interaction. When the degree of system constraints reaches the limit, the exclusion phenomenon is obvious and coupling development will be in a bottleneck or even recession state. At this time, the environmental protection industry will be likely to show negative growth, and the development of the manufacturing industry will be greatly restricted. The above coupling life cycle description is like that of the industrial life cycle, as the coupling process is based on the development of the industry and is an indicator of the external performance of industrial development. Through the description of the life cycle of the coupling system, we can obtain the future development progress of the industry coupling. There are many ways to distinguish environmental protection industry and production industry. In this study, we will adopt the Weaver-Thomas model to identify the two types of industry, which will be explained in a succeeding empirical study in Section 4.5.

### 6.2.2 Evolution of coupling systems

From the perspective of the evolution of coupling systems, endogeneity and self-organization should be emphasized, which is the key to upgrading and developing an innovative economy. On the other hand, as a policymaker and implementer, the government also plays an important role in facilitating industrial coupling. When industry coupling occurs with the evolution of industrial development and is affected by policy and other factors, it can be divided into four main processes: decline (I), stagnation (II), wave (III), and continuous growth (IV) evolution.

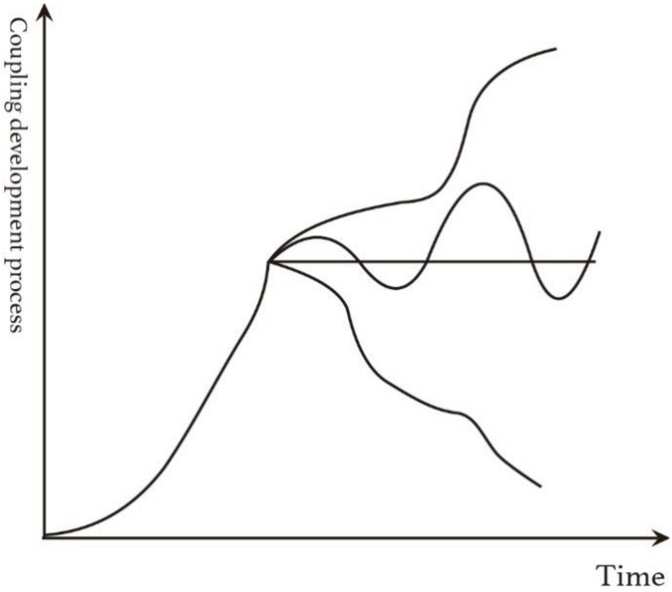


**Figure 6-2: Coupling evolution process**

As shown in Figure 6-2, the four stages of evolution do not appear until industrial coupling reaches a certain point. After reaching point P, the coupling of environmental protection and general production industries is restricted by the conditions of capital, resources, technology, and talent. At this time, if there is no supporting policy, then the production industry may not continue to be fully supported by the environmental protection industry, and the latter is influenced significantly by the disruption of coupling, resulting in decline. If after this point, the government provides policy support, the coupling system may benefit from but not fully exploit this support. In this case, the development of the coupling evolution model at the original level is likely to become stagnant. When the coupling system fully utilizes policy support but is unable to fully exploit its own market allocation of resources, there will be a dual direction seesaw effect of policy and market and a wave evolution path. When the coupling system takes advantage of the market and the supportive policy, it may follow a path of continuous growth evolution. At this time, the constraint factors at point P in the coupling system are solved and resources are reasonably allocated, allowing both the environmental protection and the production industries to reach their respective advantages and give each other the corresponding support to continue the effective coupling development. In the succeeding empirical analysis in Section 7.4, we will define two kinds of categories; industrial output indicators including basic financial sales, business income, business taxes and surcharges, etc.; and energy input indicators, including power consumption and comprehensive energy consumption. Using the above variables and the Weaver-Thomas model, we will identify the environmental protection industry and production industry.

### 6.2.3 Coupling mechanism analysis

In this section, we address the best strategies to promote coupling development between environmental protection and production type industries. To do this analysis, we incorporate elements of conduction mechanism, space-time linkage mechanism, industrial chain integration mechanism, government promotion mechanism, and the superposition of amplification mechanism analysis to understand the coupling mechanism.

Conduction mechanism mainly refers to the transmission mechanism of elements and expresses, in a certain area, all elements' transmission and interaction in the development of environmental protection and production industries. Element conduction mechanism is the basic mechanism of the coupling of the two industries, allowing formation of a coupling system with a complex and tight network system including information, talent, and market networks to allow better allocation of resources within the system and optimization of the industrial layout in the sprout stage and the initial stage of growth for the coupling process. The network system will solve the contradictions in the coupling process and accelerate coupling. Linkage mechanism refers to the linkage interaction in time and space of the environmental protection industry, the production industry, and their coupling system. It mainly acts on the growth and development period of industry coupling. From a vertical perspective, linkage mechanism can initially work in the environment-friendly industry and the production industry. In mutual cooperative relationships, there can be various types of intra-industrial enterprises for different nodes of the industry value chain. From a horizontal perspective, the linkage mechanism generates different types of industries' external competitive relationships in the same nodes in the industry value chain. The cooperation relationship for industry coupling from the vertical angle and competitive relationship for industry coupling from the horizontal angle form a competitive and cooperative relationship necessary for the development of the coupling system. This linkage mechanism widens the industry value chain and creates a better corresponding service system for industrial grouping development. The integration mechanism is for industry, a main mechanism in the middle and latter period of industrial coupling. When a perfect industrial chain exists in the industrial coupling system, the coupling effect allows a deeper level of development in the integration mechanism. Push mechanism mainly refers to the mechanism promoted by the government. If the market is an invisible hand that guides industrial coupling, the government-driven mechanism is the assistance of a booster to a rocket of industrial coupling. The government-driven mechanism can help to further promote the process allowing the optimization of the allocation of resources and adjustment of the industrial structure and layout, which the market can also promote. The role of the mechanism is multifaceted and includes economic, cultural, legal, and environment and energy aspects to promote or control the development of industry coupling. This allows the advantages of various industries to operate in the system and factors that hinder economic growth can be avoided to ensure that industries effectively and reasonably avert system noise and structural failure. Amplification mechanism, or magnifying mechanism or gain multiplier mechanism, exists between the upper reaches and downstream of the industrial chains of environmental protection and manufacturing industries or between industries of coupling system. The mechanism means that the increase of gain in a link or an enterprise has a multiplicative effect on the increase of gain in another one. Amplification mechanism occurs in the beginning of the industry coupling, as does the transmission mechanism promoting the development of coupling systems.

## 6.3 Empirical test

### 6.3.1 Industry division

The data employed here consists of two parts. One part is at the macro-level and was collected from the Anhui Statistical Yearbook of 2013 and 2014. The other part is micro survey data of the 16,375 industrial enterprises in Anhui Province in 2014. All of these are representative of industrial enterprises. The latter comes from the China Industrial

Enterprise Database.

Before performing the industrial coupling analysis, we need to identify the environmental protection and the production industries from the 39 industry sectors. To do this, we used the Weaver-Thomas model, a combined exponential model introduced by Weaver and improved by Thomas (Atkinson and Unwin, 2002; Fang, et al., 2012). This model uses comprehensiveness and correlation between industries and solves the problem of industrial optimization under the multi-index including output ones and input ones. This approach has been widely used by domestic and foreign scholars in the selection and evaluation of multi-index industry, is data-based, and is relatively effective. The model compares the actual distribution (observation distribution) with the least square of the assumed distribution to establish a close approximation distribution and thus make a comprehensive evaluation.

Assume n industry sectors and p evaluation indicators. First, the original data matrix $A=\left(a_{ij}\right)_{n\times p}$ is standardized and the processed matrix is denoted as. $B=\left(b_{ij}\right)_{n\times p}$ . The formula is written as:

$$b_{ij}=\frac{a_{ij}-\min\limits_{j} a_{ij}}{\max\limits_{j} a_{ij}-\min\limits_{j} a_{ij}} \quad (i=1,2,\cdots,n; j=1,2,\cdots,p) \tag{6-1}$$

In the $j$ index, after the standardization of the matrix sorted from large to small, we calculated the value of the Weaver-Thomas index of $i$ industry according to the ranking order, that is:

$$WT_{kj}=\sum_{i=1}^{n}(\lambda_i^k-\frac{100b_{ij}}{\sum\limits_{i=1}^{n}b_{ij}})^2 \quad (j=1,2,\cdots,p) \tag{6-2}$$

Where $WT_{kj}$ is the Weaver-Thomas value of the $k$ industry in the $j$ index. When $i\le k$ $\lambda_i^k=100/k$ and whe $i>k$ $\lambda_i^k=0$ .

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For each index, we find the position corresponding to the minimum Weaver-Thomas value and the optimal number of environmental protection industry in this index, denoted as $nq = \{q; WT_{kj} = \min_{q} WT_{qj}, q = 1,2,\cdots,n\}$. Considering the selection in all indices, we then used the arithmetic average method to get the total industry select number, denoted as $nq = \frac{1}{p}\sum_{j=1}^{p} nq_j$ . Finally, we used the Weaver-Thomas matrix calculated directly as an evaluation matrix:

$$WT = \begin{Bmatrix} WT_{11} & WT_{12} & \cdots & WT_{1p} \\ WT_{21} & WT_{22} & \cdots & WT_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ WT_{n1} & WT_{n2} & \cdots & WT_{np} \end{Bmatrix} \tag{6-3}$$

*WT* assigns corresponding weights based on the index. In accordance with the ranking, we select the former *nq* industries as the environmental protection industry for the index system.

Survey indicators include the basic financial sales of the company's current assets, total income, the main income, taxes, the main business taxes and surcharges, payable Value Added Tax (VAT), selling expenses and management fees, operating profit, total profit, industrial output value, and industrial sales output.

In addition, our results differ from previous work in that we employed power consumption and comprehensive energy consumption including coal, oil, and gas, likely improving the industrial division. In addition to the micro survey data, we also combined the industrial output and the employees in the industry to reflect the potential development of the industry.

Finally, using the Weaver-Thomas model, we can determine the selection of the industry in different indicators, shown in Table 6-1.

**Table 6-1: Industry preferred number and index weights**

| Index | Preferred number | Weight | Index | Preferred number | Weight |
|---|---|---|---|---|---|
| Current assets | 3 | 0.077 | Operating profit | 39 | 0.013 |
| Business income | 4 | 0.063 | Gross profit | 39 | 0.007 |
| Advocate of business income | 4 | 0.062 | Industrial output value | 6 | 0.051 |
| Business tax and surcharges | 1 | 0.175 | Industrial sales output value | 6 | 0.051 |
| Main business taxes and surcharge | 1 | 0.176 | Industrial value added | 19 | 0.023 |
| Payable VAT | 30 | 0.014 | Number of staff and workers | 19 | 0.025 |
| Selling expenses | 2 | 0.023 | Power | 5 | 0.073 |
| Management expenses | 39 | 0.079 | Comprehensive energy consumption | 3 | 0.111 |

Note: the weight of the index is calculated using formulas of Weaver-Thomas model.

According to the model theory, we selected the 13 top-scoring industries for the environmental protection industry. We also sorted the remaining 26 industries as part of the production industry and classified the two types of industry division using the micro enterprise data.

### 6.3.2 Coupling evaluation

To perform the dual industry coupling evaluation, we used index data from 2009–2013. Prior to 2011, industry statistics were based on the “national economic industry classification and code (GB/4754-2002)” classification criteria. The latest standards are based on “national economic industry classification and code (GB/4754-2011).” Industry classification was adjusted as follows: “communications equipment, computers, and other,” and “electronic equipment manufacturing” were combined as “computers, communications, and other electronic equipment manufacturing industry,” “rubber products industry” and “plastic products industry” were combined as “rubber and plastic products industry,” and “automobile manufacturing industry” and “railways, ships, aerospace, and other transportation equipment manufacturing industry” were combined as “transport equipment manufacturing industry.” We used the enterprise scale (0.819672, 0.180328) and reasonably split the relevant indicators of the transportation equipment manufacturing industry. Other changes in the classification are that the “beverage manufacturing industry” is now the “wine, beverage, and refined tea manufacturing industry,” “sporting goods manufacturing” is now “education, labor, sports, and entertainment products manufacturing,” the “chemical raw materials and products manufacturing industry" is now "chemical raw materials and chemical products manufacturing industry," "communications equipment, computers, and other electronic equipment manufacturing industry" is now "computer, communications, and other electronic equipment manufacturing," "instruments and cultural office machinery" is now "instrument and meter manufacturing industry," and "arts and crafts and other manufacturing" is now classified as "other manufacturing." Thus, we sorted and calculated the data for 2009–2013 including 17 indicators of the 39 industrial sectors using data from the Statistical Yearbook of Anhui Province.

We assigned empowerment for the 17 indicators of environment-friendly industry and production industry using the kernel principal component model to calculate the industry ranking results into the multidimensional linear programming model. We solved formula (4-17) using the Matrix Laboratory (MATLAB) software linear programming toolbox and found five level 1 indicators and two level 17 indicators of the weight. The importance of the various indicators for the two kinds of industries may differ in different years so we calculated the index weights for each year for both kinds of industries. For simplicity, we present the weights of the results for 2013 only in Table 6-2.

### Table 6-2: Coupling index weights for the environmental protection and production industries in 2013

| Primary indices | First-grade Index Weight (1) | First-grade Index Weight (2) | Secondary indexes | Second-grade Index Weight (1) | Second-grade Index Weight (2) |
|---|---|---|---|---|---|
| Industrial financial situation | 0.23 | 0.30 | Assets | 0.063 | 0.053 |
| | | | Liabilities | 0.065 | 0.133 |
| | | | Owner's Equities | 0.056 | 0.028 |
| Industrial operating results | 0.18 | 0.15 | Main business income | 0.029 | 0.048 |
| | | | Main Business Cost | 0.025 | 0.053 |
| | | | Advocate business taxes and add | 0.181 | 0.092 |
| | | | Payable VAT | 0.109 | 0.037 |
| | | | Total profit | 0.057 | 0.031 |
| Industrial economic efficiency | 0.27 | 0.25 | Total assets contribution rate | 0.043 | 0.227 |
| | | | Asset-liability ratio | 0.037 | 0.052 |
| | | | Industrial cost profit margins | 0.031 | 0.066 |
| | | | Product sales rate | 0.043 | 0.015 |
| Industrial development scale | 0.22 | 0.23 | Gross industrial output value | 0.032 | 0.039 |
| | | | Industrial sales output value | 0.031 | 0.041 |
| | | | Enterprise unit number | 0.016 | 0.033 |
| Industrial development vitality | 0.10 | 0.07 | Industrial value added | 0.080 | 0.027 |
| | | | Number of staff and workers | 0.103 | 0.025 |

Note: (1) is for the environmental protection industry; (2) is for the production industry.

The calculated results show that in 2013, the weights of "industrial operating results," "industrial economic efficiency," and "industrial development vitality" were relatively high for the environmental protection industry. The weights of "industrial financial situation" and "industrial development scale" were relatively high for the production industry.

We studied the maximum and minimum values in a year for Anhui Province, combined with the regional reference value of the planning period, the standard, or the ideal value. We used the annual index value, the bounds of the order parameter, and the definition of the environment-friendly industry and the production industry to calculate the first and second level operating index contribution value, as shown in Table 6-3 (only listing the first level index contribution values).

**Table 6-3: Dual industry first level operating index contribution values in 2013**

| Index | Environmental protection industry | Production type industry |
|---|---|---|
| Industrial financial situation | 0.037 | 0.053 |
| Industrial operating results | 0.084 | 0.069 |
| Industrial economic benefit | 0.090 | 0.107 |
| Industrial development scale | 0.017 | 0.036 |
| Industrial development vitality | 0.048 | 0.019 |

Source: Calculated by author.

The contribution value of 2009–2013 and formula (4-19) were used to calculate the coupling relationship between environmental protection and manufacturing industries. For this calculation of the coupling model of sustainable development, we use three settings of $p_1$ and $p_2$ as shown in Table 6-4. In case one, we assign a greater contribution coefficient to the manufacturing industry than to the environmental protection industry. In case two, we treat the two industries equally. In case three, we highlight the contribution of the environmental protection industry rather than the manufacturing industry.

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**Table 6-4: Evaluation results of dual industry coupling in 2009–2013**

| Time | | 2009 | 2010 | 2011 | 2012 | 2013 | Average |
|---|---|---|---|---|---|---|---|
| Environmental protection industry $s$ | | 0.037 | 0.097 | 0.045 | 0.047 | 0.057 | 0.057 |
| Manufacturing industry $t$ | | 0.073 | 0.050 | 0.085 | 0.057 | 0.063 | 0.065 |
| Coupling degree | | 0.473 | 0.474 | 0.477 | 0.498 | 0.499 | 0.484 |
| Sustainable development degree D | $\rho_1 = 0.3, \rho_2 = 0.7$ | 0.171 | 0.174 | 0.186 | 0.164 | 0.174 | 0.174 |
| | $\rho_1 = 0.5, \rho_2 = 0.5$ | 0.161 | 0.187 | 0.176 | 0.161 | 0.173 | 0.171 |
| | $\rho_1 = 0.7, \rho_2 = 0.3$ | 0.150 | 0.198 | 0.165 | 0.157 | 0.171 | 0.168 |

Source: Calculated by author.

The coupling evaluation results are shown in Table 6-4 and provide the dynamic development of all subsystems of the environment-friendly industry and the manufacturing industry in 2009–2013. Overall, the environmental protection industry is developing during the time period of the analysis. In addition to significant growth in 2010, the average trend was relatively flat, with a maximum growth rate of 20.95% in 2013. In this five-year period, there was little change in the growth of the manufacturing sector. Although there was some fluctuation, it showed an overall level of development of 0.065, slightly higher than that of the environmental protection industry, 0.057. This result indicates that, until 2013, the environmental protection industry in Anhui Province continued to develop but did not exceed the stable development of the production sector. However, the convergence of the two gradually increased, indicative of coupling. The average coupling degree of Anhui environmental protection and manufacturing industries between 2009 and 2013 was 0.484, and the coupling degree for each year falls into the interval [0.3, 0.5]. This result, combined with the coupling correlation degree evaluation criteria, is consistent with medium and low degrees of coupling in the running stage. The coupling relationship increases over the period, showing the degree of coupling of the two industries in Anhui Province is changing from moderate and low degree of coupling to moderate coupling. According to our analysis, although the economy of Anhui Province is still supported by traditional production industry, Anhui Province should exert different levels of control of production industries and increase the development of the environmental protection industry to promote positive coupling. The assessment of medium and low degrees of coupling is obtained by calculating the coupling correlation degree of industry. However, the coupling-sustainable development degree defined by (4-21) for the three cases presented here mostly fall into [0.1,0.19], in the perspective of dynamic, belonging to disorder development. As the contribution coefficient of the production industry decreases and the contribution coefficient of the environmental protection industry increases, the average level of coupling sustainable development degree is gradually reduced (from 0.174 in case one to 0.168 in case three). Although Anhui Province has shown a comparative advantage in industry in recent years, adjusted its industrial structure, focused on environmental protection, and vigorously developed its environmental protection industry, the dominant force in the province remains traditional pollution or production industries, as shown in the above analysis of the total contribution of the dual industry subsystem. The changes of the degree of industrial coupling and sustainable development under the three different circumstances are apparent. Although the overall level remains in the middle of imbalanced development, as the industry's positive coupling degree increases, the difference in sustainable development under the different contribution coefficients is gradually reduced, promoting barely coordinated development and even moderate coordinated development. This shows that, for Anhui Province, space and force for the sustainable dynamic development of dual industries' coupling does exist.

## 6.4 Conclusions and recommendations

Here, we used a model of industry coupling based on the operational mechanism of the environmental protection and the manufacturing industries, applied this model to understand the current situation, problems, and future development of industry coupling in Anhui Province, and find that there is a coupling relationship between environmental protection and manufacturing industries. Particularly, the coupling relationship has a growing trend over time, evolving from moderate and low degree of coupling to moderate one. At the base of above evaluation, the following policy recommendations are provided:

First, the analysis of the status quo of industrial development of Anhui Province reveals that production-type industries (production industry) constitute an important economic component, occupying a key position in capital and market. These industries include steel, nonferrous metals, chemicals, coal, electricity, which constituted approximately half of the industrial output. It is unfeasible for Anhui to follow the developed regions with regard to the replacement of production-type industries with service industries. There are no lagging industries but lagging products. Production industries are not sunset industries if they are optimized and upgraded. Thus, the coupling development of environmental protection and production industries must be initiated by utilizing the original basic advantages of the production industry. Additionally, it is necessary to use external and internal forces such as the transformation of products, technology, management, and equipment to guide and promote industrial superiority. As part of this process, industries must gradually migrate from a model of "high pollution, high energy consumption," through the upgradation of its industrial chain to accelerate the transformation from labor-based and capital-based industries to technology-based industries, which is a key step toward making provinces highly competitive in terms of industry.

Second, the development of the environmental protection industry has become an important part of the economic strategy of Anhui Province's industrial development. Under the constraints of resources, environment, science and technology, policy system, and other factors, the development of the environmental protection industry in Anhui Province is also facing bottlenecks. However, green and sustainability are the bottom line of industry transformation. Anhui Province still maintains a high rate of economic growth, and energy consumption would increase further in the future. Meanwhile, the environmental capacity for pollution cannot change. It is necessary to promote clean production, increase energy conservation and emission reduction, and implement new production methods with low resource consumption, low environmental pollution, and high input and output. For this reason, we propose additional growth and transformation of the environmental protection industry.

For this reason, we propose additional growth and transformation of the environmental protection industry.

Third, for Anhui Province and all of China, economic development must not rely solely on traditional industries, especially heavy polluting industries. Focusing on the development of heavy polluting industries only to promote economic growth is not a feasible strategy. The development of environmental protection industry is an appealing idea, although its development is not easy. We argue that the coupling development of environmental protection industry and production-type industry should be promoted as the main means of development in Anhui Province. The production industry needs the support of products and capital, and these advantages should preferentially be used to support the development of environmental protection industry. At the same time, this new industry must transfer its new technology and management experience to production-type industry, through technology and market coupling, to create a new green development path. This coupling will accelerate the pace of transformation and upgrading of traditional industry and will allow the industries to complement each other and stimulate the growth of both industries.

Apart from depending on the cooperation development of different industries to curb increasingly serious environmental pollution, policymakers also express concern about the role of regulation and increasingly adopt regulation tools. It is generally believed that, in comparison to spontaneous economic adjustment system, policy intervention may be more direct and effective. However, stringent regulation can create other side effects sometimes, such as business failures and unemployment. In Chapter 7, we will focus on how environment regulation can affect employment.

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# Chapter 7. Environmental regulation and employment under open conditions

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# *Chapter 7. Environmental regulation and employment under open conditions*

Chapters 5 and 6 focused on detecting the interactive relationship among economic variables. This kind of relationship is based on the mechanism of market. In practice, the invisible hand of the free market has often been combined with the tangible hand of government regulation to address environment problems. To boost the circular economy and build a sustained society, China has promulgated a huge number of environmental laws and rules. However, some of these policies will result in significant pollution control costs in the polluting enterprises, resulting in decreased profits or possibly even business failures resulting in unemployment. Determining the balance between environmental protection and employment is particularly important for sustainable economic growth. In this chapter, the influence of environmental regulation on employment is analyzed from the perspective of product demand and supply using Generalized Method of Moment (GMM) estimation. We used China's statistical materials after 2002 in the analysis. From the perspective of open conditions, we studied the impacts that foreign direct investment Foreign Direct Investment (FDI) and environmental regulation have on employment.



## 7.1 Introduction

Resources and a livable environment are required for the survival and development of human society, but it was not until the wasteful use of these resources caused environmental deterioration that the preciousness of this important gift was fully realized. With global pollution and the gradual depletion of resources, determining the best strategy to allow the coordinated development of economy and environment is a pressing issue facing the world. For China, after 1979, market-oriented policy stimulated rapid economic growth that coincided with increased deterioration in environmental quality. The environmental protection performance of China's export products must now meet the increasingly stringent requirements of developed countries. Additionally, at the Copenhagen (2009) and Cancun (2010) Conferences and other international climate negotiations, China has been negotiating with developed countries on environmental issues and faces significant pressure to reduce emissions.

Currently, the Chinese government is vigorously boosting sustainable development. To do so, they are enacting a series of environmental regulations and policies. However, these regulations and policies will exert considerable financial pressure on polluting enterprises as they face new pollution control costs. This financial stress could lead to increased unemployment. If these enterprises still are unable to meet emission standards after taking pollution control measures, there is increased risk of failure if there are increased costs of required pollution control, again possibly resulting in unemployment. Considering the huge number of laborers, China needs to be concerned with maintaining a good rate of employment. According to the Chinese government's Statistical Bulletin in 2014, the registered unemployment rate in cities and towns was 4.09%, but due to China's large population, the number of unemployed people was more than 9.5 million at the end of 2014.

As a developing country, China's economic development needs are urgent, and economic growth requires the consumption of resources that can result in significant and lasting environmental pollution. A plan of "treatment after pollution" is a costly approach, but focusing solely on environmental effects while ignoring the social effects of environmental protection could harm the economy and result in mass unemployment. Overall, it is important to balance environmental protection and employment. Using the industry-level statistical materials obtained from the China Statistical Yearbook (2003–2013), this chapter presents an empirical study of environmental regulation and employment under open conditions.

## 7.2 Model construction of environmental regulation and employment

According to Copeland and Taylor (2013), environmental regulation is related to the production cost. When the intensity of environmental regulation is enhanced, production costs will increase and output will decrease. However, labor demand elasticity may be less than one for labor-intensive industries, so the labor force may increase when the output is reduced (Morgenstern et al., 2002).

The trade-off of "jobs versus the environment" was studied by Morgenstern et al. (2002) through a theoretical model. They first checked the impacts of environmental regulation on employment at plant level. Second, from a perspective of specific industry, researchers studied the price effect at industry level of regulation. At last, how this price adjustment affects demand and even employment is analyzed at plant level. According to the theoretical model of Morgenstern et al. (2002) considering enterprises as a whole, for a certain enterprise, the size of the labor force can usually be calculated through cost and wage levels as in formula 7-1:

$$L = \frac{1}{p_l} v_l \cdot TC \tag{7-1}$$

L expresses the number of labors, $v_l$ is wages, $v_l$ expresses total labor income share in total cost, and TC expresses total cost, including the cost of production and environmental regulation. Taking the partial derivative of environmental regulation cost for both sides of the formula (7-1), we can get:

$$\left.\frac{\partial L}{\partial RC}\right|_{Y=\overline{Y}} = \frac{TC}{p_l}\frac{\partial v_l}{\partial RC} + \frac{v_l}{P_l}\frac{\partial TC}{\partial RC} \tag{7-2}$$

RC is the cost of environmental regulation and $Y = \overline{Y}$ expresses the assumption that output is constant. On the right-hand side, $\partial v_l / \partial RC$ expresses wage level required per unit of environmental regulation cost; this term multiplied by the total cost expresses the ratio of environmental regulation cost to the total cost, so this term can be expressed as the effects of factor substitution. Similarly, we can express the second term as cost effects. Because increased cost of environmental regulation will increase the total cost, the cost effects will increase.

In practice, an enterprise has different departments and its production process includes different steps such as purchasing, logistics, production, storage, development, and sales; the effects of environmental regulation on these different steps can be different. For example, the procurement department may not be affected by regulation policy, but the departments of production and development may be. Therefore, it is necessary to refine the formula (7-2). Assuming there is one department, the total employment of the enterprise is the total number of employments in that department. If environmental regulation can be applied to every department, if we assume the same output, then:

$$\left.\frac{\partial L_{agg}}{\partial RC}\right|_{Y=\overline{Y}} = \sum_{i=1}^{l}\frac{\partial L_i}{\partial RC_i} = \sum_{i=1}^{l}\frac{TC_i}{w_i}\frac{\partial v_l}{\partial RC} + \sum_{i=1}^{l}\frac{v_l}{w_i}\frac{\partial TC}{\partial RC} \tag{7-3}$$

Where, $L_{agg}$ expresses the total number of labors needed to control pollution. There are different departments and the environmental regulation cost of each department is different. Assuming the proportion of environmental regulation cost to the total cost in each department is the same, that is $\partial RC/\partial RC_{agg} = \partial TC/\partial TC_{agg}$ , the price movements of the intermediate products of each department can be expressed as:

$$\frac{1}{TC_i}\frac{\partial TC}{\partial RC_{agg}} = \frac{1}{TC_i}\left(\frac{\partial TC}{\partial RC}\right)\left(\frac{\partial RC}{\partial RC_{agg}}\right) = \frac{1}{TC_i}\left(\frac{\partial TC}{\partial RC}\right)\frac{TC}{TC_{agg}} = \left(\frac{\partial TC}{\partial RC}\right)\frac{1}{TC_{agg}} \tag{7-4}$$

Substituting (7-4) into (7-3) and rearranging gives:

$$\left.\frac{\partial L_{agg}}{\partial RC_{agg}}\right|_{Y=\overline{Y}} = \frac{1}{TC_{agg}}\sum\frac{TC^2}{P}\frac{\partial v}{\partial RC} + \left(\frac{\partial TC}{\partial RC}\right)\frac{1}{TC_{agg}}\sum\frac{v\cdot TC}{P}$$
$$= \frac{1}{TC_{agg}}\sum\frac{TC^2}{P}\frac{\partial v}{\partial RC} + \left(\frac{\partial TC}{\partial RC}\right)\frac{L_{agg}}{TC_{agg}} \tag{7-5}$$

Formula (7-5) represents the changes in the employment of enterprises due to the marginal cost of environmental regulation in the case of constant output. Next, the analysis will be extended to the macroeconomic level. Using the demand function setting method of Dixit and Stiglitz (1977), there will be:

$$q_{agg} = \left(\sum \omega_i q_i^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}} \tag{7-6}$$

Where $q_l$ denotes the production of specific department, $q_{agg}$ denotes the total production, $w_i$ denotes the weight of the specific department in the macroeconomy, and $\rho$ denotes the elasticity of substitution for factors. For the convenience of analysis, it is assumed that environmental regulation will make each department increase costs according to the same ratio and the market price of products will be increased at the same rate. If the total demand for a product is reduced, the total demand for all products will decline. It is assumed that the whole industry is faced with a fixed demand elasticity $\sigma_d$ and when environmental regulation makes the cost of the product rise, the cost of each department will increase at the rate of $\theta$ .Product prices increase at the rate of $\theta$ and will affect the total output $q_{agg}$ , and the total demand will be $\sigma_d \theta \cdot q_{agg}$ . Combining formulas (7-4) to (7-6) gives the level of per capita emissions of pollution:

$$z = \frac{\partial L_{agg}}{\partial RC_{agg}} = -\sigma_d \theta \times L_{agg} = -\sigma_d \frac{\partial TC / \partial RC}{TC_{agg}} \times L_{agg} \tag{7-7}$$

Where $\sigma_d$ is the elasticity of demand for industrial products.

In the model of Morgenstern et al. (2002), linkage between the environmental regulation and number of jobs was analyzed only in the closed condition. This chapter extends the model in the open perspective and draws on the ideas of Copeland and Taylor (2013) to introduce FDI into the model. FDI is one of the important indicators to measure the degree of openness of a country. FDI can not only make up for the capital shortage of the host country, but also bring technology spillovers to promote environment-related technology in the host country. According to the model of Copeland and Taylor (2013), the total effect of foreign environmental impact can be decomposed into scale effect, structure effect, and technology effect without considering the FDI's extrusion effect on internal capital. Combined with formula (7-7), the relationship between foreign capital and per capita pollution emission level can be written as:

$$\frac{dz}{dFDI}\frac{FDI}{z} = \frac{dS}{dK}\frac{K}{S} fdi + \beta_1 fdi + \beta_2 (fdi - fdi^2) \tag{7-8}$$

In formula (7-8), the term on the left of the equal sign is the elasticity of pollution emission to FDI, the coefficient of the first term on the right is the elasticity of output for capital, and $fdi = FDI / K$ , $\beta_1$ , $\beta_2$ are influence degrees of FDI and the development level of technical progress, respectively. Because the cost increase rate $\theta = \left(\partial TC / \partial RC\right) / TC_{agg}$ is constant and not affected by the FDI, formula (7-8) can be simplified as:

$$\varepsilon_{L,FDI} = \varepsilon_{K,S} fdi + \beta_1 fdi + \beta_2 (fdi - fdi^2) \tag{7-9}$$

$\varepsilon_{L,FDI}$ is the elasticity of foreign investment to total employment and $\varepsilon_{K,\ S}$ is the elasticity of capital output. This can be arranged to give:

$$\beta_2 fdi^2 - \beta fdi = \frac{\left(1 - 2\sum tc\right) \cdot tc \cdot \upsilon \cdot p - \theta l}{\upsilon p + \theta L_{agg}} \cdot FDI \tag{7-10}$$



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Where $\beta = \varepsilon_{k,s} + \beta_1 + \beta_2$, $\mathrm{v} = \partial \mathrm{v} / \partial RC$, $P = \sum (1/P_l)$, $\mathrm{tc} = dTC/dFDI$, and $l = dL_{agg}/dFDI$.

## 7.3 Econometric model specification and index selection

Using the theoretical model, we analyzed the 30 regions in China from 2002 to 2012. According to (7-5) and (7-10), the econometric model is:

$$\begin{aligned} logL_{agg,it} &= \alpha + \beta \log L_{agg,it-1} + \alpha_1 \log E_{it} + \alpha_2 \log RGE_{it} \\ &+ \alpha_3 \log FDI_{it} + \alpha_4 \log TFP_{it} + \alpha_5 \log PL_{it} + \varepsilon_{it} \end{aligned} \tag{7-11}$$

Where L denotes the year-end number of employees of the secondary industry and E denotes pollution emission intensity of the carbon emission using carbon emissions divided by the corresponding actual provincial Gross Domestic Product (GDP). Data sources are the China Environment Statistical Yearbook, the China Statistical Yearbook, and the China Industrial Economy Statistical Yearbook.

REG represents degree of regulation. Some models include the real per capita GDP, the number of administrative penalty cases, and the investment of pollution control as proxy variables for environmental supervision. Econometric analysis was performed, but the three indices only measured certain aspects of environmental supervision degree. Because the three were substituted individually, this is not a complete environmental regulation index. As seen from the data, the enhancement of environmental supervision will result in a reduction in real per capita GDP, a rise in administrative penalty cases, and a rise in investment in pollution control. Referencing the evaluation method of Tone (2001) and improving the model, we can get the programming equation of the supervision degree:

$$\max \rho = 1 - \left(1 - \frac{s_i^-}{inv_{i0}}\right) \Bigg/ \left(1 + \frac{s_r^+}{gdp_{r0}} + \frac{s_r^+}{n_{r0}}\right)$$

$$s.t. \quad \begin{aligned} &\sum_{j=1}^{n} \lambda_j inv_j + s_i^- = inv_0 \\ &\sum_{j=1}^{n} \lambda_j gdp_j - s_r^+ = gdp_0 \\ &\sum_{j=1}^{n} \lambda_j n_j - s_r^+ = n_0 \end{aligned} \tag{7-12}$$

$\lambda \geq 0, s_i^-, s_r^+ \geq 0$

Where *inv* is the pollution control investment vector, *gdp* is the per capita Gross National Product (GNP) vector, n is the number of administrative penalty cases vector, $s_i^-, s_r^+$ are non-radial slack variables, and $\rho$ is the degree of environmental supervision, where the greater the $\rho$ , the greater the degree of environmental supervision. The data source of the index is the China Environment Statistical Yearbook. In pollution-intensive industries, the higher degree of environmental supervision can cause enterprises to employ more labor to reduce pollution emission levels and cause a rise in employment. However, as mentioned above, China's employment is influenced by many factors under open conditions, so the estimated coefficient of environmental supervision degree cannot be determined.

We adopt utilization of FDI divided by GDP represent the FDI. PL is labor productivity, expressed as per capita added value, calculated by dividing the actual provincial GDP by the number of year-end employments. The data source is the China Statistical Yearbook. There are endogenous influences between labor productivity and total factor productivity that can be overcome by the GMM method or by calculating the equation separately.

Total Factor Production (TFP) is total factor productivity, which shows the degree of investment in science and technology innovation including production innovation and improvement of pollution control. Combined with model (7-9), we can find that increasing $\beta_2$(the degree of innovation investment) can increase the elasticity of foreign investment to the total employment, thus reducing the amount of employment when there is increased foreign investment. However, the improvement of technical level will replace labor demand, so the preliminary estimated coefficient is negative. Previous scholars' estimates of total factor productivity used the Solow assumption and time series data (Solow, 1957). This approach is unable to distinguish different technological progress effects. Thus, Data Envelopment Analysis (DEA)-Malmquist method was adopted to estimate (Caves et al., 1982) as follows:

$$M_i(X,Y) = D_i^T(X,Y)/D_i^S(X,Y) \tag{7-13}$$

Each Decision-Making Unit (DMU) has *m* input and *s* output. Input index vector $X_i = (x_{1i}, x_{2i}, \cdots, x_{mi})^T > 0$ and output index vector $Y_i = (y_{1i}, y_{2i}, \cdots, y_{si})^T > 0$ denotes the input and output of DMU, respectively. *i=1,2*, *...n* , *S* and *T* are periods, and  is the optimal value of linear programming. The output-oriented DEA model (Cook and Seiford, 2009) assumes variable returns to scale, so the formula becomes:

$$\begin{aligned}
&\max D^0 \\
&\sum_{j=1}^{n} X_j^0 \lambda_j \le X_0^0 \\
&\sum_{j=1}^{n} Y_j^0 \lambda_j \ge D^0 Y_0^0 \\
&\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \ge 0, j = 1,2,\cdots n
\end{aligned} \tag{7-14}$$

The input index selects the net value of fixed assets and the number in the labor force and the output index selects gross industrial output values, allowing the total factor productivity to be calculated. The data is from the China Statistical Yearbook (2003–2013).

## 7.4 Employment effect test of environmental regulation

### 7.4.1 Preliminary examination of the influence of environmental regulation on employment

The model (7-11) is estimated based on the measurement results of each individual index. Considering that the indices for labor productivity, total factor productivity, pollution emission, and environmental regulation intensity may be related to residuals, and that the amount of labor also affects total factor productivity and forms a bidirectional causal relationship, there can be serious endogeneity in the model with inconsistent and biased estimated coefficients if the least square method is used. Pollution-intensive industries are more affected by environmental regulation, and this will promote the improvement of the level of technology to alter total factor productivity.

When we have a positive impact of regulation intensity on TFP, the general least squares regression analysis will underestimate the negative impact of TFP on regulation intensity. Therefore, in the econometric test, it is necessary to first solve the problem of endogeneity. Instrument variable estimation can be used but depends on appropriate selection of instrumental variables. If lagged terms of variables are selected as instrumental variables, then part of the information will be ignored. Instead, the differential GMM can be used to estimate. The systematic generalized method of moment (systematic GMM) can be used to further improve the effectiveness of the model estimation. Because GMM estimation relaxes the strict restrictions of the classical assumptions, the estimated result is not affected by the heteroscedasticity problem of its error term. For the stability of the estimation, we separately computed results by differential GMM and systematic GMM methods. The systematic GMM method is the extension of differential GMM, and the two methods are used to estimate for reliability of results. To determine FDI's impacts on employment and China's environmental regulation and productivity, we introduced the cross terms of foreign capital, environmental regulation, and productivity into our estimation using the system GMM method. Table 7-1 presented estimates as follows:

**Table 7-1: Model estimation results**

| Index | Differential GMM | Systematic GMM | Systematic GMM including cross terms |
|---|---|---|---|
| C | 0.138<br>(1.36) | | |
| *logL*$_{-1}$ | 0.948***<br>(19.99) | 0.241**<br>(2.04) | 0.086<br>(0.69) |
| *logE* | -0.047**<br>(-2.24) | -0.059<br>(-1.06) | -0.077<br>(-1.48) |
| *logREG* | -0.025*<br>(-1.59) | -0.016*<br>(-1.82) | -0.016*<br>(-1.81) |
| *logFDI* | 0.068*<br>(1.78) | 0.078***<br>(2.98) | |
| *logPL* | 0.042<br>(0.81) | 0.258***<br>(3.81) | 0.263***<br>(3.96) |
| *logTFP* | 0.116**<br>(2.32) | -0.086<br>(-0.87) | -0.212**<br>(-2.12) |
| *logFDI*logREG* | | | -0.013*<br>(-1.61) |
| AR(2) test value | 1.91 | 1.70 | 0.95 |
| P value | 0..06 | 0.09 | 0.34 |
| Sargan test value | 4.16 | 81.22 | 69.58 |
| P value | 0.901 | 0.441 | 0.295 |
| Observed value | 300 | 270 | 270 |

Note: *, * *, * * * indicate that the coefficients pass the test at 10%, 5%, and 1% levels of significance, respectively. The standard errors are in parentheses.

In what follows, the results of estimation were discussed in detail. One-period lag item of the employment $logL_{-1}$ was positive and significant at the 1% level, which shows that employment has a certain inertia and can self-recover when a shock occurs. This result also suggests that there is a bias in the static model, and thus, a dynamic model is necessary for regression. The estimated coefficients of the pollution emission intensity $log_E$ were negative. On the one hand, this may indicate that environmental regulation increases production cost and reduces enterprise employment. On the other hand, this may suggest that workers do not prefer to work under severe environmental pollution conditions. The estimated coefficients of environmental regulation show that environmental regulation negatively affected the level of employment during the current period under open conditions, and the coefficients were significant at the 10% level. With technical improvement and increased labor productivity, enterprises gradually adapt to the effects of environmental regulation and employ alternative strategies, ultimately leading to an increase in employment. The results of other control variables are as follows: FDI has a significant and positive effect on employment. This implies that FDI can provide more job opportunities. Labor productivity *PL* affects employment positively at the 1% significant level in Systematic GMM. It is commonly believed that rising labor productivity would inhibit employment given that the output is constant. However, from a dynamic perspective, labor productivity can also facilitate employment because the increasing labor productivity can expand social product, promote accumulation, and open new sectors, which demand more labor in the long run.

We incorporated the cross terms of FDI and the environmental regulation index into model and the results are shown in Table 7-1. We found the cross terms have a negative sign, indicating that at a certain level of environmental regulation, the rise of FDI would worsen employment. This illustrates that FDI is an important factor in the increase of employment in China. With the improvement of environmental regulation intensity, the presence of foreign capital is limited. At this level, these results support the conclusion that environmental regulation can reduce employment.

### 7.4.2 The environmental regulation and employment in different regions

The analysis presented above is conducted from the macro-level, but because the intensity of environmental pollution emission produced by different regions may be quite different, there are different effects of environmental regulatory policy on different regions. Therefore, we wanted to further explore such variation at the region-specific level. To do this, we used a varying-coefficient model formulated as follows (7-15):

$$logL_{agg,it} = \alpha + \alpha_1 \log E_{it} + \alpha_2 \log RGE_{it} + \alpha_3 \log FDI_{it} + \alpha_4 \log TFP_{it} + \alpha_5 \log PL_{it} + \varepsilon_{it} \quad (7\text{-}15)$$

In formula (7-15), the coefficients of pollution emission intensity ($E$) and environmental regulation intensity ($RGE$ ) are $\alpha_2^i$ and $\alpha_3^i$ , and respectively represent the impact of intensity of environmental regulation for different regions and environmental regulation on employment under open conditions. There is a large range of intensity of pollution emission produced by different regions, and thus the effect of environmental regulation on different regions will be different, resulting in different effects on employment. As in the preceding analysis, additional environmental regulation can stimulate employment for the environmental protection businesses, but in polluting regions, environmental regulation may increase production costs that may be compensated by reducing the workforce. The estimated coefficient for some regions may not be significant due to low levels of environmental pollution. Under open conditions, the cross terms of FDI and environmental regulation intensity must be considered. The host country may deliberately reduce environmental regulation intensity in order to attract investment. An increase in foreign investment may promote economic growth of a particular industry or promote industry at the regional level, resulting in an increase in employment. Another possible consequence is that with the improvement of environmental regulation intensity, the presence of foreign capital is limited, indicating that the estimated coefficient of the cross term should be positive or negative. We used the varying-coefficient model test to evaluate the data points from 30 regions in 2002–2012 and Table 7-2 reported the estimated results.

The influence coefficients of pollution emissions and environmental regulation on different regions are sorted from the smallest to the largest in Table 7-2. As can be observed, the influence of environmental regulation on employment is negative in 21 regions, accounting for 70 percent of all provinces. Among them, the coefficients for 9 provinces passed the significance test: Inner Mongolia, Qinghai, Guizhou, Ningxia, Xinjiang, Liaoning, Hebei, Henan, and Shandong. These provinces are located either in West China with abundant resources, or in North China with a high proportion of heavy industries. In the resource-rich provinces, most of the industries involve around resources mining, primarily processing, and transportation activities, which are the main source of ecological degradation and environment pollution. Thus, employees of these industries would be sensitive to environmental regulation and the influence is negative. In North China, heavy industries account for more than half of the total industries and coal accounts for nearly 90% of the energy consumption. Industrial emission and coal-burning are the main sources of pollution in this area. It is natural for this area that environmental regulation can exert a negative effect on employees. Overall, these results are consistent with our preliminary assessment. However, the influence of environmental regulation intensity in the other regions is positive, demonstrating that the stronger the environmental regulation, the larger the workforce. This may be because these regions themselves are not pollution-intensive regions or have cleaner production sectors that can attract labor. We found that only the coefficients for Shaanxi and Chongqing are significant at the 1% level. As a western province, Shaanxi occupies the leading position in the level of science and education in China. It is also an important research and production base in the fields of aviation, machinery, and electronics. Chongqing is the only municipality that is under the direct control of the central government in the West. The municipality's industrial structure and governance level are substantially better than other nearby areas. Therefore, environmental regulation may affect high-pollution regions, resulting in a transfer of labor force to cleaner production regions.

Under open conditions, with increased environmental regulation intensity, employment and environmental regulation were negatively related in half of the regions as indicated by the cross terms of FDI and environmental regulation. The negatively related values were at a significance level of 10% for all except for Anhui, Guangxi, and Beijing. The other regions showed a significantly positive effect, but the influence coefficients of environmental regulation intensity were not significant except Shanxi, Inner Mongolia, Qinghai, and Ningxia. The positive relationship indicates that these regions are pollution-intensive regions, and the regulation would increase the cost of doing business and thus is not conducive to employment. However, foreign direct investment can significantly improve employment.

**Table 7-2: Coefficient values tested by varying-coefficient methods**

| Region | Environmental regulation intensity | Region | Cross terms of FDI and environmental regulation |
|---|---|---|---|
| Hainan | -6.210 | Jiangxi | -1.498*** |
| Inner Mongolia | -2.993*** | Fujian | -1.4770*** |
| Qinghai | -2.874** | Zhejiang | -1.224* |
| Guizhou | -2.743* | Shaanxi | -1.170*** |
| Ningxia | -2.230*** | Sichuan | -1.169*** |
| Liaoning | -1.902* | Shandong | -1.150*** |
| Tianjin | -1.737 | Guangdong | -1.145*** |
| Jilin | -1.585 | Hubei | -0.747*** |
| Hebei | -1.575** | Hunan | -0.711*** |
| Henan | -1.240** | Yunnan | -0.664*** |
| Shandong | -1.133** | Anhui | -0.649 |
| Heilongjiang | -0.900 | Jiangsu | -0.566*** |
| Xinjiang | -0.846** | Gansu | -0.4600*** |
| Anhui | -0.730 | Guangxi | -0.360 |
| Guangxi | -0.685 | Beijing | -0.150 |
| Jiangsu | -0.638* | Xinjiang | 0.007 |
| Hunan | -0.620* | Henan | 0.354 |
| Yunnan | -0.458 | Liaoning | 0.4800 |
| Guangdong | -0.210 | Shanxi | 0.535*** |
| Sichuan | -0.189 | Heilongjiang | 0.577 |
| Zhejiang | -0.157 | Guizhou | 0.695 |
| Beijing | 0.003 | Tianjin | 0.702 |
| Shanxi | 0.0900 | Hebei | 0.764 |
| Shanghai | 0.283 | Shanghai | 0.773 |
| Hubei | 0.391 | Jilin | 1.109 |
| Gansu | 0.398 | Chongqing | 1.959** |
| Jiangxi | 0.477 | Inner Mongolia | 2.621*** |
| Shaanxi | 1.753*** | Qinghai | 2.871*** |
| Fujian | 1.948 | Hainan | 5.750 |
| Chongqing | 3.610*** | Ningxia | 6.019*** |

Note: *, * *, expresses passing the test at the 10% and 5% levels of significance, respectively.

## 7.5 Conclusions

The preceding chapters, Chapter 5 and Chapter 6, primarily detected the nexus of economic variables without involving government intervention. This chapter, considering the role of government, presents a systematic analysis of the association between environmental regulation and employment and analyzes the influence of regulation on employment from the perspective of product demand and supply. Based on this, the scale, structure, and technology effects were introduced to evaluate the impact of regulation on employment from an open perspective. This theoretical analysis allowed us to describe the effects in an econometric equation. In empirical tests, to avoid endogeneity, we used instrument variables, differential GMM, and systematic GMM methods to estimate the variables. We also addressed the indirect effects of foreign capital on environmental regulation and used the cross terms to estimate the subsequent equation.

Our results show, whether in the country or region level, the environmental regulation has a negative influence on employment. For China's deteriorating environmental quality, our findings have important implications for effective strategies to formulate policies that promote employment and ensure long-term stable economic development. First, previous work suggested that environmental regulation would negatively affect employment in China. Under open conditions, our findings are consistent with this previous conclusion. The explanation for these results is as follows: more stringent regulation may increase the operation costs of companies. To cut the cost and maintain competitiveness, these companies would have to fire a certain of unnecessary or unimportant employees. Whether or not in open condition, such a mechanism of influence can work. Under open condition, the environmental regulation may also harm employment through the channel of FDI. FDI is sensitive to environmental regulation and can affect employment. With the improvement of environmental regulation intensity, the presence of foreign capital is limited. Secondly, because the intensity of environmental pollution emission produced by different regions may be quite different, there are different effects of environmental regulatory policy on different regions.

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# 8

# *Strategies to promote the coordinated development of China's economy and environment*

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# Chapter 8. Strategies to promote the coordinated development of China's economy and environment

Rapid recent developments of the world economy have increased the ecological environment problems that have existed since the last century, restricting the sustainable development of economy and society and threatening human health and survival. Energy use and environmental protection are important variables affecting economic development and are the focus of attention by governments worldwide. The oil crises of the 1970s had a serious impact on the world economy and forced us to pay more attention to environmental issues. Most economic researchers have focused on the goal of sustainable development (World Commission on Environment and Development (WCED), 1987). With economic growth, extensive utilization of resources will inevitably lead to environmental damage and energy shortage. Economic input costs will increase, thereby inhibiting economic sustainable development, and the degradation of the environment will further impede economic growth. China is now facing challenges of world economic integration and global environmental problems including global warming. For this reason, it is critical to determine the optimal strategy to maintain the development of China's economy and protect the environment while addressing global concerns.

In the context of increasingly severe deterioration of the ecological environment, realizing the coordination of economic growth and environment protection is an important research question. This chapter summarizes our results and points out that energy, environment, and the economy are multi-dimensional vectors in one and the same system and must complement each other. China needs to achieve sustainable development, advocate a low carbon life, and strengthen environmental regulation. At the same time, China should improve its industrial structure and appropriately advance the technological progress, especially in areas with low environmental efficiency and serious pollution, to comprehensively improve the level of environmental protection in China.

## 8.1 Findings of the study on environmental protection and economic growth

The main findings of previous chapters on the relationship between environmental protection and economic growth, which correspond to the research questions RQ1–RQ4 in Chapter 1, are summarized as follows:

First, this study found wide disparities in pollutant emission across regions of China. The Eastern developed provinces such as Shanghai and Jiangsu are facing the worst environmental issues, especially water pollution. On the other hand, the provinces with a lower level of economic development experience relatively less environmental problems. This phenomenon can be attributed to diverse environmental policies under respective economic conditions. Likewise, there are significant differences in the degree of pollution for different industries. Environmentally degraded industries have mainly been concentrated in the capital-intensive manufacturing sector. For example, metal production ranks first in pollution. However, with regard to labor-intensive industries, solid waste is the main source of pollution.

Second, there is a significant linkage between energy input and environmental total factor productivity, although regional differences exist in this linkage. The promotion of environmental efficiency can facilitate energy saving. Despite the role of environmental total factor productivity, rapid economic development has caused an increase in energy consumption in recent years. Therefore, the theory of rebound effect still needs to be verified further in China. Taking measures to promote energy efficiency is necessary and useful. Even if there exists a rebound effect, the promotion of energy efficiency can improve long-term availability of energy and thus the quality of life.

Third, regarding the coupling relationship between the environmental protection and manufacturing industries, the production industry maintained an important position in Anhui, whether in capital or market. Meanwhile, the environmental protection industry has enjoyed a growth momentum during the period of analysis. Overall, the degree of coupling between the above two industries increased. It evolved from moderate and low to a moderate one. However, from a dynamic perspective, the degree of coupling is not as optimistic as expected. The coupling degree of the sustainable development version defined by (4-21) fell into [0.1,0.19]. According to the coupling-evaluation criteria, it belongs to disorder development.

Forth, under open conditions, China's environmental regulation would worsen employment conditions, which is consistent with results not considering open conditions. This finding may be attributed to the cleaner production environment brought about by social economy development. Enhancing the environmental regulation intensity may block the flow of foreign capital, which may ultimately reduce employment.

This study aims to address the issues of coordination of the environment and the economy. These problems are part of a complex network with different subsystems of different interactions containing many variables. However, the tricky problem is that the influence of each variable can change in complicated nonlinear ways, making it difficult to determine the driving forces of environmental economic systems. Under different conditions, different variables can act as driving forces. Only when these subsystems are engineered and are complementary to each other can the coordination effect be produced to boost the sustainability of the environment-economy system. To achieve this goal, our future quantitative analysis will comprehensively analyze the factors that influence environmental and economic development in a more complex environment.

The forecast of environment-economy coordination shows that the coordinated development of environment and economy would be realized in China in the coming years. After 2012, China's enterprise labor cost and raw material purchase costs have risen. Meanwhile, the rate of increase in sales has slowed, and product prices continue to increase, which will inevitably lead to decreased profitability for most enterprises. This slowdown is bound to decrease the attention and availability of investment that businesses can devote to environmental protection. Therefore, to achieve coordinated environmental and economic development, the government must continue to increase efforts to implement relevant environmental protection policies. To achieve this, the government can encourage the use of green technology; promote industrial transformation; institute energy saving and environmental protection in key areas of development; design and implement strategies for fiscal, financial, and income distribution; and undertake other measures to create a favorable atmosphere for the coordination between environment and economy.

## 8.2 The optimal strategy for China: coordination of economy and environment

After 1992, China's economy has developed rapidly, and the current growth rate has continued to maintain a rapid level. In 1992, the Gross Domestic Product (GDP) was 3 trillion yuan and reached more than 40 trillion yuan in 2010. However, like many other countries with the similar developing conditions, China's environmental resources are now facing an unprecedented challenge. There are specific differences in the national conditions of China compared to Western countries, and it is urgent that China determines the best way to quantitatively evaluate the present environmental economic situation, identify its deficiencies, and determine strategies to address these deficiencies while encouraging economic development and protecting and improving the ecological environment (Thomas, 2012).

Before 2000, China's relatively low efficiency of environmental protection led to large environmental-economic efficiency differences (Song et al., 2011). We determined the relative efficiency value of the environment and economy in China from 1992 to 2010 using an environmental economic system coordination degree measurement model that uses the relative efficiency value of environment economy to calculate the static and dynamic coordination degree. We found that in 1992, increasing pressure from rapid economic development on the environment caused an increase in the degree of disharmony between the two. The resulting problems have become increasingly prominent (Cao et al., 2015). Governments made several relevant policies from 1992 to 1996 to increase the protection of the environment. Recently, Chinese government launched its "five development philosophy" as a strategy to reach the goal of environmental protection in the next five years. In support of the policy, the coordination of the Chinese environment and economy has started to improve gradually. China's environmental-economic coordination is entering a new era.

Many studies have determined that China showed strong economic growth in the early stage of Reform and Opening-up (Song et al., 2015). Recently, more attention was paid to the coordination of economy and environment. The continuous improvement of energy-saving emission reduction technology and productivity has resulted in China's growth pattern becoming more environmentally friendly. In the second part of this study, we considered ways to improve China's environmental efficiency and decrease input excess and output deficit to the minimum. To do this, we constructed and tested a series of environmental efficiency evaluation models. Traditional economic models use capital and labor as inputs but do not consider energy or the environment. Recently, many studies began to take this issue into account, such as Wu et al. (2014), An et al. (2015), Tao et al. (2016). We used mathematical methods to incorporate undesirable outputs into the evaluation system and calculate environment efficiency. We then established a theoretical framework of environmental and regional, environmental, and industrial economics. Under the conditions of an open environment, we analyzed the influence of international trading and international investment.

Next, we expanded the traditional model and investigated the influence mechanism of environment and employment by introducing additional factors such as wages, employment, and trade for a comprehensive analysis and econometric model using the data from Chinese industry. We can see from the analysis that efficiency improvement can facilitate employment and that technical progress correlates with labor productivity progress, exerting a harmful influence on employment. Generally, keeping output constant, productivity increases are often accompanied by a decline in employment. In real-life situations, however, it may be impossible for an enterprise to reduce the number of workers because of increasing productivity, and this may lead to the expansion of production and increased output. That means, employment is not only affected by productivity but also by supply and demand. From the point of view of supply and demand, the supply of a product is determined by the demand. Only if the demand decreases, will enterprises gradually reduce the production and the number of jobs to avoid supply exceeding the demand.

The development of vertical specialization in the supply chain has increased globally and research on its impact on labor income share has been studied at the macro level but also requires examination of the links between trade and investment. In this thesis, we used vertical specialization to explain the inflow of high-pollution industries across countries. We determined that China must consider the industrial structure and not rely on polluting industries while promoting economic development.

Labor-intensive enterprises dominated in the early development of the country, and capital and technology are required to update the industrial structure in China. Although the implementation of the policy of family planning has effectively controlled the growth of population, China is still the world's most populous country. Under the selective "two-child policy," China's population growth will maintain a significant growth trend that will inevitably lead to a more severe employment situation. Industrial upgrading and employment growth are two important aspects of the development of national economy, but environmental pollution must also be considered. In the early period of China's social development, little attention was paid to excessive resource consumption and environmental pollution problems. After a global strategy for sustainable development called the "21st century agenda" was proposed in 1992, China has gradually started to move towards sustainable development and this model should be used to guide future strategic objectives. In 2012, China's central government proposed to set up a red line of environmental pollution to strengthen environment regulation. These measures will change the pattern of blind pursuit of economic growth and transition towards more sustainable economic development.

## 8.3 The coordinated regional development of environmental protection

At present, we must develop technology for protecting the environment and transfer it westward to inland provinces as soon as possible. Numerous studies show that there is a regional imbalance of environmental efficiency across China (Li et al., 2013, Yang et al., 2015, Zhang et al., 2016). The imbalance of regional environmental efficiency is due to differences in technical level and deviation from policies of environmental protection in different provinces and cities. Technological progress in the western regions of Inner Mongolia and Xinjiang Provinces is insufficient to improve environmental efficiency. In many parts of the east, investment in pollutant treatment has made great progress in these years, but there has been little change in environmental protection. This is true in other parts of China as well, i.e., pollutant treatment input has not effectively improved the environmental efficiency of much of central and western China, which was verified by Zhou et al. (2013) on power industry. This regional disparity limits the improvement domestic environmental efficiency.

The government should further encourage the eastern provinces to adjust their technological structure and give priority to the development of environmental protection technology using incentive and regulatory mechanisms. The sparsely populated land in the west requires increased environmental education, which could be done through a variety of media to encourage the improvement of environmental efficiency related policies and processes and increase the intensity of financial support and national policy support. This should be region-specific according to the local financial situation and the capacity of enterprises through the effective use of an environmental technology subsidy pilot program. Development of advanced environmental protection technology in different regions can be targeted to gradually increase the financial input, improve the environmental efficiency of these areas steadily, and constantly revise and improve the development planning, to ensure that environmental efficiency and strengthened environmental regulation are priorities in the development of central and western China (Song et al., 2013, 2014).

The role of environmental regulation in improving environmental efficiency is region-specific and acts to promote the environmental performance of the north, but in central and western regions of China, including Xinjiang, Qinghai, Gansu, Ningxia, Shanxi, and other provinces and autonomous regions, such regulation generally has little influence on environment performance. This indicates that the effectiveness variation derives from the level of regional economic development. After many years of rapid economic development, the environmental efficiency of developed areas can easily be promoted by environmental regulation, but in areas just starting economic development, the financial resources are limited and these areas may require stronger environmental regulation to improve environmental efficiency quickly.

Because of the effectiveness disparity of regulation to improve China's environmental protection, government should implement effective policies to enhance the environmental efficiency and promote sustainable economic development of the northwest areas. First, we should guide these areas to improve the environmental protection through local laws and regulations. Second, through the media and with policy guidance, we should encourage companies owned by the state to move westward and construct an environmental protection model for the country to reduce the pressure on the environment. We must establish an environmental efficiency evaluation system that includes environmental efficiency testing and assessment to support the development of the environmental protection industry. We should strengthen the coordination and sustainability in the central region, which will have a large national impact. After 60 years of development, this region has formed a relatively strong foundation of traditional economy with a certain scientific and technological strength. The central region of China acts as a bridge, linking the east and west, south and north. This region should seek to improve the environmental efficiency and improve industrial structure to avoid future negative factors in economic development. By moving forward in a sustainable way, this region can adapt to China's rapid social and economic development.

The central region is actively undertaking industrial transfer. Using our empirical analysis, we can further study the central region and efforts for industrial transfer and industrial upgrading to provide a quantitative basis for environmental protection based on sustainable development of the regional economy.

## 8.4 Coordinated development of environment and industry

This thesis provided an analysis of China's current overall employment situation and analyzed the effects of environmental regulation, structure industry upgrade, and pollution index system on employment. We provide the following policy suggestions:

First, focus on capital and technology as the main industry development direction and strengthen the labor-intensive industrial advantage. Since 1979, the traditional pattern of industrial development was maintained for nearly 40 years. China has been at the level of output of labor and China's overall industrial employment remains mainly in labor-intensive industries. Change from these industries should not be too fast, and gradual industrial upgrading is required to ensure the steady development of the economy and the steady growth of employment.

Second, we should promote the rationalization of industrial structure and appropriately boost the development of advanced industries. The rationalization of industrial structure is the first step for smooth industrial development (Ding et al., 2014). From the empirical results, we can see that the industrial employment convergence increased, and employment was reduced. We should not give up the long-term goal of industrial development to increase short-term employment. Based on the industrial employment demand and supply structure and the coordinated development of various sectors, the rationalization of industrial reform is feasible. For the upgrading of the industrial structure, changes at a high level cannot be achieved overnight. The relationship of employment and long-term stability is clear, and the negative effect of an excessively high level of employment is significant. Different schemes are required for different industries, and rationalization of industries need to be stressed based on employment elasticity, a ratio of growth rate of employment to the rate of industry growth. However, priority should be assigned for industrial upgrading instead of rationalization. We should utilize the connection of rationalization and industry upgrading to achieve the goal of employment growth.

Third, we should support the small businesses and emerging industries to accelerate upgrading of the industrial value chain. Compared to the past decades of China's industrial development process, the pulling power of state-owned enterprises and large enterprises to obtain employment has been gradually reduced. In contrast, the development of small and medium enterprises continues to increase. Therefore, we need to constantly improve the market mechanism and formulate laws and regulations to protect and foster small and medium-sized enterprises to maintain employment growth. In addition, Chinese enterprises in the international environment often have low profitability, due to being positioned at the low end of international division of labor. Improvement in total factor productivity and upgrading of the industrial value chain are necessary steps to increase foreign investment. It is essential to introduce, learn, and develop advanced technology to improve technical efficiency. This must be done differently for specific types of industry and based on scale efficiency in order to stimulate employment and improve the overall quality of the workforce.

Fourth, continue to support green economy and advocate green life by strengthening environmental regulation and creating a good employment environment. With increasing attention focused on the degree of Chinese environmental pollution, transferring to green economy is essential. A green economy may impose a shock on some industries so that production costs may increase in the short term, which can lead to downsizing or even bankruptcy. This could affect the labor employment situation ultimately, especially for Chinese enterprises with high pollution and labor-intensive features (Song et al., 2011). However, in the long-term, a low-carbon policy will allow realization of China's strategic objectives of achieving sustainable development and the transformation of economic growth mode. Therefore, we propose that China needs to continually advocate green and sustainable development, to introduce the laws and regulations to make the market access costs high for high carbon industries, and to establish and develop low-carbon industrial clusters gradually. Under the open environment, industries with high energy-consumption and high pollution relocated to China. Although this can produce positive effects on employment, it puts a huge pressure on the environment that will affect labor force employment through the industrial structure. We need to strengthen the intensity of environmental regulation to avoid becoming a so-called "pollution haven". Besides, people should have confidence in the prosperity of a "green economy," and advocate this lifestyle. There can be both positive and negative effects of a low-carbon economy on employment. We should give priority to the development of low carbon industry that meets Chinese national conditions and ensure its coordinated development with high carbon industry. We should increase the technological progress of the low carbon industry, strive to develop new energy, and strive to stimulate the economy and employment in the transformation to a low carbon economy.

There are still some limitations in this research. The first limitation lies in the data used. Most of our data is collected from the public Statistics Yearbook, which only provide macro data. The data size of this study was not very large and the sample of 30 provinces unit or 30 industries were used frequently. Micro survey data is rarely employed in our analysis, which is mainly constrained by the higher cost of data collection. Micro data, such as household and firm data, have many advantages in detecting the individual relationship. Take for instance the impact of consumer behavior on environmental had attracted increasing attention and discussion among researchers. Schipper et al. (1989) concluded that "about 45–55% of total energy use is influenced by consumers' activities for personal transportation, personal services, and homes." It is worthwhile to reinvestigate this problem in the future based on more detailed data resources.

The second limitation lies in the methodologies used. Although undesirable output is considered in Data Envelopment Analysis (DEA) in this study, the directions along which the Decision-Making Units (DMUs) move to frontier is not considered. Different direction vector selection will lead to different score of evaluation, which has triggered a comprehensive discussion in recent years. Directional distance function was largely employed with the considering undesirable output. However, how to choose a direction vector remains a problem which needs to be solved. There are two strands of studies on seeking optimal directions in the existing literature. One chooses the direction toward to the closest or farthest benchmark by some kind of optimized strategy. The other depends on economic theory, such as cost minimization, revenue or profit maximization, to get a theory-based direction. In the future, we will construct an endogenous directional distance function model based on first strand of study above to reevaluate environmental efficiency.

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## SUMMARY

China has maintained rapid growth for nearly 40 years, achieving significant economic development. However, it also caused many problems including resource shortages and environmental pollution. This is partly because China pursued a pattern of extensive growth by relying on primary resource inputs. China has now begun to adjust its development and environmental protection policies to handle these problems. The 18th National Congress of the Communist Party of China emphasized the construction of an ecological civilization given China's energy constraints, serious environmental pollution, and degraded ecosystem.

This study aims to characterize the relationship between economic growth and environmental protection in China. Using data envelopment analysis, the generalized method of moments, and a coupled modelling method, we studied the mutual relationship between environment and growth, as well the effect environmental regulation has on economic activities. The following results were obtained: (1) There are wide disparities in pollutant emissions across regions of China. The developed eastern provinces are facing the worst environmental issues, especially water pollution. The provinces with a lower level of economic development experience relatively fewer environmental problems. There are also significant pollution differences across industries. Environmentally degraded industries are mainly concentrated in the capital-intensive manufacturing sector. (2) A significant linkage is found between energy input and environmental total factor productivity, which is the promotion of environmental efficiency that can facilitate energy saving. Therefore, it is necessary and useful to promote environmental efficiency. (3) There is a coupling relationship between environmental protection and manufacturing industries, which is evolving from a moderate and low to moderate one. However, from a dynamic perspective, the degree of coupling is not as optimistic as expected. The coupling relationship is associated with disordered development. (4) China's environmental regulation would worsen employment conditions, which is consistent with results that do not consider open conditions. This finding may be attributed to the cleaner production environment brought about by socioeconomic development. Enhancing the intensity of environmental regulation may block the flow of foreign capital, which may ultimately reduce employment.

Based on these results, we provide the following policy suggestions. China's central government should encourage the eastern provinces to adjust their technological structure and give priority to the development of environmental protection technology using incentives and regulatory mechanisms. In addition, the eastern provinces should transfer such technology westward to inland provinces as soon as possible. China should strengthen the coordination and sustainability in the central region, which will have a significant national impact. China should promote the rationalization of industrial infrastructure and appropriately boost the development of advanced and clean industries. The rationalization of industrial infrastructure is the first step towards smooth industrial development. The central regions should actively undertake industrial transfer from the east in this process. China should support small businesses and emerging industries to achieve the goal of employment growth. Industrial upgrading from labor-intensive industries to capital- and technology-intensive industries should not be too rapid in order to ensure the steady growth of employment.

## SAMENVATTING

China maakt een proces van snelle economische groei door, al bijna 40 jaar lang. Dat proces veroorzaakte echter ook veel problemen, waaronder tekorten aan grondstoffen en milieuverontreiniging. Dit ten dele het gevolg van het patroon van groei, dat een sterke afhankelijkheid inhield van de inzet van primaire grondstoffen. Pas onlangs is China begonnen om zijn beleid inzake ontwikkeling en milieubescherming hierop aan te passen. Het 18e Nationale Congres van de Communistische Partij van China benadrukte de opbouw van een ecologische beschaving als antwoord op de uitdagingen op het gebied van energie, milieuverontreiniging en achteruitgang van het ecosysteem.

Deze studie beoogt de relatie tussen economische groei en milieubescherming in China te onderzoeken. Daarvoor werden gebruikt: de methode van Data Envelopment Analysis (DEA), de statistische techniek van gegeneraliseerde momenten (GMM) en een methode om de koppeling tussen milieu en economie te modelleren. Naast de relatie tussen milieu en economische groei bestudeerden we de effecten van milieubeleid op economische activiteiten. Dat leidde tot de volgende resultaten: (1) Er zijn grote regionale verschillen in uitstoot van verontreinigende stoffen in China. De meer ontwikkelde provincies in het Oosten staan voor de ernstigste milieuvraagstukken, vooral op het gebied van waterverontreiniging. De provincies met een lager economisch ontwikkelingspeil hebben hier minder mee te maken. Er zijn ook significante verschillen in uitstoot van verontreinigende stoffen tussen bedrijfstakken. De bedrijfstakken met de grootste milieu-uitdaging komen vooral voor in de kapitaalintensieve maakindustrie. (2) Er is een belangrijk verband gevonden tussen de inzet van energiedragers en milieuproductiviteit (total factor productivity). Dat onderstreept het belang van beleid dat zich richt op het vergroten van de energy efficiency. (3) Er is een positieve verband tussen milieubescherming en maakindustrie, dat geleidelijk sterker aan het worden is. Vanuit een dynamisch perspectief is de mate van koppeling niet zo gunstig als verwacht, omdat er sprake is van ongelijkmatige ontwikkeling in de industrie. (4) Milieubeleid in China zou de werkgelegenheid in negatief kunnen beïnvloeden, wat samenhangt met de condities van een open wereldmarkt waarop Chinese bedrijven concurreren. Strenger milieubeleid zou buitenlandse investeringen in China kunnen beperken, en uiteindelijk de werkgelegenheid verminderen.

Op grond van dit onderzoek komen we tot de volgende beleidsaanbevelingen. De nationale overheid in China zou de Oostelijke provincies moeten stimuleren om hun technologische structuur aan te passen, en voorrang te geven aan de ontwikkeling van technologie die gericht is op milieubescherming. Daarbij zouden zowel economische prikkels als directe regulering ingezet moeten worden. Daarnaast zouden de Oostelijke provincies zo snel mogelijk moeten gaan werken aan de overdracht van milieutechnologie naar Westelijke provincies. China zou verder de coördinatie en duurzaamheid in de centrale regio van China moeten versterken, wat een significant effect op nationaal niveau zal hebben. China zou ook de verbetering van de industriële infrastructuur moeten bevorderen, en daarmee de ontwikkeling van geavanceerde en schone bedrijvigheid. Daarmee worden tevens eerste stappen gezet naar een meer geleidelijke industriële ontwikkeling. De centrale regio's in China zouden, als onderdeel van dit proces, actief de overdracht vanuit Oostelijke provincies moeten bevorderen. China moet het midden- en kleinbedrijf, en ook nieuwe bedrijven (emerging industries) bevorderen om werkgelegenheidsdoelstellingen te behalen. Het uitbouwen van arbeidsintensieve industrie naar kapitaal- en technologie-intensieve industrie zou echter niet te snel moeten gaan, om een geleidelijke groei van de werkgelegenheid te borgen.