ESSAYS OF THE POLLUTION EFFECTS ON SUSTAINABLE ECONOMIC DEVELOPMENT

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Abstract

Since the arouse of Environmental Kuznets Curve (EKC) hypothesis first established by Simon Kuznets in 1950s, the analysis of the relationship between economic growth and environmental degradation have become popular among different economic researchers. Some studies tested this relationship by making similar theoretical models (Baldwin(1995), Lieb (2004), Palivos and Varvarigo (2010),etc), while others tested this relationship empirically (Grossman and Krueger (1991), Panayotou (1993), Shafik and Bandyopadhyay (1992),etc).

The motivation of my study is to analyze the long-run economic relationship between economic growth and pollution pressures with both theoretical and empirical methods. Pollution is a key indicator of economic growth, but on the other hand it hurts our environment quality as well as the people's health condition. Therefore, Both developed and developing countries need to deliberately deal with this conflict relationship between economic growth and pollution pressures. The results and findings will help us to understand about this relationship better and help the policy makers to make their decisions about solving this conflict in a cost efficient way. In addition, not only does this thesis provide a suitable way for policy makers to choose an optimal choice between choosing pollution and economic growth, but also it teaches people how to choose their pollution abatement in order to for them to live longer under pollution.

There are five chapters in this dissertation. The first and last chapters are introduction and conclusion, while the main contents starts from chapter two. Second Chapter entitled "Pollution, Disease and Long-run Economic Growth" investigates the relationship between long-run economic growth and individuals' health conditions under pollution. The results of this chapter find that poor countries tend to converge to poverty trap and can't even afford pollution. They need to gain capital accumulation first in order to achieve growth. On the other hand, pollution abatement is the key element for rich countries to reach its long-run sustainable equilibrium. The Third Chapter "The Environmental Pressure and Economic Development Based on Environmental Kuznets Curve Hypothesis: Evidence from China" presents the relationship between economic development and pollution pressures empirically in the Chinese society based on EKC hypothesis. In this chapter I collected 7 different pollutants and used Principal Component Analysis (PCA) to create a pollution index to test its relationship with other independent variables. By doing this innovation, I can produce an accurate definition of the pollution pressure and also can eliminate the inconsistencies from the results of analyzing different pollutants separately. The fourth chapter tests this triangle relationship empirically, taking China as the study object. In this chapter, I implement the panel unit root tests, panel causality tests, panel co-integration, and error correlation model (ECM) to investigate the relationship between human mortality, GDP and SO2 emissions for 30 provinces of China from 1995 to 2013. The findings of this chapter will reveal that there is a short-run causal relationship moving towards from economic growth to human mortality as well as a short-run causal relationship moving towards from air pollution to economic growth. However, there is bidirectional long-run causal relationship between Individual's Mortality Rate and Economic Growth.

Dedicated to my dear parents, my beloved wife and my adorable son, Jayden L Yihao Wang

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Chapter 1

Introduction

Pollution and environmental quality issues have been growing significantly in recent studies. Problems like the degradation of air quality and the contamination of both food and water[1] are the main issues to threaten human health conditions and life-span. Jerrett et al (2005) extracted data of 22,902 subjects from the American Cancer Society cohorts and assessed associations in standard and spatial multilevel cox regression models. At the end, they concluded that the causality of chronic health effects and specificity in cause of death which are associated with within-city gradients in exposure to PM2.5 is significant. Without a good health conditions for individuals, our economic development will be affected by losing human capitals and may not reach its long run equilibrium.

An augmented health status induces agents to accumulate more capital (physical and human capital) since an increased longevity enhances the rate of return of investments, like savings for instance. Individuals can enjoy and benefit longer from their investment in the future. Hence, by promoting accumulation of assets, longevity has crucial repercussions on the long-term development. Cervelatti and Sunde (2005) established a model to test the interplay between economic variables, namely the process of human capital formation, technological progress, and the biological constraint of finite lifetime expectancy and provided an empirical support to such an argument.

However, although pollution hurts our environment quality and individual's health conditions, it is also an indicator of economic growth. Therefore, both developed and developing countries must choose one suitable way for dealing with this conflict. This thesis seeks for the most cost efficient ways to help countries to deal with this problem. These are considered to be my primary motivations and contributions for my work.

In addition, the depletion of the natural resources is another big issue caused by pollution and it

[1] In the high density of industrialized locations, there will be many industries built close to the civilization area in order for them to produce the goods. Those industries will release some chemical and toxin and contaminate both crop and water qualities for civics.

affects the long-run economic growth as well. However, in this thesis we mainly consider the relationship among pollution, health characteristics, and economic growth. The natural resource is assumed as a constant factor in this thesis.

1.1 The relationship between pollution and economic growth-Environment Kuznets Curve

There are many different explanations about the relationship between the pollution pressures and economic development. Grossman and Krueger, (1991) studied the relationship between economic growth and environmental quality in 42 countries based on the North American Free Trade Agreement. This paper is the first study on the relationship between environment pollution and economic growth based on the EKC hypothesis [2]. They have tested the relationship between income per capita and many different pollutants such as, SO2, NOx, SPM, etc. The research indicates a relationship of inverted U-shaped EKC curve between average income and environmental pollution. Azomahou, et al, (2006) relied on a nonparametric model to examine the empirical interactions between the economic growth and the CO2 emission by using panel data. They found that the economic development process has a negative effect on CO2 emission, especially for the early and advanced development stages and therefore suggested that both developed and developing countries to reduce their CO2 emissions. In addition, Galeotti and Lanza (2005) based on the empirical emergence of the Environment Kuznets Curve (EKC), and used a newly developed data set covering over one hundred countries around the world for the last twenty five years and combined with alternative functional forms to analyze the relationship between CO2 emission and the economic development. At the end, they reviewed that there are unidirectional positive relationships running from CO2 emission to economic development and unidirectional negative relationships between CO2 emission and energy consumption.

Most of the papers test the relationship of EKC by using an empirical method as I have mentioned above, whereas, Xepapadeas (2003) underlined the discussion of the EKC by providing theoretical foundations. He pointed out that the theoretical foundations of the income-pollution relationship with respect to EKC, are based on the dynamic or static optimization models with environmental considerations. He introduced an emission function as denoted as $Z = v(k, a)$ and by assuming no population growth or exogenous technical change with a separable utility function, he observed that the pollution-income relationship represented an inverted U shape.

There are two main theoretical explanations for rationalizing the EKC relationship. First, the Kuznets behavior is treated as an income effect since the environmental quality protection is categorized

[2] Environment Kuznets Curve is an inverted-U-shaped historic relationship between measures of pollution pressures and per capita GDP identified by Simon Kuznets, 1950s.

as a luxury good (Lieb, 2004). It is easy to understand that in the early stage of the economic development process, individuals are not rich enough and unwilling to trade their consumption for investment in environmental protection; therefore the environmental quality declines as the development increases. Once individuals reach a given level of consumption or income, they begin to consider longevity and increase in the demand for investments in environmental protections. Second, the Kuzents behavior is described as expression of the stages of economic growth, because the economic development has to make a transition from agriculture-based to industry-based and then from post-industrial to service based stages (Baldwin, 1995). It is clear that during the transition from an agricultural stage to an industrial economic stage results in a huge increase in the environmental degradation due to the massive production and consumption growth which need to release a significant amount of pollution emissions. On the other hand, during the transition from an industrial to a service-based economy, the environment degradation will be mitigated since there aren't many industrialized activities under service-based economy.

1.2 The relationship between individual's health conditions and economic growth

Economic development can definitely be affected by lack of human capitals. Thus, Individuals' health conditions and lifespan are important factors that affect the economic growth. pollution on the other hand might have a significant negative correlation with individuals' health conditions, or even cause pre-mature death for individuals. Chakraborty, (2004), built a two-period overlapping generation model (OLG) combined with a mortality risk to discuss the relationship between endogenous lifetime and economic growth. He suggested that high mortality prevent healthy pace of economic growth since shorter lifespans countermand the saving rate and investments. He also suggested that high mortality reduces returns on investment as well, such as education since the risks are undiversifiable and therefore, multiple steady-states are possible. I will address this issue in sufficient details in Chapter 2. Furthermore, Chakraborty et al, (2010), established an overlapping generation growth model with incorporating mortality and morbidity to explain the relationship between the long-run economic growth equilibrium and the infectious diseases. He pointed out that even when all economies converge to the same long-run growth rate, countries that are exposed to infectious diseases take much longer to achieve robust growth. This implies that the mortality with respect to infectious diseases causes development trap and the morbidity causes poverty trap.

Raffin Natacha and Seegmuller Thomas (2012) expressed a different view of the relationship between life expectancy, environmental quality and economic growth. They also developed an OLG model and inserted both longevity and fertility as endogenous variables. They emphasized two types of public expenditures: health services and environmental maintenance. If the government implements a valid fiscal policy, there will be multiple aspects of equilibrium: a high growth rate accompanied by a longer life expectancy and a declined fatality rate. In contrast, if the fiscal policy is inefficient, like the environmental maintenance tax rate is too large, the economy collapses.

As a result,the health conditions and the life expectancy significantly contribute to the economic growth. In order to reach a sustainable economic growth, individuals need to be healthy and live long.

1.3 The relationship between natural resources and economic growth

Although natural resources are not the main element for us to aim in this thesis, it is inevitable to the achievement of the economic growth, especially on the long-run. Scholl Almuth and Semmler Willi (2000) studied models of sustainable economic growth with resource constraints. The central part of their perspective is to present the stylized facts on exhaustible resources and analyze the question to what extent the economic growth process can be restricted by the limitation of the resource stocks. They also estimated a basic model with resource constraints for U.S time series data and tried to figure out whether sustained consumption and utilization levels are feasible. At last, they argued that the lack of strong evidence showing a threat to sustainable growth in the future. Cavalcanti et al, (2009) proposed a similar model to that of Scholl Almuth and Semmler Willi (2000). in which they didn't divide[3] natural resources into exhaustible resources and non-exhaustible resources[4]. Their goal is to determine whether or not the natural resource abundance is a curse or a blessing. In the end, they concluded that the natural resource abundance is a blessing not a curse.

Dustin and Guo Jang-Ting, (2007), developed a one sector endogenous growth model[5] to capture the environment's role for the sustainability of natural resources. Environment provides factors of production and a stock of renewable natural resources that accumulates over time in order to preserve the environmental quality when GDP continues to grow. They found that a sustained economic growth can coexist with the non-deteriorating natural environment along with the economic balance growth path (BGP). They also found that the production growth rate is positively related with the equilibrium level of natural resource utilization in production.

However, natural resources only partially explain the relationship between pollution and long run

[3] The main difference of model between Cavalcanti et al (2009) and Scholl and Semmler (2000) is the resource constrain: the formal is $S_t = S_0 - \int_0^\infty R_t d_t$,and the latter is $\dot{S} = I^S - \gamma S$

[4] Exhaustible resources die out when they are used up, but Non-exhaustible resources can be re-created after used up.

[5] One sector endogenous growth model in Dustin and Guo (2007): The production function is $Y_t = AK_t H_t^{1-\alpha}$, capital K as the only factor and labor assumed to be fixed.

economic growth in this thesis, as I have assumed that the natural resource is infinite and can never be used up in the production of the goods.

I will discuss my research about above mentioned relationships and their combined effectiveness in chapter 2,3,4 and 5. Chapter 2 discusses a theoretical explanation of the relationship between economic growth, pollution-caused disease and pollution pressures. Chapter 3 tests the relationship between pollution pressure and economic growth empirically under the analysis of 30 provinces in China. Chapter 4 exams the long-run causality relationship among individual's health term, pollution pressure and economic growth empirically by using China's evidence again, and Chapter 5 conclusion.

Chapter 2

Pollution, Diease and Long-run Economic Growth

2.1 Background

2.1.1 Innovations

This chapter relates to several theoretical contributions, Chakraborty (2004), Chakraborty (2010), Palivos and Varvarigos (2010), and John and Pecchenino (1994). Similarly, this chapter also built a two period OLG model with pollution abatement factor related to an endogenous health factor affected by the quality of the public health service and the natural environment same as Palivos and Varvarigos (2010) did. However, the main differences between my model and Palivos and Varvarigos (2010) are listed as, first, this chapter considered the pollution abatement from an individual's side and treat it as an investment for each individual while Palivos and Varvarigos (2010) looked the pollution abatement issue through a perspective of the government fiscal policy. Based on my own knowledge, I'm the first author to consider that the pollution abatement as an issue from the individuals' point of view and this is never done by any predecessors. In detail to explain this difference, I assume that the abatement investment a_t are taking the form of net food intake (that is, the organic food and purified water), low carbon products, more energy conservative utilities and other related environmental protection expenditures for each individual in order to sustain her standard health condition from the impacts of pollution. Also, this abatement effect is complemented by government financed public health g_t, where g_t is taking a form of part of firm' production revenue tax. On the other hand, Palivos and Varvarigos (2010) treated both the pollution abatement and the public health service as a tax charged by the government for the firm's production only. Therefore, the individual's budget constraints in this chapter contain the pollution abatement term a_t while Palivos and Varvarigos (2010) didn't include this factor into their budget constraints in their paper. By doing this, I can look through the question how an individual's behavior will affect the existing of the abatement, whereas Palivos and Varvarigos (2010) cannot.

Second, this chapter introduced the concept of probabilities and divide individuals into two possible groups due to some people may get fetal disease under pollution while others might stay healthy: (i) healthy individuals towards to pollution and (ii) sick individuals towards to the pollution. This is because an individual is more likely to invest in the pollution abatement if she feels threaten of her health condition under pollution. Therefore, I need to form an optimal condition for both types of the individuals to invest in this abatement. I derived and claimed only when the condition that the marginal benefit of abatement (MBA) is greater than the marginal cost of abatement (MCA) holds, there will be exist pollution abatement for both of the individuals. I also concluded that an individual will invest in this abatement only if this abatement has a positive return or if she has reached a given level of consumption which means rich enough. There is a equation represent this condition in section 2.2.6.3 and there is an numeric example for this equation in Appendix 2.1

In Palivos and Varvarigos (2010) on the other hand, they ignored to derive and consider this condition in their research and also they didn't cover the probability issue respected to the pollution levels. However, this condition is important to explain between different groups' behavior toward to pollution abatement. For example, China now has the most top pollution level and is categorized as one of the most top polluted country in the world, but it is not categorized as an Appendix I[1] country in the Kyoto Protocol. This implies that not all high polluted countries are sufficient to pollution abatement although there is a threaten of their health there. Therefore, this condition will generate richer implications between the countries' economic development and their pollution levels.

By doing this, I supposed that an individual lives in a country with uncertainties about getting sick respected to pollution. Let π_t and $1 - \pi_t$ be the probabilities that an individual could be either become ill or not affected by the pollution. Therefore, she will behave differently between her saving and consumption choice for different groups. Also, there is a survival rate for her if she becomes ill under pollution in long-run. By looking for an expected lifetime utility for an individual and combining it with the solutions of her maximized problems under both types of individual, I will find the optimal condition for choosing pollution abatement as $MBA \geq MCA$. This condition generates two intuitions: (i) an individual will only invest in this abatement if the return of this abatement is positive and (ii) an individual will only invest in this abatement is she reach a given level of the consumption. Back to my previous example of China, this condition explains that although China has the most pollution

[1] Appendix I countries under Kyoto Protocol are the countries need to be enforced to reduce CO2 emissions, one of the air pollutant. The Appendix I countries under Kyoto Protocol are: All advance countries + East Europe + Russia

in the world, it is not categorized as an Appendix I country under the Kyoto Protocol is because the return of this abatement hasn't seemed to be positive for individuals in China, or they haven't reached a given level of consumption. Palivos and Varvarigos (2010) didn't consider this condition which contains important implications.

Third, in my model, because the function of the probabilities, I generate one temporary equilibrium for two different individual groups at $k_{t+1} = \pi_t s_t^S + (1 - \pi_t) s_t^H$(discussed in section 2.7). In contrast, Palivos and Varvarigos (2010) only established one simple temporary equilibrium at $k_{t+1} = s_t$ respect to an economy in their paper. Moreover, I analyze the dynamics of the equilibrium. In detail, I break the analysis into two cases (i) without an abatement and (ii) with an abatement. At last, I find out that if the country starts its economy at a relatively low capital per work, it will always end up converge to a poverty trap and pollution abatement is no needed under this case, such like an agriculture based country, while only if the country starts its economy at a relatively high capital per worker, it will at last converge to a long-run sustainable equilibrium with an abatement decision.

Therefore, my model suggested that an existing of pollution abatement is not a key factor for a poor country to reach its long-run equilibrium, since its capital accumulation is too small. This also implies that an individual living in a poor country, do not always match the requirement of the condition $MBA \geq MCA$ I mentioned before. She is less willing to trade her consumption to pollution abatement. Therefore the procedure for such a country to get out of the poverty trap and reach its long-run equilibrium should be gaining capital accumulation first. Again, we can't acquire these suggestions by looking through the model in Palivos and Varvarigos (2010).

Fourth, in my model, I established a standard level of capital per worker $\tilde{k}$ as the turning point and pointed out that before this turning point the abatement decision $MBA \geq MCA$ is not held and also this implies that the country is still in an underdeveloped status. Thus, under this situation, a country needs not to consider pollution abatement since the positive effect of the public health service on an individual's health condition dominates the negative effect of the pollution. On the other hand, if the capital per worker reach and even past this turning point, the abatement decision $MBA \geq MCA$ is held and implies that the return of the abatement is positive or an individual reach a given level of consumption which indicates a rich country. Thus a country needs to consider pollution abatement in order to reach a long-run sustainable equilibrium, since the negative effect of the pollution on an individual's health condition now dominates the positive effect of the public health service. If without the pollution abatement, she will die fast because of the pollution effect.

However, in Palivos and Varvarigos (2010), they have missed the discussions of maintaining and analyzing this turning point. Again, back to the China's problem, combining both this turning point and the condition $MBA \geq MCA$, we could explain why China is not considered to be Appendix I country under Kyoto Protocol. It is because when you consider the capital per worker and GDP per worker in China, it is still lower than it in an advanced country such as the US. That's why China is still a developing country rather than a developed country. It still needs to produce and release pollution in order to its economic growth and therefore, although it is considered as a high polluted country, it is not categorized as an Appendix I country under the Kyoto Protocol. Such conflict in China is abnormal, since in order to expand the economy, it needs to produce and release pollution, but on the other hand seems the pollution problem has already affected individuals' health condition now. This type of issue can only be observed by my model while Palivos and Varvarigos (2010) cannot.

As a result, there are richer implications could be generated by my model contrast with the model in Palivos and Varvarigos (2010).

2.1.2 Motivation

The motivation of this chapter is to learn the cause and effect between pollution, human health condition and economic growth. To see if pollution abatement plays an important role to a long-run economic equilibrium. Again from an economic review, based on this chapter, individuals are able to choose their optimal level of pollution abatement investment in order to maximize their utilities and health condition which will lead the economy to reach a long term development. From the societal side, it is an alarm to inform the society that the pollution protection issue for each individual is also important for living in a better nature environment situation.

The remainder of this chapter is organized as follows. Section 2.2 sets up the economic models. In section 2.3 I analyzed the different equilibria on the BGP separately from without pollution abatement to with pollution abatement. And discussed whether the pollution abatement is the key factor for these two different economies to reach a long-run equilibrium. In section 2.4, I analyzed the importance of the thresh hold and in section 2.5 I discussed some other implications caused by this model and phased some corollaries, and section 2.6, concludes.

2.2 The Economic Model

2.2.1 Pollution and Health Frameworks

I developed an overlapping generation (OLG) economy with discrete time intervals and infinite horizon sequence. Each individual in the economy potentially lives for two periods, youth and old-age. An individual will live after her birth, but she may not survive to her old age because of the impact from pollution. We assume that before the mortality aspect caused by pollution is realized, each individual reproduces asexually and gives birth to an offspring. Therefore, the newly born individuals won't be affected by the premature death of the youth caused by pollution. The size of the newly born individuals can be normalized to one (Palivos and Varvarigo, 2010).

As a youth, each individual is endowed with one unit of labor which they can supply it to labor market. The firm pays each labor a salary w_t and it is the only income for the individual who works during youth period, since she doesn't have an ability to work when she gets old. Because of this, each individual has to save money during youth period in order for her to consume when gets old. She deposits an amount of s_t to a financial institution, like banks. This s_t earns r_{t+1} and will be repaid by the financial institution in the next period.

2.2.1.1 Chance of pollution-caused diseases

This chapter assumes that pollution emissions are mainly caused by the production of goods. Thus, high productivity causes high pollution emissions. Under a polluted environment,such as the bad air qualities, and the contamination of both foods and waters,individuals' health condition behaves differently towards to the pollution pressures. Some people may get fetal sickness, such as lung cancer but others may still able to stay healthy. Thus, there is a probability issues toward to pollution-caused diseases.

Pollution-caused diseases inflict three types of costs on an individual. First, she is less productive at work and supplies only δ units of efficient labor instead of unity. Second, there is a utility loss from being sick: the individual derives a utility flow of $\theta u(c)$ instead of $u(c)$ from a consumption bundle c, where $\delta, \theta \in (0, 1)$. We interpret this as a quality-of-life effect. Third, a sick young individual faces the risk of premature death and may not live through his entire life.

Younger individuals can undertake preventive pollution abatement investment, a_t, early in life. This takes the form of net food intake (that is, the organic food and purified water), low carbon products, more energy conservative utilities and other related environmental protection expenditures. The key is that such investments are privately costly but improve resistance to pollution-caused diseases.

Suppose the probability that a young will get sick under pollution is π_t and it depends on the abatement investment a_t, and the provision of health service g_t such as,

$$\pi_t = \pi(a_t, g_t) = \frac{bg_t}{g_t + a_t} \qquad (2.1)$$

and it has the properties that satisfies the conditions of $\pi'(a_t) < 0$, $\pi(0) = g_t$, $\pi(\infty) = 0$, and $\pi'(0) = -\infty$. As q_t falls, private pollution abatement investment becomes more productive for preventing the pollution-caused diseases. In this sense, public and private effort are complementary inputs. The evolutionary parameter b gives the probability of getting sick without having any prevention of pollution-caused diseases, whereas, the probability of staying healthy toward pollution is $1 - \pi_t$.

2.2.1.2 Survival rate

Since pollution-caused diseases may lead to premature death for a sick individual, the survival rate from this situation is uncertain. I assume that an individual will survive from the pollution to her old age with a probability of ϕ where $\phi \in (0, 1)$ and on the other hand the probability that an individual will face a premature death is $1 - \phi$. Furthermore, I assume that this survival rate is highly correlated with a health factor h_t since it depends on the life expectancy. Therefore, the survival rate is defined as,

$$\phi_t = \phi(h_t) = \frac{\lambda h_t}{1 + h_t} \qquad (2.2)$$

where $\phi'(h_t) > 0$,$\phi''(h_t) < 0$,$\phi(0) = 0$, $\phi(\infty) = \lambda$,$\lambda \in (0, 1)$ (Chakraborty,2004).

2.2.1.3 Health condition

I further develop that the individual's life expectancy also depends on the government support of the public health service g_t (e.g., public hospitals, the presence of a national health system, preventive measures, funding and support of medical research ,etc.) and the quality of the environment e_t (the cleanliness of air quantity, soil and water, the relative abundance of natural resources such as forestry and other forms of plantation etc). The better of the public health service the better the health condition for each individual and also the better quality of the natural environment the better the health condition of each individual. This implies that h_t is positively correlated with g_t and e_t. Formally these ideas can be reviewed by,

$$h_t = g_t^c e_t^d \qquad (2.3)$$

where $0 < c < 1$ and $0 < d < 1$, where $c + d = 1$[2]. Finally, once the pollution and health issues are determined, the consumption and saving choice need to be evaluated in my model.

2.2.2 Individuals' Preferences

2.2.2.1 Healthy individual's preference

By considering the period utility function is an increasing, concave and homothetic function, such that $u' > 0$ and $u'' < 0$. I tag a superscript letter S on the sick individual's utility function and a superscript letter of H on the healthy individual's utility function respectively. First, considering the consumption and saving decisions of an individual who is able to stay healthy under pollution,

$$\underset{s_t^H}{Max}\{u(c_t^H) + \beta(u(c_{t+1}^H)\}, \beta \in (0, 1) \qquad (2.4)$$

[2]Chakraborty (2004), considered that $c = 1$ and $d = 0$ since he didn't consider the effect of nature environment,but in this chapter I consider both g_t and e_t take proportion effects on individuals' health condition

subject to

$$c_t^H = w_t - a_t - s_t^H \quad (2.5)$$

$$c_{t+1}^H = r_{t+1} s_t^H \quad (2.6)$$

where s_t^H is the saving rate for a healthy individual toward to pollution at time t. w_t represent wage, r_{t+1} is the return of saving for the individual at time $t+1$, and a_t is the pollution abatement investment that an individual will choose at time t.

2.2.2.2 Sick individual's preference

Second, the consumption and saving decisions of a sick individual under pollution may different since she may encounter a premature death. I consider that the survival rate for a sick individual, ϕ_t is relatively low if the level of capital per-worker is greater than $\tilde{k}$[3]. I will explain this more when I get to Section 2.3. Assuming zero utility from death, she maximizes expected lifetime utility,

$$\underset{s_t^S}{Max}\, \theta\{u(c_t^S) + \beta\phi_t u(c_{t+1}^S)\}, \beta \in (0, 1) \quad (2.7)$$

subject to

$$c_t^S = (1 - \delta)w_t - a_t - s_t^S \quad (2.8)$$

$$c_{t+1}^S = r_{t+1} s_t^S \quad (2.9)$$

Here, since the labor has lower incentive to work due to the sickness condition caused by pollution, she earns δw_t less than the labor who is not sick. In addition, her utility has a discount rate because of the pollution-caused disease and $\theta u(c)$ captures this effect. The first order conditions will bring us to find the Euler equations in both situations as,

$$u'(c_t^H) = \beta r_{t+1} u'(c_{t+1}^H) \quad (2.10)$$

$$u'(c_t^S) = \beta\phi_t r_{t+1} u'(c_{t+1}^S) \quad (2.11)$$

In order to be practically I assume a natural log utility function such as,

$$u(c) = ln(c) \quad (2.12)$$

[3] $\tilde{k}$ which I have proved in my Appendix A.2, is the global maximum level or a turning point that the capital growth will start to fall if pollution abatement doesn't apply.

which equals to one if c is zero.

2.2.3 Production Technology

By assuming that natural resources are infinite and normalized to one in the economy, I consider a single commodity that can be produced by a continuum of perfectly competitive firms who rely on only two factors-physical capital, K_t and labor, L_t. Capital needs to be rented from some financial intermediaries, and paid R_t by firms. Labor earns wage, w_t from firm. The output Y_t will be produced according to

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha}, 0 < \alpha < 1 \qquad (2.13)$$

where A_t is a productivity parameter, and it is positively related to the economy's average capital per effective unit of labor across the firm, $\bar{k_t}$.This idea implies that when workers produce goods with more capital good, they gain knowledge and become more productive (Romer, 1986; Frankel, 1962). Formally,

$$A_t = \tilde{A}\bar{k_t}, \tilde{A} > 0 \qquad (2.14)$$

where $\tilde{A}$ is a constant parameter and equation (2.14) represents a learning-by-doing externality. Hence the capital per worker and production per worker are equals respectively as,

$$k_t = \frac{K_t}{L_t} \qquad (2.15)$$

$$y_t = \frac{Y_t}{L_t} \qquad (2.16)$$

2.2.4 Pollution Factor Definitions

Pollution is the main factor to be concerned in this chapter. Since I assumed that it is caused only by production of goods, I defined that one unit of the output can release γ amount of the emission, where $\gamma > 0$, and therefore, by Xepapadeas, A (2003) the total pollution is defined as,

$$P_t = \gamma Y_t \qquad (2.17)$$

There exists a level of degradation of the total natural environment, D_t caused by the pollution emission. The relationship between environmental degradation and pollution abatement can be formally described as,

$$D_t = \frac{P_t}{1 + a_t}, a_t \geq 0, \qquad (2.18)$$

I define a variable E be the initial natural environment. The value of the aforementioned argument,

e_t as an environmental quality at time t will be captured by the combination of both E and D_t. The idea is as,

$$e_t = \begin{cases} E - D_t, & \text{if} D_t < E \\ 0, & \text{otherwise} \end{cases} \qquad (2.19)$$

where $E > 0$.[4] Note that, according to (2.18), the environmental impacts of pollution and abatement are negatively correlated.

2.2.5 Government Finance

Lastly, I assume that government finances the improvement of public health service, g_t by implement a tax rate τ on firm's production revenue (Palivos and Varvarigo, 2010). Formally, the public health service g_t can be expressed as,

$$g_t = \tau Y_t \qquad (2.20)$$

A firm is mandatory to pay tax to the government for their productions which can be used for the improvement of public health services. Working along with the effect of pollution abatement a_t, public and private efforts are complementary inputs together to prevent the pollution-caused diseases.

2.2.6 Pollution Abatement Decision

2.2.6.1 Firm's problem

Before I discuss about the optimal decision for investing in pollution abatement, I need to establish that a labor market clear condition is when $L_t = 1$. From production function (2.13), I can solve the profit maximization by firms. Formally, I find that,

$$w_t = (1-\alpha)K_t^{\alpha} A_t^{1-\alpha} L_t^{-\alpha} = (1-\alpha)k_t^{\alpha} A_t^{1-\alpha} \qquad (2.21)$$

$$R_t = \alpha K_t^{\alpha-1} (h_t L_t)^{1-\alpha} A_t^{1-\alpha} = \alpha k_t^{\alpha-1} A_t^{1-\alpha} \qquad (2.22)$$

Since the labor market clear condition is $L_t = 1$ and combines this condition with equation (2.15), it implies that $k_t = K_t = \bar{K}_t = \bar{k}_t$. Furthermore, with the condition $\tilde{A}^{1-\alpha} = A$ as well as equation

[4]For the purpose to maintain analytical convenience, I have changed dynamics of environmental quality by assuming that nature has the ability to completely regenerate and restore itself within a period. With a two-period overlapping generations setting, one period may include many years. Thus this is not a very restrictive assumption. Moreover, it has been used in the analyses of Jones and Manuelli (2001) and Hartman and Kwon (2005), Stokey (1998),and Palivos and Varvarigos (2010).

(2.14), I can rewrite (2.21) and (2.22) as,

$$w_t = (1-\alpha)Ak_t \qquad (2.23)$$

$$R_t = \alpha\Gamma \equiv \hat{R} \qquad (2.24)$$

In addition, I use the labor mark condition together with equation (2.16) to obtain the per effective output per worker as,

$$y_t = Ak_t \qquad (2.25)$$

2.2.6.2 Individual's problem

In order to analyze the private optimal pollution abatement decision, I need to find the optimal savings s_t^H and s_t^S for each type of individual by using Euler equations (2.10), (2.11), together with the log utility in equation (2.11), formally as,

$$s_t^H = \frac{\beta}{1+\beta}(w_t - a_t) \qquad (2.26)$$

$$s_t^S = \frac{\beta\phi_t}{1+\beta\phi_t}[(1-\delta)w_t - a_t] \qquad (2.27)$$

where $s_t^H > s_t^S$, since the sick individual has less incentive to save.

Note that at beginning of period t, individuals choose a_t to maximize their expected lifetime utility at,

$$U_t = \pi_t V^S(a_t) + (1-\pi_t)V^H(a_t) \qquad (2.28)$$

where $V^S(a_t)$ and $V^H(a_t)$ are indirect utility functions.[5] Next, substituting the optimal saving conditions into the indirect utility functions, I can figure out the optimal level of indirect utility functions as,

$$V_t^{H^*} = \zeta^H + (1+\beta)ln(w_t - a_t) \qquad (2.29)$$

which is the optimal indirect utility function for a healthy individual under pollution and where $\zeta^H = ln(1-z^H) + ln(r_{t+1}z^H)^\beta$, and $z^H = \frac{\beta}{1+\beta}$,

and

$$V_t^{S^*} = \zeta^S + \theta(1+\beta\phi_t)ln[(1-\delta)w_t - a_t] \qquad (2.30)$$

which is the optimal indirect utility function for a sick individual towards to pollution and where $\zeta^S = \theta ln(1-z^S) + ln(r_{t+1}z^S)^{\theta\beta\phi_t}$, and $z^S = \frac{\beta\phi_t}{1+\beta\phi_t}$.

[5] To find the indirect utilities, we need substitute equations (2.5), (2.6), (2.7), (2.8) into (2.4), (2.7) and (2.12), then we get the indirect utilities as $V_t^L = ln(w_t - a_t - s_t^H) + \beta ln(r_{t+1}s_t^H)$, and $V_t^S = ln((1-\delta)w_t - a_t - s_t^S) + \beta^l n(r_{t+1}s_t^S)$

2.2.6.3 Optimal abatement decision

Finally, I combine the Kuhn-Tucker first order condition for pollution abatement from equation (2.28) together with the equilibrium savings, equations (2.2), (2.3), (2.17),(2.18), (2.19), (2.29) and (2.30) to get the optimal abatement investment decision as

$$\begin{aligned}\pi_t\Big\{&\frac{\theta[1+\beta\phi(h_t)]}{(1-\delta)w_t-a_t}+\theta\beta\phi'(h_t)g_t^c(E-\frac{P_t}{1+a_t})^{d-1}\frac{P_t}{(1+a_t)^2}ln[(1-\delta)w_t-a_t]\Big\}\\&+(1-\pi_t)\Big\{\frac{1+\beta}{w_t-a_t}\Big\}\leq-\frac{bg_t}{(g_t+a_t)^2}(V_t^{H*}-V_t^{S*}) \qquad (2.31)\end{aligned}$$

The left hand side of inequation (2.31) (relaxed in Appendix A.1) is the marginal cost of pollution abatement (MCA) and the right hand side is the marginal benefit of pollution abatement (MBA). Two possibilities arise from inequation (2.31). First, the pollution abatement is positive and greater than zero if the marginal benefit of pollution abatement dominates the marginal cost of pollution abatement. Second, there will be zero pollution abatement if the MCA is greater than MBA. Now I can define a variable according to equation (2.31), such that,

$$\begin{aligned}\chi_t=&\pi_t\Big\{\frac{\theta[1+\beta\phi(h_t)]}{(1-\delta)w_t-a_t}+\theta\beta\phi'(h_t)g_t^c(E-\frac{P_t}{1+a_t})^{d-1}\frac{P_t}{(1+a_t)^2}ln[(1-\delta)w_t-a_t]\Big\}\\&+(1-\pi_t)\Big\{\frac{1+\beta}{w_t-a_t}\Big\}+\frac{bg_t}{(g_t+a_t)^2}(V_t^{H*}-V_t^{S*}) \qquad (2.32)\end{aligned}$$

If $\chi\leq 0$, there will be an optimal level of a_t exist and if $\chi\geq 0$, the optimal level of a_t equals to zero. This makes sense since if the return of this abatement is negative, an individual will not invest in this abatement or if an individual does not reach a given level of consumption, she is unwilling to invest in this abatement neither.

2.2.7 Temporary Equilibrium

From the enlightens of Palivos and Varvarigos (2010), I assume that the perfectly competitive financial intermediaries can access to a technology which can convert the output from time t into capital of time $t+1$ on a one to one basis to transform saving deposits into capitals. Hence, the asset market clears at $K_{t+1}=L_ts_t$. Combined with the labor market condition, $L_t=1$, this implies that $K_{t+1}=k_{t+1}$. Hence, I derive the intense form of the asset market clearing condition as,

$$k_{t+1}=s_t \qquad (2.33)$$

where s_t is the aggregate saving weighted by a sick individual and a healthy individual, and it is formally as

$$s_t = \pi_t s_t^S + (1-\pi_t)s_t^H \qquad (2.34)$$

As a result, according to equations (2.33) and (2.34), the general equilibrium for my model when the probability is π_t as,

$$k_{t+1} = \pi_t s_t^S + (1-\pi_t)s_t^H \qquad (2.35)$$

A labor market condition combined with equations (2.16) and (2.20) implies that $y_t = Y_t = \tau A k_t$. Hence, by plugging this condition together with all other expressions (2.1),(2.2),(2.3),(2.17),(2.18),(2.19),(2.20),(2.23),(2.25),(2.26),(2.27), into equation (2.35) I can derive the steady state equilibrium of model as,

$$\begin{aligned} k_{t+1} =& \pi(a_t)\left\{\frac{\beta\phi\{(\tau A k_t)^c(E-\frac{\gamma A k_t}{1+a_t})^d\}}{1+\beta\phi\{(\tau A k_t)^c(E-\frac{\gamma A k_t}{1+a_t})^d\}}[(1-\delta)(1-\alpha)Ak_t - a_t]\right\} \\ &+ [1-\pi(a_t)]\left\{\frac{\beta}{1+\beta}[(1-\alpha)Ak_t - a_t]\right\} \equiv f(k_t) \qquad (2.36) \end{aligned}$$

or we can rewrite this equation into a compressed form by combining z^S, z^H and equation (2.36), we have,

$$k_{t+1} = \pi(k_t)z^S[(1-\delta)w(k_t)) - a(k_t)] + [1-\pi(k_t)]z^H[w(k_t) - a(k_t)] \qquad (2.37)$$

Thus, I establish my model into a dynamical system with capital per worker and equations (2.36) and (2.37) show a general level of steady state equilibrium depends both on the sick individual and the healthy individual. Next I will analyze the dynamics of this equilibrium and the possibilities for which to exist a long run equilibrium.

2.3 Dynamic and Long Run Equilibrium

2.3.1 Definitions and Assumptions

Before analyzing the economic dynamic equilibrium, and finding a long-run sustainable equilibrium, I make some definitions to relax the understandings about this problem.

Definition 1. All countries start their economy at k_0 and for $k_0 > 0$, the dynamic equilibrium is a sequence of temporary equilibria that satisfy $k_{t+1} = f(k_t)$, for $\forall t$ (Palivos and Varvarigos, 2010).

Therefore, I define a new variable ρ_{t+1} as the growth rate of the physical capital per worker. Formally, it is defined as,

$$\rho_{t+1} = \frac{k_{t+1} - k_t}{k_t} = \frac{k_{t+1}}{k_t} - 1 \qquad (2.38)$$

Definition 2 (Palivos and Varvarigos, 2010). Consider $k_0 > 0$,

(i) If $k_{t+1} = k_t = 0$ and $\lim_{t\to\infty} k_t = 0$, the equilibrium is a "poverty trap".

(ii) If $lim_{t\to\infty}\rho_{t+1} = 0$, such that an equilibrium with $k_{t+1} = k_t = \tilde{k} > 0$ is a "zero growth" steady-state equilibrium. Or a "growth trap".

(iii) If $\lim_{t\to\infty} \rho_{t+1} = \tilde{\rho} > 0$, there will exist an equilibrium with $k_{t+1}/k_t = 1 + \hat{\rho}$ and such as $1 + \hat{\rho}$ will always be greater than one.

My main purpose here is to examine the scenarios that whether or not the pollution abatement decision from either type of the individual will lead to a long term prospect. I will divide my further analysis into two separate parts: (i) an individual is not willing to invest their money for pollution abatement. This implies that MCA is greater MBA. This will be done under different level of capital per worker analysis. (ii) an individual is willing to invest her money into the pollution abatement. Hence, MBA is greater than MCA under this case. Notice that all proofs of my subsequent results are relaxed within Appendix A. Moreover, besides the definitions above, I need some assumptions as well in order to reach my own goal as,

Assumption 1. $(1-\alpha)(1-a)A\frac{\beta}{1+\beta} > 1$ always.

This assumption is the necessary condition of the relative rich country facing pollution to exist a long run sustainable equilibrium and it is discussed in section 2.3.3 and relaxed in Appendix A.7.

2.3.2 Dynamic Equilibrium without Pollution Abatement

I begin to consider the case that when MCA is greater than MBA, individuals do not have an interest in investing the pollution abatement since they are not rich enough or $a_t = 0$. Given equation (2.36), we have,

$$\begin{aligned} k_{t+1} =& b\left\{\frac{\beta\phi\{(\tau A k_t)^c(E-\gamma A k_t)^d\}}{1+\beta\phi\{(\tau A k_t)^c(E-\gamma A k_t)^d\}}[(1-\delta)(1-\alpha)Ak_t]\right\} \\ &+ (1-b)\left\{\frac{\beta}{1+\beta}[(1-\alpha)Ak_t]\right\} \equiv f(k_t) \qquad (2.39) \end{aligned}$$

Equation (2.39) shows the general equilibrium condition of the economy without a pollution abatement decision for my model between sick individuals and healthy individuals. A formal analysis of (2.39) gives us,

Lemma 1.[6] There exists three steady state equilibria $\hat{k}_1$,$\hat{k}_2$,and $\hat{k}_3$ for the economy, such that $\hat{k}_1 = 0$, is locally asymptotically stable, $\hat{k}_2$ is unstable and $\hat{k}_3$ is either locally asymptotically stable or unstable.

By using Lemma 1 I can formally present the ideas below in the form of the economy,

Proposition 1.[7] Consider $k_0 > 0$, then:

[6]Lemma 1 is relaxed in Appendix A.2

[7]Proposition 1 is relaxed in Appendix A.3. The intuition of it is that for a country starts its economy at a relatively low capital endowment, its saving is not sufficient enough to guarantee a positive rate of capital accumulation. Therefore, its capital per worker declines constantly and until it rest at a poverty trap

If an economy starts with a relative low capital per worker at $k_0 < \hat{k}_2$, then the economy will converge to the "poverty trap" where is $\hat{k}_1 = 0$.

and

Proposition 2.[8] Consider $k_0 > 0$, then:

(i) If $\hat{k}_3$ is locally asymptotically stable:

If a country starts its economy at a relatively high k_0, such that $k_0 > \hat{k}_2$ and also $\hat{k}_2$ is unstable, the economy will converge to a steady state $\hat{k}_3$ with a "zero growth" equilibrium or a "development trap".

(ii) If $\hat{k}_3$ is not locally asymptotically stable:

The economy converges to an equilibrium permanently cycles around $\hat{k}_3$.

Intuitively, since the economy starts at a relatively low level of initial capital endowment, saving is not sufficient enough to guarantee a positive capital accumulation rate. Therefore the capital per worker of this economy declines until it hit on equilibrium, a poverty trap. For a country starting with a relatively high capital endowment, it can escape from the poverty trap eventually, but a high level of capital endowment implies a high pollution emission.

The level of the survival rate plays an important characteristic for explaining this situation. Since the individual's survival rate is large due to a good health condition in the beginning of the economic development, higher productivity ensures positive capital accumulation and therefore the economy grows fast in the earlier stage of the economic stage. Since the growth of the capital per worker is fast, it will reach the turning point $\tilde{k}$ a lot of faster for an economy starts with a relative high level of capital endowment than an economy starting with a relatively low capital endowment. However, the individual's survival rate decreases along with the increase of the pollution after the level of capital per worker passes the turning point $\tilde{k}$. Then capital accumulation starts to decline drastically along with the decrease of survival rate. The economy starts to grow slowly in the long-run in this case and until the growth rate hits zero.

If $\hat{k}_3$ is unstable, there might be a cycle of this situation. Intuitively, high level of capital per worker causes high pollution, and high pollution affect negatively for the individual's health condition, as well as the saving rate. This implies that capital accumulation is mitigated, but also the degradation of the environment is reduced. When next period the health status improves, then the same procedure will be repeated again. This result seems following with EKC hypothesis.

[8] The proposition 2 is relaxed in Appendix A.4.

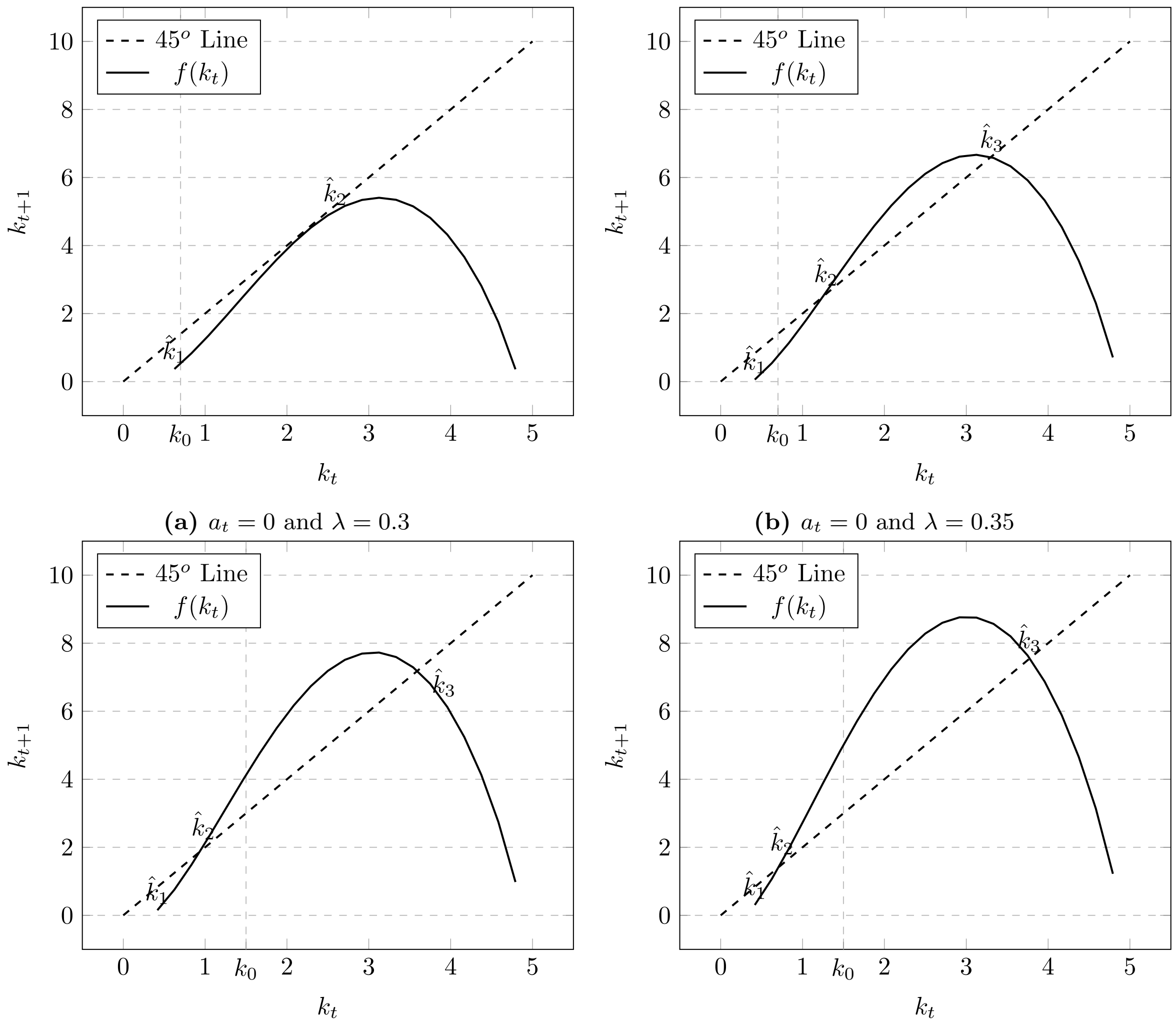
2.3.2.1 Numeric results of dynamic equilibria without pollution abatement

We can illustrate these results by means of a simple numerical example for above propositions by giving some numbers to all parameters, such as

Table 2.1: Benchmark Parameter Values

Parameters	Values	Parameters	Values	Parameters	Values
b	0.5	α	0.2	A	10
c	0.7	d	0.3	E	10
τ	0.2	δ	0.2	γ	0.3
λ	0.3				

By having these values we are able to do the numerical analysis of the above propositions.



(a) $a_t = 0$ and $\lambda = 0.3$

(b) $a_t = 0$ and $\lambda = 0.35$

(c) $a_t = 0$ and $\lambda = 0.45$

(d) $a_t = 0$ and $\lambda = 0.56$

Figure 2.1: Numerical Results: Without Pollution Abatement

Figure 2.1 (a) to (d) illustrates different possible scenarios. we see that the point $\hat{k}_2$ acts as a natural threshold which allows history to determine the prospects of economic development. The parameter λ plays an important role in determining the survival rate of individuals who get the disease under pollution. In addition, it also plays a very important role in determining the equilibria for our model. If it is too small, it means that less sick individuals survived from pollution and our economy cannot reach a higher steady state except the original one (the one at $\hat{k}_1$ with poverty trap), since savings are not high enough for sick people to gain capital accumulation. This is happening when $\lambda < 0.3$. If $\lambda = 0.3$ in the beginning, the function $f(k_t)$ is the tangent to the 45^0 degree line and hence there is only one interior steady state $\hat{k_2}$ besides the original steady state $\hat{k_1}$. However, since $\hat{k_2}$ is not a stable steady state, our economy will eventually converge back to the original steady state $\hat{k_1}$. Figure 2.1 (a) depicts this situation. If $\lambda > 0.3$ and equals to 0.35 there are two interior steady-state equilibria, say $\hat{k_2}$ and $\hat{k_3}$. The lower equilibrium, $\hat{k_2}$, is repelling, whereas the stability of the higher equilibrium, $\hat{k_3}$, depends on the value of λ. If the economy starts at a relatively low level of capital per worker, k_0, then the economy will again converge back to $\hat{k_1}$, a poverty trap. However, if k_0 is large enough, then the economy will converge to $\hat{k_3}$. This is captured by figure 2.1 (b).

The problem is that since the pollution level depends on the production of goods or capital accumulation, the sufficiently high values of k_t, implies that the negative effect of pollution on life expectancy and saving dominates the positive effect of publicly provided goods and services on health. Hence, the dynamics of capital accumulation are non-monotonic and $\hat{k_3}$ may actually lie on the downward sloping part of $f(k_t)$. Figure 2.1 (c) shows the result of $\lambda = 0.45$, and at the moment, the convergence to $\hat{k_3}$ occurs. The intuition is that since an economy starts from a relatively high capital endowment, it can escape from the poverty trap. In the beginning of the economic development (before the capital per worker reaches the turning point of $\tilde{k}$ and $MBA \geq MCA$ not hold), every individual under pollution will have a higher survival rate and not easy to get the disease towards to pollution, since the positive effect of the public health service dominates the negative effect of the pollution on the individual's health condition. Therefore, she is able to keep a higher productivity as well as the saving rate and the capital accumulation will be guaranteed.

However, if the capital per worker reaches and even pass the turning point $\tilde{k}$ ($MBA \geq MCA$ holds), the negative effect of pollution on an individual's health condition will now dominate the positive effect of the public health service. The probability of the survival rate, which is high at first period caused by a higher λ will be declined faster due to the increase in pollution in future periods, and so as the saving rate at this point. Therefore the growth rate of the capital per worker will become non-monotonic and declines until it hits zero. This happens when $\hat{k_3}$ is a stable steady state.

Next, suppose $\lambda = 0.56$ in the beginning, $\hat{k_3}$ has become a repelling steady state since the slope of the graph at the steady state $\hat{k_3}$ is really steep. The economy converges to an equilibrium in which capital per worker oscillates permanently around $\hat{k_3}$. Without a pollution abatement, the high pollution affects negatively on individuals' health condition as well as the saving and therefore the capital accumulation will be mitigated. However, the degradation of the environment is also reduced. When next period improvement of the public health service refreshes the health status, and so as the saving, the same procedure will be repeated again and again around $\hat{k_3}$.

2.3.3 Dynamic Equilibrium with Pollution Abatement

Now, I consider the case that $MBA \geq MCA$ holds, and then individuals are willing to invest in pollution abatement. Formally, we have the equation (2.36) under our concern this time with a little modification, since we have considered that the pollution abatement is a proportion of an individual's income. Therefore, by giving $a_t = aw_t = a(1-\alpha)Ak_t$, we substitute this condition into the equation (2.36). Instead of choosing a_t we choose a. The steady state implications under this situation is summarized as following

Lemma 2.[9] Assume that $aE > \gamma$ is always true [10], there exists two steady state equilibria, $\hat{k}$ and $\hat{k_2}$, such that $\hat{k_1} = 0$ is a locally asymptotically stable equilibrium and $\hat{k_2} > 0$ is an unstable equilibrium.

Using lemma 2, I can generate the following propositions as,

Proposition 3.[11] Consider $k_0 > 0$,

An economy, although there is an active pollution abatement, if it starts at a relatively low capital per worker at $k_0 < \hat{k_2}$, and the economy will again converge to the "poverty trap" where is $\hat{k_1} = 0$. This implies that an economy starting at a relatively low capital per worker has not always met the requirement of $MBA \geq MCA$.

and

Proposition 4.[12] Consider $k_0 > 0$,

Consider an economy, who starts at a relatively high capital endowment k_0, such that $k_0 > \hat{k_2}$, the economy eventually converges to a "long run equilibrium" in which both capital per-worker and output per-worker grows at a rate at $\tilde{\rho} = (1-a)(1-\alpha)A\frac{\beta}{1+\beta} - 1$.

The intuition of proposition 3 is same as the intuition of proposition 1. when a country starts economy at a relatively low level of initial capital endowment, the saving is not sufficient enough to guarantee a positive capital accumulation rate. Capital per worker declines under this situation and

[9] Lemma 2 is relaxed in Appendix A.5.

[10] $aE > \gamma$ ensures that the portion invested on pollution abatement is always greater than the pollution emission rate. Then the environmental degradation can never reach its limit.

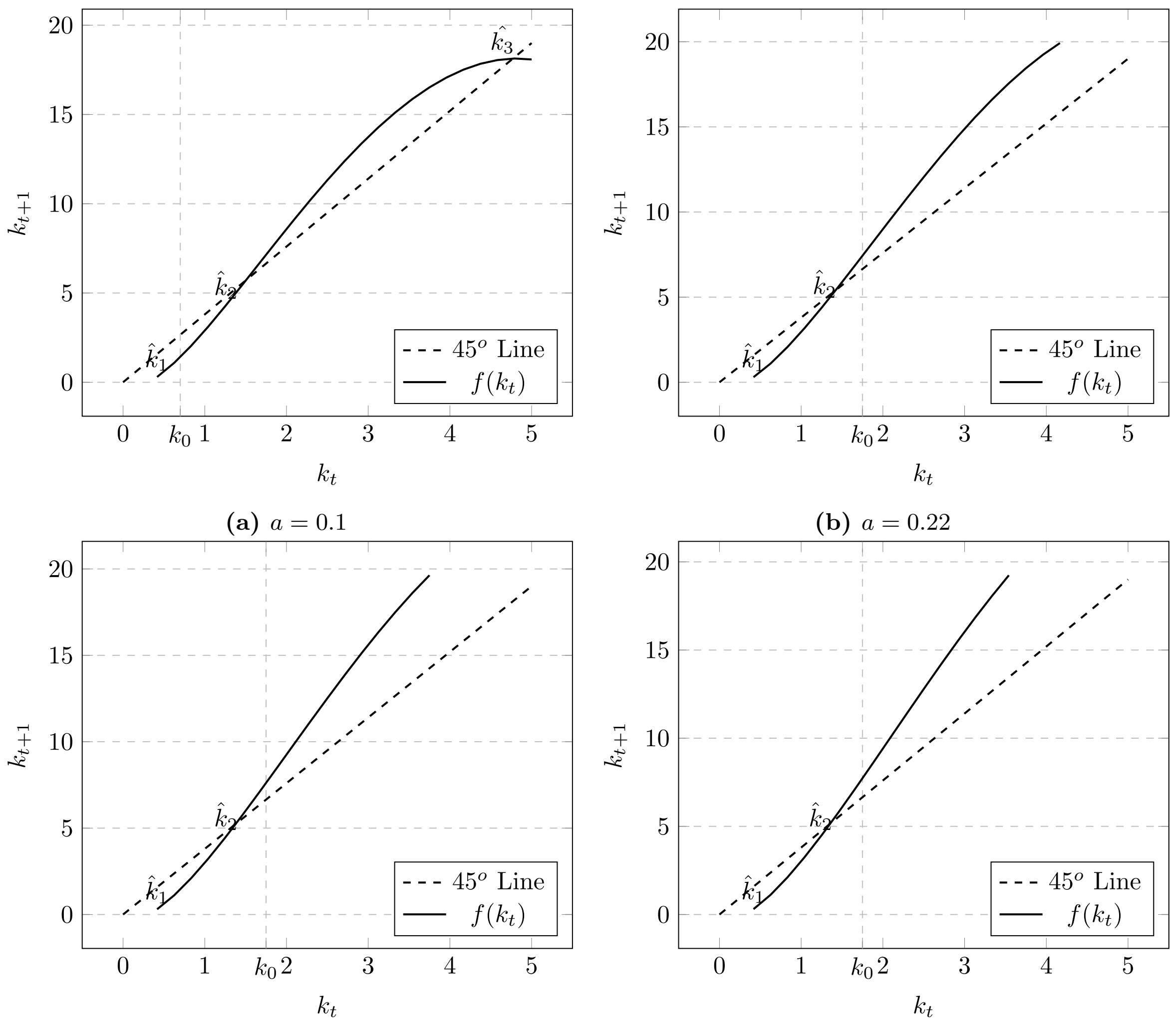
[11] The proposition 3, is relaxed in Appendix A.6.

[12] Proposition 4, is relaxed in Appendix A.7.

until the economy reaches a poverty trap. The country starts its economy at a relatively high capital endowment on the other hand will escape from the poverty trap and the permanent cycle, which I have described in proposition 2 when there is positive pollution abatement. Intuitively, high level of capital per worker causes high pollution while high pollution damages the health condition of the individual and mitigate the capital accumulation. With an active pollution abatement, the degradation of the natural environment will be reduced extensively. Along with the next period health improvement, capital accumulation will be continuously positive. Therefore a long run sustainable equilibrium exists.

2.3.3.1 Numeric results of dynamic equilibria with pollution abatement

Again, we can illustrate these propositions 3 and 4 by means of a simple numerical example by giving some values to all parameters same as in table 2.1 above, but this time, parameter a takes a very important role instead of λ. Given $\lambda = 0.56$,we have,



(a) $a = 0.1$

(b) $a = 0.22$

(c) $a = 0.26$

(d) $a = 1$

Figure 2.2: Numerical Results: With Pollution Abatement

Figure 2.2 (a) shows that if the pollution abatement is at 10% of the individual's income, the dynamics of capital accumulation starts to become monotonic again and $\hat{k_3}$ gets out of the negative slope part of $f(k_t)$. This implies that $\hat{k_3}$ starts to become a stable steady state equilibrium of the economy. As the pollution abatement reaches to 22%, there is only $\hat{k_2}$ exist and if the economy starts at a relatively low capital per worker, such as $k_0 < \hat{k_2}$, it will still converge to a poverty trap. However, at this time if the economy starts at a relatively high capital per worker, such as $k_0 > \hat{k_2}$, it is able to sustain a positive rate of economic growth in the long-run.

Again, intuitively, if the country starts economic development at a relative low capital endowment, its saving is not sufficient enough to guarantee a positive rate of capital accumulation. It will end up coverage to a poverty trap. The reduced pollution cannot be translated into improvements in the health characteristics of the population, since it has not satisfied the condition of $MBA \geq MCA$ which means poor. On the other hand, if an economy starts at a relatively high capital per worker, pollution abatement controls the extent of economic activity causing environmental damage. Thus, pollution abatement protects the population's health against the damage from environmental degradation and the saving behavior of workers is not interfered as the economy grows. A positive rate of capital accumulation is guaranteed eventually, and this allows the economy to achieve balanced growth as an equilibrium outcome. Furthermore, as the economy grows without bound, environmental quality approaches from above a constant level that is equal to the level of $E - \frac{\gamma}{a}$. For this to be positive it must be the case that $aE > \gamma$, which I have assumed in Lemma 2.

Figure 2.2 (c) depicts more pollution abatement shows faster growth of capital accumulation in the long run, but the growth almost same after $a = 0.26$ until $a = 1$. This implies that the pollution abatement investment, maximize the effect at 26% of an individual's income.

2.4 Allocation of Consumer's Pollution Abatement Choice

In this Section I analyses the case of optimal choice of an individual to choose her abatement investment. Since the Maximizing amount of abatement is extremely hard to calculate in section 2.2 by analyzing the individual's expected utility, I did the maximizing problem in the individual's health condition instead in this section. Accordingly, suppose that in every period an individual allocates her spending on abatement investment so as to maximize her health status, That is,

$$\underset{0 \leq a \leq 1}{Max} \left\{ h_t = (\tau A k_t)^c \Big(E - \frac{\gamma A k_t}{1 + a(1-\alpha) A k_t} \Big)^d \right\} \quad (2.40)$$

By choosing a and solving the above equation (40) we have,

$$a^* = \begin{cases} \frac{-1+E-\gamma A k_t}{(1-\alpha)A k_t}, & \text{if} k_t > \tilde{k} \\ 0, & \text{if} k_t \leq \tilde{k} \end{cases} \tag{2.41}$$

where $\tilde{k} = \frac{E-1}{\frac{\gamma A}{E}(1-\alpha)+\gamma A}$ by assuming $aE > \gamma$ is the threshold to choose pollution abatement for an individual.

The result from the equation (2.41) states that the individual will find it optimal to initiate its efforts towards environmental protection only at later stages of the economic development process.

As a result, there is a turning point exist between choosing or not choosing the pollution abatement. before this turning point the abatement decision $MBA \geq MCA$ is not held and also this implies that an individual is not rich enough and mostly likely will not interest in investing in the pollution abatement. Thus, under this situation, a country needs not to consider pollution abatement since the capital accumulation is not enough to cause too much pollution.

In contrast, if the capital per worker reaches and even past this turning point $\tilde{k}$, the abatement decision $MBA \geq MCA$ is held and implies that the return of the abatement will be positive or an individual reach a given level of consumption. Thus she starts to consider pollution abatement investment in order to maintain her health condition and long life expectancy. This therefore leads to a long-run sustainable equilibrium, since the capital accumulation is guaranteed all the time.

This complies with the hypothesis of Lieb (2004) who has considered that environmental protection as a luxury good. The idea is that in the early stage of the economic development process, the individual is not rich enough and unwilling to trade her consumption for environmental protection, and therefore the environmental quality declines as the development increases. Once the individual reaches a giving level of the consumption or income, she begins to consider longevity and demand the increase in investments in improving the environmental quality.

2.5 Other Important Implications

In section 2.3 I have illustrated that only if a country starts its economy with a relatively high capital per worker will eventually converge to the long-run equilibrium with the pollution abatement. Surprisingly, a country with a relatively low capital endowment always converges to a poverty trap no matter if there is an active pollution abatement or not. It makes sense when we come to think about that poor countries always start their economy at a lower level of capital and the savings are not large enough to ensure the capital accumulation for the next period under this situation. This scenario seems always valid in a developing country. According to my model, lower pollution ensures a higher quality of the health condition for individuals. On the other hand, lower pollution also implies a lower capital per worker and a lower production rate of the country. Since the country does not endow a rich capital at the beginning of the development, its capital per worker will never pass or even reach the turning point $\tilde{k}$. Therefore, the pollution abatement factor is ignored for its development, because it even doesn't have enough capital to create the pollution. Therefore, one significant implication from my analysis is given as,

Corollary 1. Poor countries who start at a low level of capital endowment cannot even afford pollution.

As a result, a poor country doesn't even have the power to create pollution, since their capital accumulation is too low, causing them to converge poverty trap all the time. It might be the case for it to gain enough capital accumulation first rather than considering a pollution abatement. There might be a solution to solve this problem. Delbosc and Perthuis (2009) pointed out that permit markets have been much easier to implement than taxes of the case of controlling green gas emission. They suggested that the participating countries may offset their excess emissions by buying permits from other countries that are willing to emit below their established cap. And now this idea is implementable around the world. This implies that if there is a compulsive agreement that forces pollution abatement internationally, such as the Kyoto Protocol,[13] the low polluted countries may benefit from it. They could trade their permits to the countries who need these, and therefore, earn capital accumulation for their own development.

For the countries starting with a relatively high capital per worker on the other hand, the survival rate in the long run, and the existing of the pollution abatement are both key factors to determine a long run equilibrium. Without a pollution abatement, the survival rate ϕ_t gets low after the turning point $\tilde{k}$ and the individual stays unhealthy, causing low productivity and low saving rate and, thus, the long run sustainable equilibrium cannot be reached. With pollution abatement, we can always keep the individual at a healthy level, even after the turning point $\tilde{k}$. Therefore, the long-run sustainable equilibrium is realized since there will be always a positive capital accumulation. Thus, the second important implication is,

[13]The Kyoto Protocol was adopted on Dec, 11, 1997 in Kyoto, Japan, and entered into force on Feb, 16, 2005. It is an agreement that sets binding obligations on industrialized countries to reduce emissions of greenhouse gases. The US signed but did not ratify it and Canada withdrew from it in 2011.

Corollary 2. Rich countries who start at a relatively high capital endowment, pollution abatement is the sufficient engine of the robust long-run economic growth.

By analyzing the above important implications, I found that the pollution abatement decision only works efficiently for richer countries. Since individuals are more productive toward to less pollution in the early development of the economy, they will produce more and create more pollution. Once when capital per worker passes a turning point $\tilde{k}$, individuals become rich enough and start to think about longevity, and thus invest in environmental protection. Pollution abatement helps to increase the quality of the environment and improve the individual's life expectancy and therefore, sustainable positive economic growth will be guaranteed.

There are many methods for the pollution abatement, Nordhaus D, William (2006), has made an argument that established two types of approaches: (i) the price type approach to climate change and (ii) the quantity approach to climate change and compared these these two types of the approaches. At last, he concluded that he would convey that a price-type approach to economic global public goods like global warming should be carefully considered. Also, Copeland, R, Brian and Taylor M, Scott (2004) pointed out that the international market creates links between the country pollution levels. They mentioned that this point of view generates important implications for explaining the EKC relationship. They treated an income effect as an explanation of the EKC relationship and stated that the rich countries could reduce their pollution, either by abating more or migrating their dirty industries to a poor country. They found that if the former approach for pollution abatement is the main driving force, then all countries could follow a similar path of EKC. However, if the latter approach for the pollution abatement is the main driving force, even if there is an EKC exists in rich countries, the newly industrialized countries may not experience a same situation as the current rich countries.

2.6 Further Discussion

Finally, we come as a conclusion. In this chapter, I have introduced a two-period OLG model to illustrate that an individual could get sickness under pollution with probabilities and analyzed that how important is individual's health to affect the long-run equilibrium for an economy. By testing the relationship between health and economic growth, I inserted the health factor which depends on the public health services and the pollution abatement into the OLG growth model. The public health service takes a tax form charged by the government on firms, whereas the pollution abatement is an optional investment for an individual. An individual who gets sick under pollution has a lower productivity than a healthy individual, causing her savings decline, since she may not live until her old age. By analyzing the individual's optimal choice between choosing pollution abatement investment and other consumption goods, I constructed that the optimal condition exists when the marginal benefit of abatement is greater or equal than the marginal cost of the abatement. There are two implications under this optimal condition: (i) an individual will only invest in environmental protection only if the abatement investment generates positive returns and (ii) an individual will only invest in this environmental protection only if she reaches a giving level of consumption. This totally matches with the ideas of Lieb (2004) who has categorized that the environmental protection as a luxury good.

By doing dynamic analysis, I found that the pollution abatement is not a key factor for a poor country to reach a long-run equilibrium, since it has a low capital endowment in the beginning of the economic. In contrast, a rich country starting its economy at a relatively high capital endowment, with an active pollution abatement combined with the condition $MBA \geq MBC$, it will eventually reach a long-run sustainable equilibrium. Otherwise it converges to a long-run equilibrium with zero growth rate or a permanent cycle around one level of steady state.

In section 2.4. I found the optimal level of pollution abatement as a proportion of the individual's income by considering choosing it to maximize health condition h_t and this only exist if capital per worker k_t is greater than some turning point $\tilde{k}$. otherwise the pollution abatement will be not considered. The result states that the society will find it optimal to initiate its efforts towards environmental preservation only at later stages of its development process. Again, this implies that the return of abatement investment negative or the individual is not rich enough before this turning point. Therefore, the pollution abatement will not prevail before this turning point. This is again hit the ideas of Lieb (2004).

At last I found some other important implications from my model in this chapter. The poor country starting its economy at a low capital per worker cannot afford pollution and will converge to a poverty trap. The key effort of it to get out of this poverty trap is capital accumulation first rather than a pollution abatement. On the other hand, a rich country starting at a high capital per worker, the pollution abatement is the sufficient engine to guarantee a long-run robust economic growth.

Pollution damages our lifespan around the world, but it is also an indicator of economic development. In order for the economic growth, countries need to produce goods and release pollution emissions. Therefore, there exists a turning point $\tilde{k}$ of economic growth with respect to the decision of pollution. Before this point, people need to produce and not consider about pollution abatement, in order to reach some level of standard livings first. However, after this point, people need to consider pollution abatement to protect their health conditions which will lead the economy to reach sustainable long-run equilibrium.

2.7 Bibliography

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Chapter 3

The Environmental Pressure and Economic Development Based on Environmental Kuznets Curve Hypothesis: Evidence from China

3.1 Background

In light of recent events in frequent air quality alerts in Beijing, it is becoming extremely difficult to ignore the existence of pollution in China. Since the reform and opening-up policy, China's economy has grown in a sustainable and fast pace. However, the traditional economic growth framework with high productions, high consumption, and high investments cause high pollution emissions which lead to a growing contradiction between China's economic growth and environment. It is true that the fast economic expansions will cause pollution and increase the degradation of the natural environment. Peng (2006) pointed out that along with industrialization and urbanization, the social economy develops in an unparalleled speed, while it inevitably increases the consumption of natural resources and the pressure to protect ecological environment. That is the exploitation of natural resources makes emissions of industrial pollutants increases and finally leads to environmental quality degradation.

A number of cross-sectional studies suggest an association between pollution and economic growth by analyzing a EKC[1] relationship. Grossman and Krueger (1991) reported that there is an inverted-U relationship between environmental quality and economic growth in long-run. The phenomenon has

[1]Explained its definition and background in Chapter 2.

been labeled as Environmental Kuznets Curve (EKC) by Panayotou (1993) base on Kuznets behavior[2]. There are two main explanations for rationalizing the EKC relationship. First,(Lieb, 2004) treated the Kuznets behavior as an income effect since he categorized the environmental quality protection as a luxury good. It is easy to understand that in the early stage of the economic development process, people are not rich enough and unwilling to trade their consumption for investment in environmental protection, and therefore the environmental quality declines as the development extends. Once people reach a given level of the consumption or income, they begin to consider longevity and increase in the demand of investments in environmental protections. Second, the Kuzents behavior is the expression of the stages of economic growth, since the economics has to make a transition from agriculture-based to industry-based and then post-industrial-based to service-based stages (Baldwin, 1995). It is clear that the transition from the agricultural-based economy to the industrial-based economy results a huge increase in the environmental degradation since the massive production and the consumption growth need to release a significant amount of the pollution emissions. The transition from the post-industrial-based economy to a service-based economy instead results in decreasing environment degradation since there aren't many industrialized activities under service-based economy.

Therefore, Whether there is an inverted-U shape EKC relationship between China's national income per capita and pollution pressure is an increasingly important area in applied economics of policy makers in China. If there is an inverted-U shape EKC relationship between China's national income per capita and pollution pressure, the government of China needs to balance the economic growth and pollution level in an intimidate way. If the Inverted-U EKC relationship does not exist which implies that the turning point of national income per capital has not been reached, then polluting first and improving afterward in China will be the main policy for the Chinese government to use for its economic growth.

A series of empirical studies about EKC relationship have been released. Again, Grossman and krueger (1991), studied the relationship between economic growth and environmental quality in 42 countries based on the North American Free Trade Agreement. This paper is the first study on the relationship between environment pollution and economic growth based on the EKC hypothesis. Their results indicated a relationship of inverted U-shaped EKC curve between average income and environmental pollution. Most of the empirical studies are based on multi-countries, but cross-section analysis assumes that all cross-section countries react identically regardless their different income level, geographical conditions,culture and history (Dijkgraaf and Vollebergh, 1998; Hill and Magnani, 2002; etc).Therefore, recently, some researchers tested the EKC relationship within an individual country (Firedel and Getzner, 2003; De Bruyn, 2000; Lekkakis, 2000; Stern and Common, 2001; etc). In fact, besides income per capita, pollution pressures are affected also by other variables, such as Industry's

[2]Explained its definition and background in Chapter 2.

structures of a country. Surprisingly, no previous study has investigated the relationship between pollution and different industry structures. In this chapter, I attempt to defend the view that we can generate more implications by testing the industry structures rather than GDP per capita. Simply, I switch income per capita to the added values of three different industry structures in China from the original EKC model and test how they are related with pollution emissions.

In addition, pollution pressure is hard to be defined since it contains many type of pollutants and different pollutants hurt environment quality at a different level. That's why Most studies in the field of testing EKC relationship have only focused on one pollutant or several pollutants separately (Grossman and Krueger, 1991; Firedel and Getzner, 2003; De Bruyn, 2000; Lekkakis, 2000; Stern and Common, 2001; suri and Chapman, 1998; Kaufmann et al, 1998; Torras and Boyce, 1998; Chen, 2007; Wen and Cao, 2009; etc). Such approaches, however, have failed to address how economic growth relates with pollution emissions, because the results are varied from different pollutants. Regarding this drawback, this paper introduces the Principal Component Analysis (PCA [3]) to generate a general pollution emission index based on 7 main pollutants in China and test the relationship between this index and other explanatory variables.

The rest of the chapter is structured as follows. Section 2 Methodology of generating pollution emissions index. A data information is given in Section 3. In section 4 I build an econometric model to test the relationship between China's pollution emission index and added values of three industrial structures. Estimation results and analysis are presented in section 5. Section 6 Suggestions and further discussion.

3.2 Principal Component Analysis for Creating Pollution Emission Index

Considering that there are many pollutants exist in the real world, the meaning of pollution becomes ambiguous when we define it just by one pollutant. For many years, this phenomenon was surprisingly neglected by other researchers, especially for economists to test the EKC relationship. Normally, they chose one pollutant or several pollutants separately. This paper proposes a new methodology of PCA method to generate an index, which reviews an overall performance of several pollutants together, and it is the first paper to create a pollution emission index (PEI) which contains better explanations than just single pollutant. The success of this innovation will devote a huge contribution to the future studies in the filed,since the benefit of this approach is that it can remove the inconsistencies of single pollutant analysis. Principal component analysis (PCA) is a technique from statistics for simplifying a

[3] Principal component analysis is a statistical procedure was invented in 1901 by Karl Pearson. It is mostly used as a tool in exploratory data analysis and for making predictive models and creating an index.

data set. It was developed by Pearson (1901) and Hotelling (1993), and also,the best modern reference is Joliffe (2002). The function or aim of this method is to reduce the dimensionality of multi-variate data while also preserves as much of the relevant information as possible. The procedures of this statistical calculation show as follows:

Step 1. Standardize the variables:

Suppose n independent observations are taken on each $X_1, X_2, ..., Xp$. It implies that there are p dimension vectors and each dimension has n different variables. Therefore the original data can be established as a $n \times p$ matrix and where $X_{n\times p} = (x_{ij})_{n\times p}$, such as,

$$X_{n\times p} = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{n\times p} \end{pmatrix} = (X_1 \;\; X_2 \;\; X_3 \;\; \cdots X_p) = \begin{pmatrix} X_1^T \\ X_2^T \\ \vdots \\ X_P^T \end{pmatrix}$$

Since by analyzing the raw data directly, we will tend to find that the results give more emphasis to those variables that have higher variances than those variables that have very low variance. In fact, the results of the analysis will depend on the measurement that used to measure each variable. This implies that a PCA should only be used with the raw data if all variables have the same unit of measurement and even in this case, only if you wish to give those variables who have higher variances more weight in the analysis. On the other hand, if the variables either have different units of measurement, or if we wish to receive equal weight for each variable in the analysis, we should standardize the variables before a PCA is carried out (Smith, 2002). We do this standardization by using the following equation:

$$Z_{ij} = \frac{X_{ij} - \bar{x}_j}{s_j}, \qquad i = 1, 2, \cdots, n; \;\; j = 1, 2 \cdots, p \qquad (3.1)$$

where,

X_{ij}=Data for variable j in sample unit i

$\bar{x}_j$=Sample mean for variable j

s_j=Sample standard deviation for variable j.

Step 2. Calculating variance co-variance matrix:

After standardizing the data set, we will calculate the variance co-variance matrix for Z. Note that, the variance co-variance matrix of the standardized data is equal to the correlation matrix for the standardized data. Therefore, PCA using the standardized data is equivalent to PCA using the correlation matrix of standardized data. The variance co-variance can be calculated by following equation:

$$\Sigma = \frac{1}{N-1} Z^T Z \qquad (3.2)$$

where Σ is the variance co-variance matrix such as,

$$\Sigma = \begin{pmatrix} \sigma_1^2 & \sigma_{12} & \cdots & \sigma_{1p} \\ \sigma_{21} & \sigma_2^2 & \cdots & \sigma_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{p1} & \sigma_{p2} & \cdots & \sigma_p^2 \end{pmatrix}$$

Step 3. Computing eigenvectors and eigenvalues of the variance co-variance matrix:
In order to find the coefficients for a principal component, we need to solve the eigenvalues and eigenvectors of the variance co-variance matrix Σ. Eigenvectors can only be found from square matrices and not every square matrix has eigenvectors. Given an $n \times n$ matrix that does have eigenvectors, there are n of them. All the eigenvectors of a matrix are perpendicular. It means that at the right angle to each other, no matter how many dimension you have. This implies that we can express the data in terms of perpendicular eigenvectors, instead of expressing them respect x and y axes (Smith, 2002). Let λ_1 through λ_p denote the eigenvalues and let e_1 through e_p denote the eigenvectors of the variance co-variance matrix Σ, such that,

$$\Sigma e = \lambda e \qquad (3.3)$$ [4]

We want to find the egenvectors whose length is exactly one, so that, $e_j^T e_j = 1$. This is because whether it is an eigenvector or not, it is not affected by the length of a vector while the direction does. Therefore, whenever we find an eigenvector we usually scale it and make it have a length of 1, in order to keep eigenvectors standard, so that all eigenvectors have the same length (Sayad, 2010). These eigenvalues are ordered, so thatλ_1 has the largest eigenvalue and λ_p is the smallest, such that,

$$\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p$$

[4] Example:

$$\begin{pmatrix} 2 & 3 \\ 2 & 1 \end{pmatrix} \begin{pmatrix} 3 \\ 2 \end{pmatrix} = \begin{pmatrix} 12 \\ 8 \end{pmatrix} = 4 \begin{pmatrix} 3 \\ 2 \end{pmatrix}$$

where 4 is the eigenvalue and $\begin{pmatrix} 3 \\ 2 \end{pmatrix}$ is the eigenvector.

and also let the eigenvectors e_1 through e_p, such as,

$$e_1, e_2, \cdots, e_p$$

Therefore, we can find the proportion of variation explained by j th component by using following formula:

$$b_j = \frac{\lambda_j}{\sum_{j=1}^{p} \lambda_j}, \qquad j = 1, 2 \cdots, p \qquad (3.4)$$

Therefore,

$$\frac{\sum_{j=1}^{m} \lambda_j}{\sum_{j=1}^{p} \lambda_j} = \frac{\lambda_1 + \lambda_2 + \cdots + \lambda_m}{\lambda_1 + \lambda_2 + \cdots + \lambda_p} \qquad (3.5)$$

calculates the accumulative proportions of variation of first m principal components, where $\lambda_1 + \lambda_2 + \cdots + \lambda_p$ equals $trace(\Sigma)$[5].

Step 4. Determining the principal components and the coefficients:
Consider the linear combinations,

$$\begin{aligned}
Y_1 &= a_{11}Z_1 + a_{12}Z_2 + \cdots + a_{1p}Z_p \\
Y_2 &= a_{21}Z_1 + a_{22}Z_2 + \cdots + a_{2p}Z_p \\
&\vdots \\
Y_p &= a_{p1}Z_1 + a_{p2}Z_2 + \cdots + a_{pp}Z_p
\end{aligned}$$

Each of these can be thought of as a linear regression, predicting Y_i from Z_1,Z_2,$\cdots$,Z_p,where Y_1 through Y_p are the principal components from 1 to p and $a_1 1$,$a_1 2$,$\cdots$,$a_i p$ are regression coefficients and there is no intercept. Note that Y_i is a function of our random data, and so it is also random. Therefore, it has a population variance as,

$$Var(Y_i) = \sum_{k=1}^{p} \sum_{l=1}^{p} a_{ik} a_{il} \sigma_{kl} = a_i' \Sigma a_i \qquad (3.6)$$

Moreover, Y_i and Y_j will have a population covariance as,

$$Cov(Y_i, Y_j) = \sum_{k=1}^{p} \sum_{l=1}^{p} a_{ik} a_{jl} \sigma_{kl} = a_i' \Sigma a_j \qquad (3.7)$$

[5] $trace(\Sigma) = \sigma_1^2 + \sigma_2^2 + \cdots + \sigma_p^2 = \lambda_1 + \lambda_2 + \cdots + \lambda_p$

Here the coefficients a_{ij} are collected into the vector,

$$a_i = \begin{pmatrix} a_{i1} \\ a_{i2} \\ \vdots \\ a_{ip} \end{pmatrix}$$

The first principal component is the linear combination of Z-variables that has maximum variance among all linear combinations, so it accounts for as much variation in the data as possible. Specially we will define coefficients $a_{11}, a_{12}, \cdots, a_{1P}$ for that component in such a way that its variance is maximized. We need to subject the variance constraint to the sum of the squared coefficients which equals to one. This constraint is required so that a unique answer may be obtained. Formally, we select a_{11}, a_{12},$\cdots$, a_{1p} that maximizes,

$$Var(Y_1) = \sum_{k=1}^{p} \sum_{l=1}^{p} a_{1k} a_{1l} \sigma_{kl} = a_1' \Sigma a_1 = \lambda_1 \qquad (3.8)$$

subject to the constraint that

$$a_1' a_1 = \sum_{j=1}^{p} a_{1j}^2 = 1 \qquad (3.9)$$

After solving the maximization problem from equations (3.8)and (3.9), we find that the solution of the coefficients which satisfies the condition are just the eigenvector, e_1. Therefore, we take $a_1 = e_1$. That means that first component will be,

$$Y_1 = e_{11} Z_1 + e_{12} Z_2 + \cdots + e_{1p} Z_p = \sum_{j=1}^{p} e_{1j} Z_j \qquad (3.10)$$

Where Y_1 has the largest variance among all linear combinations of the Z's.

The second principal component is the linear combination of Z variables that accounts for as much of the remaining variation as possible. With the constraint, we will see that the correlation between the first and the second component is 0. Again,we select a_{21},a_{22},$\cdots$,a_{2p} that maximizes the variance of this new component, such as,

$$Var(Y_2) = \sum_{k=1}^{p} \sum_{l=1}^{p} a_{2k} a_{2l} \sigma_{kl} = a_2' \Sigma a_2 = \lambda_2 \qquad (3.11)$$

subject to the constraint where the sums of squared coefficients add to one,

$$a_2'a_2 = \sum_{j=1}^{p} a_{2j}^2 = 1 \qquad (3.12)$$

along with the additional constraint that first component and second component are not correlated with one another,

$$Cov(Y_1, Y_2) = \sum_{k=1}^{p}\sum_{l=1}^{p} a_{1k}a_{2l}\sigma_{kl} = a_1'\Sigma a_2 = 0 \qquad (3.13)$$

Again, After solving the maximization problem through equations (3.11)to(3.13), we will find that the solution of the coefficients satisfies the condition are just the eigenvector, e_2. Therefore, we take $a_1 = e_2$. That means that second component will be,

$$Y_2 = e_{21}Z_1 + e_{22}Z_2 + \cdots + e_{2p}Z_p = \sum_{j=1}^{p} e_{2j}Z_j \qquad (3.14)$$

where Y_2 has the largest variance among all linear combinations of the Z's which are orthogonal to Y_1. As a result, all subsequent principal components have this same property where they are linear combinations that account for as much of the remaining variation as possible and they are uncorrelated with other principal components. Therefore the ith principal component Y_i can be defined using same method. Similarly, we select a_{i1}, a_{12},$\cdots$, a_{ip} that maximizes,

$$Var(Y_i) = \sum_{k=1}^{p}\sum_{l=1}^{p} a_{ik}a_{il}\sigma_{kl} = a_i'\Sigma a_i = \lambda_i \qquad (3.15)$$

subject to the constraint of variance for the ith component that the sums of squared coefficients add up to one,

$$a_i'a_i = \sum_{j=1}^{p} a_{ij}^2 = 1 \qquad (3.16)$$

along with the additional constraint that the new component will be not correlated with all the previously defined principal components,

$$\begin{aligned}
Cov(Y_1, Y_i) &= \sum_{k=1}^{p}\sum_{l=1}^{p} a_{1k}a_{il}\sigma_{kl} = a_1'\Sigma a_i = 0,\\
Cov(Y_2, Y_i) &= \sum_{k=1}^{p}\sum_{l=1}^{p} a_{2k}a_{il}\sigma_{kl} = a_2'\Sigma a_i = 0,\\
&\vdots\\
Cov(Y_{i-1}, Y_i) &= \sum_{k=1}^{p}\sum_{l=1}^{p} a_{i-1,k}a_{il}\sigma_{kl} = a_{i-1}'\Sigma a_i = 0 \qquad (3.17)
\end{aligned}$$

Similarly, we will find that the solution of the coefficients satisfies the condition are just the ith eigenvector, e_i. Therefore, we take $a_i = e_i$. we have the ith component as,

$$Y_i = e_{i1}Z_1 + e_{i2}Z_2 + \cdots + e_{ip}Z_p = \sum_{j=1}^{p} e_{ij}Z_j \qquad (3.18)$$

where Y_i is the linear combination of the Z's, which has largest variance, subject to the constraint that Y_p is uncorrelated with Y_1, Y_2,$\cdots$,Y_{i-1}.

Note that all of these calculations are defined in terms of the population variance-covariance matrix Σ which is unknown.However, we may estimate Σ from sample variance-covariance, S, which can be calculated by a given standard formula,

$$S = \frac{1}{n-1}(Z_i - \bar{z})(Z_i - \bar{z})' \qquad (3.19)$$

Further, computing the eigenvalues $\hat{\lambda}_1$,$\hat{\lambda}_2$,$\cdots$,$\hat{\lambda}_p$, of the sample variance-covariance matrix S, and the corresponding eigenvectors $\hat{e_1}$,$\hat{e_2}$, $\cdots$, $\hat{e_p}$. Then we will define our estimated principal components using the eigenvectors as our coefficients as,

$$\begin{aligned}
\hat{Y_1} &= \hat{e_{11}}Z_1 + \hat{e_{12}}Z_2 + \cdots + \hat{e_{1p}}Z_p \\
\hat{Y_2} &= \hat{e_{21}}Z_1 + \hat{e_{22}}Z_2 + \cdots + \hat{e_{2p}}Z_p \\
&\vdots \\
\hat{Y_p} &= \hat{e_{p1}}Z_1 + \hat{e_{p2}}Z_2 + \cdots + \hat{e_{pp}}Z_p
\end{aligned}$$

Generally, in order to reduced the dimensionality, we only retain the first m principal components and need to balance two conflicting desires:
1. We want m to be as small as possible in order to obtain the simplest possible interpretation. If we can explain the most of the variation just by first two or three principal components, this would give us a much simpler description of the data.
2. We want the proportion of variation explained by the first m principal components to be large in order to avoid loss of information. Ideally, as close to one as possible (Smith, 2002), such as,

$$\frac{\hat{\lambda_1} + \hat{\lambda_2} + \cdots + \hat{\lambda_m}}{\hat{\lambda_1} + \hat{\lambda_2} + \cdots + \hat{\lambda_p}} \simeq 1 \qquad (3.20)$$

Step 5. Choosing components and generating index:

If m components have been chosen from p principal components, such as, Y_1, Y_2,$\cdots$,Y_m, we can compute the comprehensive evaluation index taking every principal component Y_i's proportion of variation b_i as a coefficient by using the following equation:

$$Y = b_1 Y_1 + b_2 Y_2 + \cdots + b_m Y_m \qquad (3.21)$$

We calculate all principal components at first place and arrange them from high to low based their proportion of variations. Then we choose first m components which are accounted for the most proportion of the variation for explaining the data set and plug them into the above equation (3.21) to create the general index. Where $b_i = \frac{\lambda_i}{\lambda_1+\lambda_2+\cdots+\lambda_m}$.

3.3 Data Information

3.3.1 Data Set for Creating Pollution Emission Index

According to the drawback of using one single pollutant as a pollution indicator, I have collected 7 different pollutants' data: CO_2 emission, SO_2 emission, Other waste gas emissions, Industrial waste water, Industrial soot, Industrial dust and solid waste of China's 30 provinces from 1998 to 2012 respectively. As a result, I can create a pollution index based on these 7 pollutants by using the PCA method mentioned above. The data of all 7 pollutants is coming from China Statistical Yearbook 1999 to 2013. Many researchers have done relative studies by using just one pollutant or several pollutants separately. Li (2011) studied the relationship between carbon emissions per capita and GDP per capita of high-emission regions, low-emission regions and medium-emission regions of China from 1995 to 2009 based on the EKC model. He concluded a N-shaped EKC curve among all three regions. Wen and Cao (2009) tested the relationship between China's GDP per capita and 4 different pollutants: waste water emission per capita, waste gas emission per capita, SO_2 emission per capita and solid waste emission per capita separately. They found a different relationship reviews a different shape of curve from these 4 pollutants. Therefore, taking only one pollutant as pollution indicator creates an inconsistent and unpersuasive result for this topic. Therefore, A major advantage of PCA generating a pollution index based on several different pollutants will conquer this problem and make the result more realistic. This chapter is the first paper to use PCA method to create a pollution index under the research of studying the EKC relationship. It is never done from the previous studies. The summary table of these 7 pollutants show as in Table 3.1.

The 7 pollutants almost covered all pollutants' information collected from the China's year book

Table 3.1: Summary table of 7 pollutants (Per Capita)

Pollutants ($10,000$ Tons)	Number of Obs	Mean	Std Dev	Min	Max
CO_2 Emission per capita	450	5.459	3.939	0.492	31.387
SO_2 Emission per capita	450	0.018	0.012	0.002	0.064
Other Waste Gas Emission per capita	450	26639.040	26693.300	4157.562	257866.500
Waste Water Emission per capita	450	16.762	9.393	3.252	61.489
Industrial Soot Emission per capita	450	0.007	0.005	0.001	0.041
Industrial Dust Emission per capita	450	0.006	0.004	0.0003	0.031
Solid Waste Emission per capita	450	0.018	0.044	$6.33e-08$	0.544

from 1999 to 2013 and NBS[6] of China. The pollutant *Otherwastegas* emission per capita contains all other gas emission information except CO_2 Emission and SO_2 Emission. These 7 pollutants together are strong enough and able to explain China's pollution pressure.

3.3.2 Generating Pollution Emission Index By PCA

After collecting the 7 pollutants, we can perform the PCA method to compute the pollution emission index by following the steps which I have described in section 2. After standardizing the each variable, we get the following variance co-variance matrix in Table 3.2.

Table 3.2: Variance co-variance matrix

	co_2	so_2	owg	ww	$isoot$	$idust$	sw
co_2	1.0000	0.5324**	0.8728**	0.1895**	0.0846	-0.2982**	-0.2563**
Sig (2-tailed)	.	0.0000	0.0000	0.0001	0.0729	0.0000	0.0000
N	450	450	450	450	450	450	450
so_2	0.5324**	1.0000	0.6274**	0.1915**	0.5652**	0.3184**	0.3188**
Sig (2-tailed)	0.0000	.	0.0000	0.0000	0.0000	0.0000	0.0000
N	450	450	450	450	450	450	450
owg	0.8728**	0.6274**	1.0000	0.2703**	0.1822**	-0.1552**	-0.2067**
Sig (2-tailed)	0.0000	0.0000	.	0.0000	0.0001	0.0010	0.0000
N	450	450	450	450	450	450	450
ww	0.1895**	0.1915**	0.2703**	1.0000	0.0827	0.0439	-0.1941**
Sig (2-tailed)	0.0001	0.0000	0.0000	.	0.0796	0.3524	0.0000
N	450	450	450	450	450	450	450
$isoot$	0.0846	0.5652**	0.1822**	0.0827	1.0000	0.6730**	0.4453**
Sig (2-tailed)	0.0729	0.0000	0.0001	0.0796	.	0.0000	0.0000
N	450	450	450	450	450	450	450
$idust$	-0.2982**	0.3184**	-0.1552**	0.0439	0.6730**	1.0000	0.5877**
Sig (2-tailed)	0.0000	0.0000	0.0010	0.3524	0.0000	.	0.0000
N	450	450	450	450	450	450	450
sw	-0.2563**	0.3188**	-0.2067**	-0.1941**	0.4453**	0.5877**	1.0000
Sig (2-tailed)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	.
N	450	450	450	450	450	450	450

**. correlation is significant at the 0.01 level (2-tailed)

[6]NBS: Nation Bureau of Statistics

As what we expected in Table 3.2, the co_2 emission is more correlated with other waste gas emission and so_2 emission. Waste water emission is more correlated with other waste gas emission but not that strong. Both industrial soot emission and industrial dust emission are highly correlated with solid waste emission and so_2 emission and each other. By finding this variance co-variance matrix showing in Table 3.2, we can further to proceed the PCA method in order to find all its eigenvalues and proportion of explained variance in Table 3.3.

Table 3.3: Total variance explained

Components	Initial Eigenvalues			Extraction Sums of Squared Loading		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.5377	0.5054	0.5054	3.5377	0.5054	0.5054
2	1.86496	0.2664	0.7718	1.86496	0.2664	0.7718
3	.708083	0.1012	0.8730	.708083	0.1012	0.8730
4	.433981	0.0620	0.9350			
5	.203526	0.0291	0.9640			
6	.175611	0.0251	0.9891			
7	.0761345	0.0109	1.0000			

Extraction Method: Principal Component Analysis.

Table 3.3 lists the eigenvalues of the correlation matrix, ordered from largest to smallest. The eigenvalues add up to the sum of the variances of the variables in the analysis: the total variance of the variables. The variables are standardized to have unit variance since we are analyzing a correlation matrix. Therefore, the total variance is 7 or $trace(\Sigma) = 7$. The eigenvalues are the variances of the principal components. The first principal component has variance 3.5377 and it explains 51% (3.5377/7) of the total variance. The second principal component has a variance of 1.86496 and it explains about 27% (1.86496/7) of the total variance and so on so forth for the rest principal components. All 7 principal components together explain all variance in all variables and therefore the cumulative % is 100% at the 7th principal component, meaning zero percentage left in explanation. As a consequence, the first three principal components explain about 87% of the variation which is more than 85% explanations. This is an acceptably large percentage. An alternative method to determine the number of principal components is to look at a scree plot. Since the eigenvalues are ordered from largest to the smallest, a scree plot is the plot that describes the relationship between the eigenvalues $\hat{\lambda}_i$ and the component number i. The number of components is determined by the point, beyond which the remaining eigenvalues are all relatively small and of comparable size.

In Figure 3.1, we can see that the first three principal components will be selected since there is a break or sharp drop from principal components one to three. As a result first three principal components will be selected for creating the pollution emission index. The initial and selected eigenvectors or component score coefficients can be shown in Table 3.4.

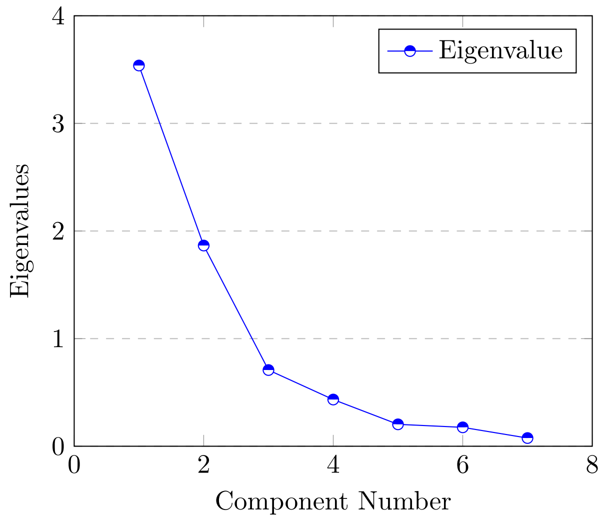


Figure 3.1: Scree Plot of Eigenvalues after PCA

Table 3.4: Component Score Coefficient Matrix

Variables	Initial Components								Extraction of Components			
	1	2	3	4	5	6	7	Unexplained	1	2	3	Unexplained
co_2	0.4288	-0.3666	0.2614	-0.0237	0.1614	-0.0495	0.7644	0	0.4288	-0.3666	0.2614	.05046
so_2	0.4845	0.0029	0.1149	-0.2286	-0.7709	0.2956	-0.1349	0	0.4845	0.0029	0.1149	.1604
owg	0.4244	-0.3347	0.3350	-0.0329	0.4667	0.0922	-0.6068	0	0.4244	-0.3347	0.3350	.07433
ww	0.3825	-0.1527	-0.5532	0.7108	-0.0777	-0.0935	-0.0662	0	0.3825	-0.1527	-0.5532	.2224
isoot	0.3786	0.4435	0.0210	-0.1999	0.0130	-0.7842	-0.0666	0	0.3786	0.4435	0.0210	.1257
idust	0.3252	0.4418	-0.4549	-0.3177	0.3918	0.4718	0.1229	0	0.3252	0.4418	-0.4549	.1153
sw	0.0769	0.5817	0.5412	0.5476	0.0462	0.2355	0.0733	0	0.0769	0.5817	0.5412	.1407

Extraction Method: Principal Component Analysis.

The "Initial Components" block shows the corresponding eigenvectors in above table 3.4. These are 7 principal components in total and have unit length, which the column-wise sum of the squares of the loading is 1.[7] In addition, principal components are uncorrelated.[8] As a result, all the principal components together explain all variances for all variables, and therefore, the unexplained variation listed in the last column of the "Initial Components" block are all zeros. The first three principal components, shows at "Extraction of Components" block in table 3.4 are selected principal components from analysis and more than 85% variances are explained by them. These three components do not contain all information in the data, and therefore some of the variances in the variables are unexplained or unaccounted for. These unexplained variances equal the sums of squares of the loadings in the deleted components, weighted by the associated eigenvalues. The unaccounted variances in all variables are with similar order. The average unexplained variance is equal to the overall unexplained variance of 12.7%[9].

The first component has positive loadings of roughly equal size for all variables, except *sw*. This can be interpreted as the overall effects of all pollutants on environmental degradation. The second principal component has positive loadings on variables, so_2, *isoot*, *idust* and *sw* and negative loadings for the variables of co_2, *owg* and *ww*. Thus the second principal component distinguishes the effects on environmental degradation between co_2, *owg*, *ww* and other variables. The third principal component similarly differentiates the effect of environmental degradation for the variables of *ww*, *idust* versus the other rest of the variables. As a result, according to the component score coefficient matrix of extracted component we can find the first component score, $\hat{Y}_1$; the second component score, $\hat{Y}_2$ and

[7] According to the equation (16) in section 2 we can check that:

$$0.4288^2 + 0.4845^2 + \cdots + 0.0769^2 = 1$$
$$(-0.3666)^2 + 0.0029^2 + \cdots + 0.5817^2 = 1$$
$$\vdots$$
$$0.7644^2 + (-0.1349)^2 + \cdots + 0.0733^2 = 1$$

[8] According to the equation (13) in section 2 we may check that:

$$0.4288(-0.3666) + 0.4845(0.0029) + \cdots + 0.0769(0.5817) = 0$$
$$0.4845(0.2614) + 0.4845(0.1149) + \cdots + 0.0769(0.5412) = 0$$
$$\vdots$$
$$-0.0495(0.7644) + 0.2956(-0.1349) + \cdots + 0.2355(0.0733) = 0$$

[9] $1 - 0.873 = 0.127 = 12.7\%$

the third component score, $\hat{Y_3}$ as,

$$\hat{Y_1} = 0.4288co_2 + 0.4845so_2 + 0.4244owg + 0.3825ww$$
$$+0.3786isoot + 0.3252idust + 0.0769sw \quad (3.22)$$
$$\hat{Y_2} = -0.3666co_2 + 0.0029so_2 - 0.3347owg - 0.1527ww$$
$$+0.4435isoot + 0.4418idust + 0.5817sw \quad (3.23)$$
$$\hat{Y_3} = 0.2614co_2 + 0.1149so_2 + 0.3350owg - 0.5532ww$$
$$+0.0210isoot - 0.4549idust + 0.5412sw \quad (3.24)$$

From equation (3.22) to (3.24) together with equation (21) we can find our Pollution Emission Index (PEI) in per capita level as,

$$PEI = \hat{Y} = (\frac{0.5054}{0.873})Y_1 + (\frac{0.2664}{0.873})Y_2 + (\frac{0.1012}{0.873})Y_3 \quad (3.25)$$

As a consequence, the pollution emission index is generated by using above equation (3.25). The summary table of this new variable is described below in Table 3.5.

Table 3.5: PEI summary table (Per Capita)

variable	Number of Obs	Mean	Std Dev	Min	Max
PEI	450	18.17547	16.8725	.5972482	102.7444

Extraction Method: Principal Component Analysis.

In addition, in order to distinguish the PEI level for each province from 1998 to 2013, we can describe the above summary in Figure 3.2.

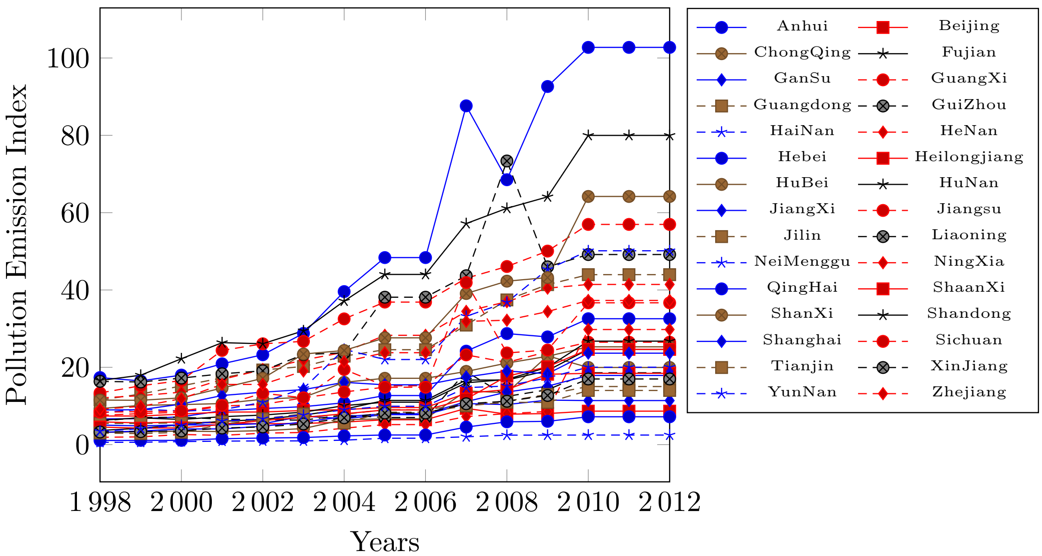


Figure 3.2: PEI Report Across 30 Provinces of China.

Based on Figure 3.2, pollution pressures represent an upward trend across provinces from 1998 to 2012 in China. Among provinces, Heibei, Shandong, Liaoning, Neimenggu and Jiangsu provinces generate much more pollution than other provinces. This is make sense since those provinces are involving much more industrialization activities activities. Moreover, Hebei province has the highest slope among all provinces. This indicate that the pollution pressure is growing faster in Hebei province than other provinces. Again this is due to the huge industrialization activities under Hebei province.

3.3.3 Other Variable Data Information

The data of total population for each province of China is collected from the Department of Population and Employment Statistics of NBS[10], China population and employment statistics yearbook from 1999 to 2013. The data of GDP of each province in China are collected from China statistical yearbook from 1999 to 2013. The added value of Primary industry, Secondary industry and Tertiary industry and all other explanatory variables such as FDI, openness, urbanization are all collected from both China Statistical Yearbook of 1999 to 2003 and National Bureau Statistics from 2004 to 2013. The variables, added value of primary industry, secondary industry and tertiary industry and FDI are all adjusted by taking 1998 as the base year. Table 3.6 provides the statistic descriptions of other variables used in this paper.

Table 3.6: Statistic Description of Other Variables

Variables	Number of Obs	Mean	Std Dev	Min	Max
GDP per capita (10000 RMB)	450	1.587192	1.181681	.234661	6.798816
Value Added of Primary Industry (10000 RMB)	450	6789267	4907172	416382	2.25e+07
Value Added of Secondary Industry (10000 RMB)	450	3.45e+07	3.90e+07	854400	2.37e+08
Value Added of Tertiary Industry (10000 RMB)	450	2.53e+07	2.49e+07	925400	1.65e+08
Population (10000 people)	450	4300.044	2603.02	503	10594
FDI (10000 RMB)	450	5.55e+08	9.26e+08	4010000	6.25e+09
Openness (%)	450	.2808853	.3724121	.0241	1.9998
Urbanization (%)	450	.3867247	.2260869	.1243	0.8976

3.4 Econometric Methodology

3.4.1 Theoretical Framework

The EKC hypothesis demonstrate that pollution, a by-product of economic activity, increases with a country's income during the initial stage of development, but starts to reduce along with continued economic growth after a certain point. The theoretical explanation of the EKC hypothesis are generally based on three effects: the scale or level effect(the scale of economic activities), the structure or

[10]Data Source: Department of Population and Employment Statistics of NBS. China Population and Employment Statistics Yearbook[M]. China Statistics Press, 1999-2013

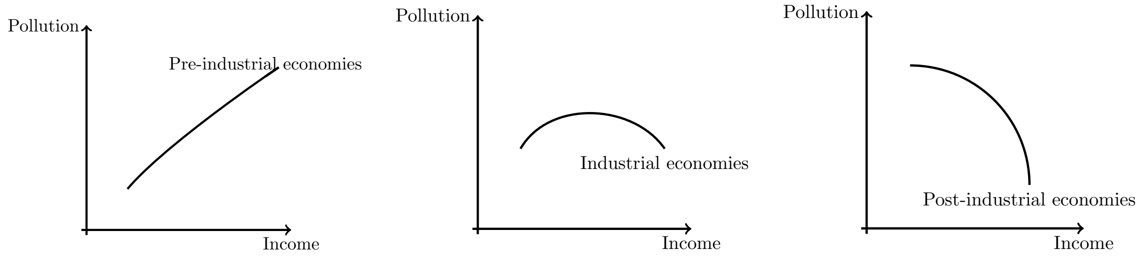
composition effect (the composition of economic activities or economic structure) and the abatement or pure income effect.(pollution abatement efforts)(Panayotou,1997; Islam, Vincent, and Panayotou, 1999). Algebraically:

$$\begin{bmatrix} Ambient \\ Pollution \\ Level \end{bmatrix} = \begin{bmatrix} GDPper \\ unitof \\ area \end{bmatrix} \times \begin{bmatrix} Composition \\ of \\ GDP \end{bmatrix} \times \begin{bmatrix} Abatement \\ Efforts \end{bmatrix} \tag{3.26}$$

Grossman (1995) pointed out that a fast growing world needs more inputs to expand outputs which implies that economic activities causing more waste and emission will increase. Therefore along with the economic growth path, the scale of the eocnomy tends to become lager and lager. This has explained the scale effect of EKC hypothesis and it is match with my previous discussion with Lieb (2004), since he traded environmental quality protection as a luxury good. Obviously, the scale of economy is monotonically increasing with the income when other two effected are fixed. Panayotou (1993) and Baldwin (1995) explained that the economic development experienced different transition stages. When the production of an economy shifted mainly from agriculture to industry, pollution intensity increases and the degradation of the natural environment increased rapidly. It is because that more and more natural resources are exploited and the exhaustion speed of resources started to exceed the regeneration speed of resources. Therefore, if the industrial structure enhances further, it would change from energy-intensive heavy industry to service and technology-intensive industries, pollution falls as income grows. This is the structure effect and it is a non-monotonic function of income. Once the economic grows to a certain level, environmental pollution will decrease, because individuals achieve a standard level of income which makes them rich enough. Moreover, a series of environmental regulations are issued and implemented with the buildup of the government's financial resources and management capacities. This is back with my previous discussion with Leib (2004) as mentioned that the individuals will consider about environmental protection when they have reached a certain level of income. This is the so-called abatement effect.If we simply consider the environmental management capabilities, Pollution is a monotonic decreasing function of income. The relations between the three effects and income are shown in Figure 3.3.

3.4.2 Empirical Framework

A number of empirical models of how EKC relationship may exist have presented. Especially in recent decades, lots of domestic and foreign scholars make considerable empirical studies on the degradation of environmental quality caused by the economic growing process. These studies have the prominent commonness that they use one single pollutant represented the pollution pressure in their



(a) Scale Effect **(b)** Structural Effect **(c)** Abatement Effect

Figure 3.3: Three Effects between Pollution Pressure and Income

study. they adopt the basic model from Grossman and Krueger (1991) which is to make regression on the relationship between environmental pressure P and national income per capita Y.

$$P_{it} = \alpha + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + X_{it} + u_i t \qquad (3.27)$$

where P_{it} is pollution pressure per capita in country i at year t. Y_{it} means GDP per capita in country i in year t. X is the vector of other control variables. α is the intercept of abscissas. $\beta \equiv (\beta_1, \beta_2, \beta_3)$ is the parameter vector and u_{it} is an error term. If the coefficient on GDP per capita, β_1 is positive and the coefficient on GDP per capita squared, $\beta_2$is negative, the relationship between GDP per capita and pollution emissions is not monotonic but displays an inverse-U shaped.

The equation (3.27) enables to test the various relationships between pollution emission and the income per capita as follows 7 conditions:

(i)$\beta_1 > 0, \beta_2 = 0$ and $\beta_3 = 0$ implies a monotonic increasing linear relationship. It means that when income rises, environmental degradation also increases.

(ii)$\beta_1 > 0, \beta_2 < 0$ and $\beta_3 = 0$ implies that the inverted U-shaped EKC relationship exist.

(iii)$\beta_1 > 0, \beta_2 < 0$ and $\beta_3 > 0$ implies a N-shaped relationship. It means once the the pollution emission dropped to the ground as income increase, it increase again as the further increase in income level.

(iv)$\beta_1 = 0, \beta_2 = 0$ and $\beta_3 = 0$ implies a horizontal line or no relationship. It means that income level does not affect environmental degradation at all.

(v)$\beta_1 < 0, \beta_2 = 0$ and $\beta_3 = 0$ implies monotonic decreasing linear relationship. It means that as the income increase, the environmental degradation is decreasing.

(vi)$\beta_1 < 0, \beta_2 > 0$ and $\beta_3 = 0$ implies an U-shaped relationship.

(vii)$\beta_1 < 0, \beta_2 > 0$ and $\beta_3 < 0$ implies a reverted N-shape.

Therefore, the inverted U-shaped EKC is only one of the seven results from the equation (3.27) and an EKC results from $\beta_1 > 0, \beta_2 < 0$ and $\beta_3 = 0$.

There is a way to find the turning point if the EKC curve exist. The turning point or threshold level of income, where the pollution emission is at maximum can be calculated by taking the First Order Condition of P_{it}) in equation (3.27) with respect to Y_{it} and solving for Y_{it}, then we have the turning point as,

$$Y^* = -\frac{\beta_1}{2\beta_2} \qquad (3.28)$$

or if every variable is in a logarithm form in equation (3.27), we need to use equation (3.29) instead of equation (3.28) to calculate the turning point.

$$Y^* = exp(-\frac{\beta_1}{2\beta_2}) \qquad (3.29)$$

The turning point measures the maximum relationship between pollution emissions and the income per capita if the inverted U-shaped EKC present. It explains that when the income reaches a certain level for individuals, the environment degradation will reach its limit and needs to be recovered in order to reach to a long-run sustainable equilibrium.

After the breakthrough studies of EKC hypothesis from Grossman and Krueger (1991), (1993), Panayotou (1993) and Shafik and Bandyopadhyay (1992), an extensive amount of research has been conducted to study the EKC hypothesis. However, these studies have a major commonness which they used one single pollutant as an indicator of the environmental degradation. The main disadvantage of using one pollutant as pollution indicator is to generate inconsistent results. Grossman and Krueger (1991) and (1993) test the EKC relationship between income per capita and several different pollutants individually. The results are different from individual pollutants. Grossman and Krueger (1995) studied the relationship between urban air pollution and GDP per capita by using a single pollutant, SO_2. The data are tested by the Global Environmental Monitoring System (GEMS) that is designed by the World Health Organization and the United Nations Environment Programme in 42 countries from 1977 to 1993. They found a N-shape relationship instead of an inverted U relationship between SO_2 and GDP per capita. However, Shafik (1992) and Panayotou (1993), concluded an inverted-U relationship between these two in same study. They found a turn point of income per capita around 3,700 US dollars and 10,000 US dollars respectively. Li (2011) studied the relationship between CO_2 per capita and GDP per capita of high-emission regions, low-emission regions and medium-emission regions of China from 1995 to 2009. He concluded a N-shaped EKC curve among all three regions. However, He (2014) thought that there is a reverse U-shape relationship between these two and he found a turning point around 35,000 US dollars in same study. Grossman and Krueger (1995) and Selden and Song (1995) found an inverted-U shape relationship between income per capita and CO per capita and the turning point that they have found are around 22,800 US dollars and 6,200 respectively. Panayotou (1993), Shafik (1994), and Cole, Rayner and Bates (1997)found an inverted-U relationship between Suspended Particulate Matter(SPM) per capita and income per capita. The turning points they found are around 4,500 USD, 3,200 USD, 8,100 USD. Whereas, Grossman and Krueger (1993), Selden and Song (1994), Vincent (1997) and Carson, Jeon and McCubbin (1997) thought there wasn't an inverted U-shaped relationship between these two. Panayotou (1993), and Cole, Rayner and Bates (1997) got an inverted U-shape relationship between NO_x and income per capita and found turning points of 5,500 USD and 15,100 USD respectively. Grossman and Krueger (1995) found an inverted U-shaped relationship between Biochemical Oxygen Demand (BOD) and income per capita while Shafik and Bandyopadhyay (1992), Shafik (1994) and Cole, Rayner and Bates (1997) all thought there is a linear positive relationship between these two.

3.4.3 Empirical Estimation

Based on the drawbacks of the previous studies. This chapter analyzes the relationship between income per capita and Pollution Emission Index (PEI) first and then tests the relationship between different industry structures and PEI. Furthermore, in this chapter I collected provincial data within a country, China. Chintrakarn and Millimet(2006) pointed out that there are two major advantages of using within country data comparing with the cross-section data. First, the consistency of measurement of pollution, income and government policy can be assured. Second, although the differences exist among different provinces in China, the samples are more homogeneous in political freedom, legal institution, cultural norms and corruption compared to cross country data.

3.4.3.1 Estimation under GDP per capita

In order to study the relationship between pollution pressure and the economic growth in China, I estimate a regression that relates the level of pollution (PEI) to a flexible function of the income per capita and other co-variates, such as population, FDI, openness and urbanization which concerned to be possible to affect the pollution level. All of them are included in this model. Specifically, we estimate all variables are in log values as,

$$e_{it} = \alpha + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 y_{it}^3 + \beta_4 pop + \beta_5 open + \beta_6 ur + \beta_7 fdi + \eta_i + \gamma_t + u_i \qquad (3.30)$$

where e_{it} is a measure of pollution pressure level, which is an index calculated by PCA using seven pollutants in province i of year t in China, y_{it} is GDP per capita in province i in China in year t, pop measures the total population of province i in China in year t, $open$ is the percentage rate of openness of ith province in China in year t, ur stands for the percentage rate of urbanization of province i in China in year t, fdi means the value of Foreign Direct Investment of province i in China in year t, η_i is the province specific effect, γ_t is the time specific effect and u_i is an error term. The βs are parameters to be estimated and α is the intercept. By covering population, FDI, urbanization and openness,we are able to test whether they affect the EKC's slope or intercept or both if it exists.

The pollution pressure indicator working as the dependent variable is defined as the yearly emission data level.Compared with the drawbacks of other recent studies, there are seven pollutants, carbon dioxide, sulfur dioxide, other waste gas, waste water, industrial soot, industrial dust and solid waste are selected to create PEI by using PCA in this chapter. This improvement has not been noticed by any other recent studies. By doing this we can avoid of the inconsistent results from each unique pollutant and make a consistent result of an overall pollution level. Each pollutant has two kinds of data, namely emission and concentration[11]. The emission data is calculated by practical energy consumption multiplying emission coefficient. Concentration data is from practical measure on the other hand. It is improper to use concentration data to analyze the relationship between environmental pressure and the GDP per capita.Firstly, concentration data merely reflect the pollution pressure on the monitoring spots, most large cities and the income per capita is usually different from the GDP per capita in these large cities. Secondly, Many polluting industries move to some undeveloped areas around cities since people pay more attention to more developed cities' environmental quality. This industrial transfer will only affect the concentration data in the monitoring spots, but not affect the GDP per capita. In addition, weather can easily affect concentration data, but the effect is not apparently related with the change in GDP per capita. For example, rain can shorten the moving distance of pollutants in the air (Cao and Wen, 2009). Therefore, we choose emission data, which are highly correlated with GDP per capita in order to make the regression more precise.

The variable of GDP per capita is measured at the province level. It is adjusted by the GDP index taking 1998 as the base year. Since economic development in China has made great achievements in these decades, GDP per capita has grown fast. However, the huge amount of population and the different pace of development among regions still cause a weak economic foundation of China. Therefore, continuous economic development, eliminating poverty and improving individual's living standard are still being the main goals of Chinese government. However, by facing the severe environmental degradation in China now, developing first or environment refreshment first needs to be concerned

[11]China Statistical Yearbook 1999 to 2013 contains all these two kinds of data

immediately.

In order to estimate the relationship between pollution pressure and income per capita, I adjust the year and province by including time and region proxies as separate regressors.[12] By doing this we can ignore that the province level of income growth attribute to the effects of any improvement in local environmental quality. These effects might actually be caused by the national advances in the technology for environmental preservation or by an increase in national awareness of the severity of environmental problems.

In my model, besides GDP per capita, time and region dummies I also add other covariates. These variables are the population, openness, urbanization and foreign direct investment. By including these additional variables, we are able to reduce the residual variance in the relationship between pollution pressure and income per capita and thus generate more precise estimates. They are several hypotheses assumed upon these covariates.

First, the population is expected to be significantly positively correlated with the pollution pressure. With the increasing demand of the people in basic necessities in their life, the growing populations cause an increase in the consumption of energies and nature resources. Since more and more energies and nature resources are been consumed, more pollution emissions are produced (Grossman and Krueger, 1991).

Second, the rate of the openness[13] is expected to be significantly negative correlated with the pollution pressure. With an increase in openness of one location, there will be an increase in the interaction with other countries and will more easily to get assistant from the advanced country to solve the pollution problem. Moreover, The positive spillover should dominates the negative effect of trade.

Third, the urbanization is expected to be significantly positive related to pollution pressure. Urbanization is chosen as population structure factor which equals that non-agricultural population divided by the total population. Grossman and Krureger (1991) pointed out that production mode is transferred from the agricultural production mode to the industrial production mode, which results in a huge activities of pollution emissions. In addition, if a large proportion of the population choose to stay in the urban area, it will lead to the construction of many facilities and buildings which may result in a large amount of pollution emissions being released.

Fourth, the foreign direct investment is expected to be significantly positive correlated with the pollution pressure. The relationship between FDI and pollution can be explained by scale effect, structure effect and abatement effect (Grossman and Krueger, 1991). Early FDI can cause an economic

[12] When the experiment including time and region dummies, the coefficients on them were approximately linear, and the other coefficients were not meaningfully different.

[13] Openness is measured by trade volume which is calculated by: $\frac{(Export+Import)}{GDP}$

development in the beginning because it leads to an increase of consumptions and productions which result a release of a large amount of pollution emission. This follows with scale effect. For the investing country, when it develops to a certain degree, the government will improve the regulation to balance the economic development and environmental protection which reflects the structural effect. Both "Marginal Industry Expansion Theory"(MIET) by Kojima (1978) and "Pollution Haven Hypothesis Theory" (PHHT) by Taylor and Copeland (1994) are related to this explanation. Kojiima (1978) in his MIET pointed out that the investing countries need to shift the domestic industries with more comparative disadvantages out of the domestic countries since they always arrange their investment according to the intensity sequence of comparative disadvantages of different industries. Taylor and Copeland (1994)in their PHHT pointed out that the country's environmental regulation reduces the competitiveness of the domestic polluting industries and cause them to be transferred from domestic country to other countries. Thus pollution-intensive industries will be transferred from the countries with a higher internal environmental cost to countries with a lower internal environmental cost. In the contrary, the FDI could cause positive spillover to the host countries from investing countries in the late FDI stage. This positive spillover will make the host country to improve its productivity efficiency of resource utilization and reduce pollution emission. This follows abatement effect. However, it seems that China is still under the early stage of the FDI.

3.4.3.2 Estimation under three industry structures

The further analysis between the pollution pressure and the economic growth in China will be the three industry structures being added in the estimation in our model. This haven't been done by other previous studies in this field in China. Generally, besides GDP per capita I added primary industry value added per capita, secondary industry share[14] and tertiary industry value added per capita into the equation (3.30) and make them to match the three effects I have mentioned in the previous discussion.

The reason for doing this is because China's GDP format is mainly constructed by these three industry structures. I intend to get a result that demonstrates the relationship between pollution pressure and different industry structures respectively in China. The result will help us to understand what type of industry structure will hurt the environment most and also helps the Chinese government to issue a specific restriction under each industry. Primary industry contains mainly of agriculture, forestry, graziery and fishing, second industry, mainly contains industries (factories and plants) and manufacture industry and tertiary industry, mainly contains transportation industries and service industries (Hitoshi and Satoko, 2009) Thus,

[14]Secondary industry share is calculated as added value of secondary industry divided by total GDP.

$$GDP_{China} = PrimaryIndustryValueAdded + SecondaryIndustryValueAdded + TertiaryIndustryValueAdded \qquad (3.31)$$

Therefore the income variable or an income effect can be decomposed by values of these three industrial structures. Recall equation (3.26) from Panayotou (1997) and Islam, Vincent, and Panayotou (1999), I made a little innovation on to this model. First, I switch GDP per unit of area which stands for scale effect into the added value of the primary industry per capita, secondary industry share for structure effect and the added value of the tertiary industry per capita for abatement effect. Second, I assume each effect takes proportional effect on the result of pollution pressure. Therefore, equation (3.26) now as,

$$\underbrace{\begin{pmatrix} Ambient \\ Pollution \\ Level \end{pmatrix}}_{\text{Pollution}} = \underbrace{\begin{pmatrix} Primary \\ Industry \\ ofGDP \end{pmatrix}^{\beta_1}}_{\text{Scale}} \times \underbrace{\begin{pmatrix} Secondary \\ IndustryShare \\ ofGDP \end{pmatrix}^{\beta_2}}_{\text{Structure}} \times \underbrace{\begin{pmatrix} Tertiary \\ Industry \\ ofGDP \end{pmatrix}^{\beta_3}}_{\text{Abatement}} \qquad (3.32)$$

where $0 < \beta_1 < 1, 0 < \beta_2 < 1, 0 < \beta_3 < 1$ and $\beta_1 + \beta_2 + \beta_3 \leq 1$. If we take a logarithm from both sides of the equation (3.32) then we have,

$$Ln(Pollution) = \beta_1 Ln(Primary) + \beta_2 Ln(Secondary) + \beta_3 Ln(Tertiary) \qquad (3.33)$$

The scale effect on pollution is expected to be a monotonically increasing function of income by controlling other two effects fixed. The larger the scale of economic activity per unit of area the higher the level of pollution pressure is presented. It is happened at pre-industry economy stage (Panayotou, 1991). Therefore, the added value of primary industry has matched this scale effect well since the industries under primary industry structure are mainly pre-industry sectors. The structural change along with economic growth affects environmental quality by changing the composition of economic activity toward sectors of higher or lower pollution intensity. This means that at a lower income level, the economy shifts its structure from agriculture based, a lower pollution intensity to industry based, to a higher pollution intensity and results in an increase of environmental degradation. At higher income, the economy switches its structure from industry based to service based, a lower pollution intensity and results a decrease of environmental degradation. The structural effect is likely to be a non-monotonic (inverted-U) function of GDP and It happens in industry economy stage (Panayotou, 1991). This effect matches with secondary industry, which mainly contains industries under this structure. The share of industry first rises and then falls, then the environmental pollution will first rise and then fall with income growth by holding other effects constant.

After determining scale and structure effects in my model, the added value of tertiary industry just perfectly describes the abatement effect representing pure income effects on the demand and supply of environmental quality. On the demand side, at a lower income, when income increases, people increase in demanding food and shelter, but not too much demand for environmental quality. In contrast, at a higher income level, when income increases people demand more for environmental quality since they have already reach a living standard for food and shelter. On the supply side, higher incomes cause an increase in private and public expenditures on pollution and make more resources provided on a service sector and environment regulations available to internalize pollution externalities (Panayotou, 1991). Thus the added value of tertiary industry capture this effect since individuals are rich enough and willing to invest their money in the pollution abatement effort at this stage. The abatement effect is expected to be a monotonically decreasing function of income.

As a result,from equation (3.33) I decompose the three effects based on primary, secondary and tertiary industry into equation (3.30), we estimate,

$$\begin{aligned} e_{it} =& \alpha + \beta_1 p_{it} + \beta_2 p_{it}^2 + \beta_3 p_{it}^3 + \beta_4 s_{it} + \beta_5 s_{it}^2 + \beta_6 s_{it}^3 + \beta_7 (te)_{it} + \beta_8 (te)_{it}^2 + \beta_9 (te)_{it}^3 \\ &+ \beta_{10} pop + \beta_{11} open + \beta_{12} ur + \beta_{13} fdi + \eta_i + \gamma_t + u_i \qquad (3.34) \end{aligned}$$

where p_{it}, s_{it} and $(te)_{it}$ are logged values of primary industry value added per capita, secondary industry share and tertiary industry value added per capita respectively to represent the scale, structure and abatement effect and the rest of the variables remain same as from the equation (30).

The primary industry share is expected to be positive sign since, other things equal, the larger the volume of economic output, the higher level of pollution emissions are. The secondary industry share is also expected to a positive sign since it is highly correlated with energy consumption from industrialization. Having controlled for the scale and structure of the output, the tertiary industry share is expected to be a negative sign since service industries are the main sectors in tertiary industry where it is a stage of high demand for pollution abatement. By controlling all scale effect, structure effect and abatement effect GDP per capita should be negative sign since income effect kicks in from both demand and supply sides.

I estimate both models (1)-only GDP per capita and (2)-both GDP per capita and other variables by both fixed and random effects. The fixed effect treats differences in the intercepts as due to deterministic factors. The random effect treats those differences as due to stochastic factors. Whether the fixed effect is a better method, or whether the random effect is a better method, I use the Hausman test(Hausman 1978) to determine the preferred version by testing the null hypothesis of that the other variables were correlated with both year and region. The fixed effect model is preferred if the null hypothesis is rejected at a significance level of five percent otherwise the random effect model is preferred.

3.5 Results

3.5.1 Estimation results under GDP per capita

Before I do the estimation of both models (1) and (2), Multicollinearity is one of the potential problems in concern, as it is for previous EKC studies. Although panel data effect may reduce but not able to eliminate this potential problem. No multicollinearity was detected among any of my basic explanatory variables, but there was some collinearity between lower and higher order terms of some variables as one would expect with polynomial regressions. By dealing with this problem, I chose a simple and less satisfactory approach of dropping the insignificant variable from estimation. Although this may lead to specification bias, this is thought not to be the case in my model since all the theoretically essential variables still appear, and there is no a former theoretical reason why higher order forms should also be included (Panayotou,1995).

Another potential problem that my concern is heteroscedasticity problem, since the use of observations which are aggregations over varying numbers of sub-units to test the EKC hypothesis is likely to give a rise to heteroscedasticity problems in estimation. Stern et al (1996) pointed out that the ordinary least squares (OLS) estimations are inefficient under EKC studies because of this problem. Therefore, my model is using a generalized least squares (GLS) and I have also checked for heteroscedasticity by performing the Breusch-Pagan test. The null hypothesis is homoskedasticity. I found that none of the variables are heteroscedasticity since we can not rejected the null hypothesis as indicated by the χ^2 value is 0.11 and the p-value of χ^2 is 0.7435 which is greater than the critical value of 0.05.

By solving the above problems, the panel regression results for equation (3.30)are reported in Table 3.7. I have done estimate equation (3.30) twice. First only with GDP per capita itself and I called it model one. Second I added population, openness,urbanization and FDI to see how these factor will affect pollution pressure and I call it model two. Both Models have done a fixed effect and random effect estimation. The results show that the null hypotheses that the random effects were uncorrelated with year was rejected by the Hausman test and thus the fixed effect estimation was favored in both models. All variables in model (1) are statistically significant at least at the 10% level expect the cubic term. Also the expected sign of GDP per capita indicates the presence of an inverted U-shape relationship between pollution pressure and income per capita. The signs of other variables in model (2) are all following the expectations we have discussed in the previous section and all presented to be significant.

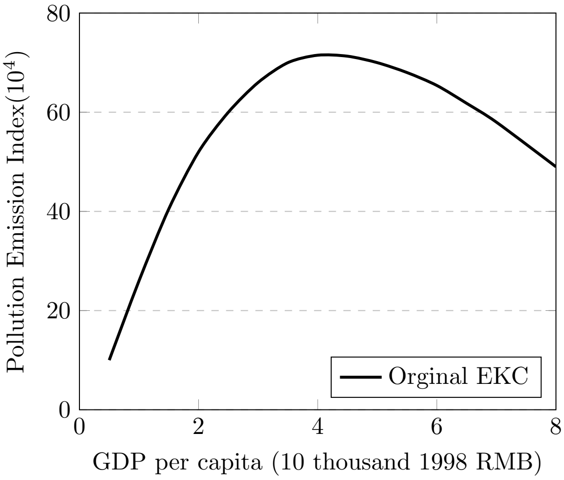
Table 3.7: The estimation result for the relationship between PEI and GDP per capita: The role of population,openness,urbanization and FDI

	Model One		Model Two	
Explanatory Variables	Fixed Effect	Random Effect	Fixed Effect	Random Effect
Constant	18.89654***	18.90742***	7.179357**	16.33711***
	(.3881948)	(.6227733)	(0.14389)	(4.56523)
$GDPpercapita$	3.78606***	3.810878***	3.015464***	2.983877***
	(.6722755)	(.568946)	(1.047179)	(.6367465)
$(GDPpercaptia)^2$	-.9587251***	-.9570919***	-.9532276***	-.9750131***
	(.1408212)	(.1400713)	(.1425226)	(.1371056)
$(GDPpercaptia)^3$	-	-	-	-
Population	-	-	.2670292	-.7866575*
			(.1506784)	(.5170984)
Openness	-	-	-1.084733***	-1.073693***
			(.2511076)	(.2170991)
Urbanization	-	-	.5415338**	.6344486**
			(.2572177)	(.2480815)
Foreign Direct Investments	-	-	.7166635***	.6661284***
			(.1843343)	(.179557)
R^2	0.182	0.183	0.54	0.62
Hausman Test	-	32.11	-	81.19
Prob> CH2	-	0.0000	-	0.0000
N	450	450	450	450

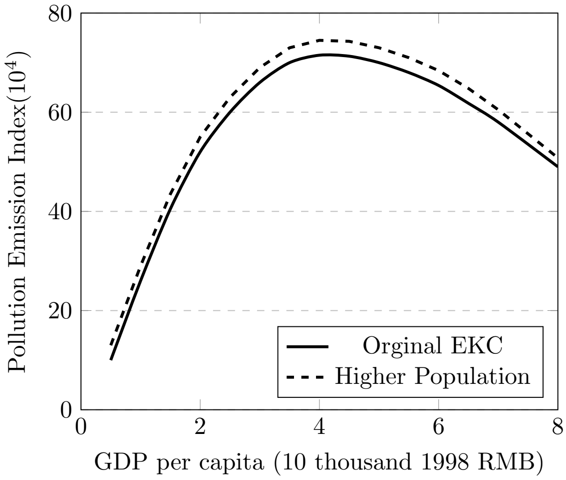
* is significant at 10% level; ** is significant at 5% level and *** is significant at 1% level

By holding other variables fixed,one percent of people increase in the total population results in 0.27 percent increase in the pollution index level, whereas an improvement of the connections with other countries by 1% results in reduction of pollution index by 1.08%. An increase of urbanization by 1% will lead to an increase of pollution index level by 0.54% and an increase of 1% of FDI results an increase of pollution index level by 0.71% by holding other variables constant.The overall fitness of Model I is below 20%, implying that variables other than income also matters. In the contrary, Model (2) is more efficient than model (1) since its R^2 is around 55%.

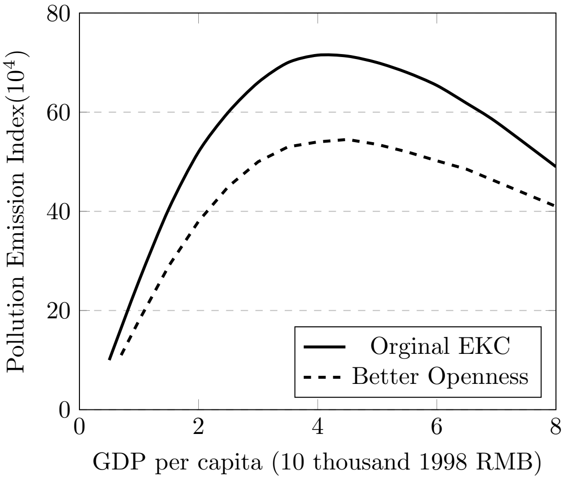
The EKC for pollution index reaches a turning point at an income per capita around 44,000 RMB which is about 6,000 USD if we consider the exchange rate of 6.8 Yuan per dollar. This finding comparable with those of Grossman and Krueger (1993), Panayotou (1993; 1995) and Shafik(1994) for using SO2 as their pollution indicator, since they found the turning point was about 5,000 USD of cross country analysis. After 44,800 per capita, ambient pollution pressure falls. Figure 3 depicts the environmental Kuznets curve derived from Model 2 (fixed effects) and the effects of a higher population, a higher openness, a larger urbanization and a higher Foreign Direct Investment.



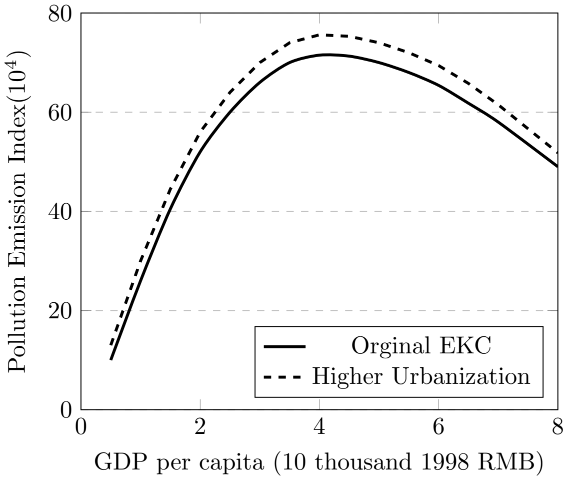
(a) Environment Kuznets Curve



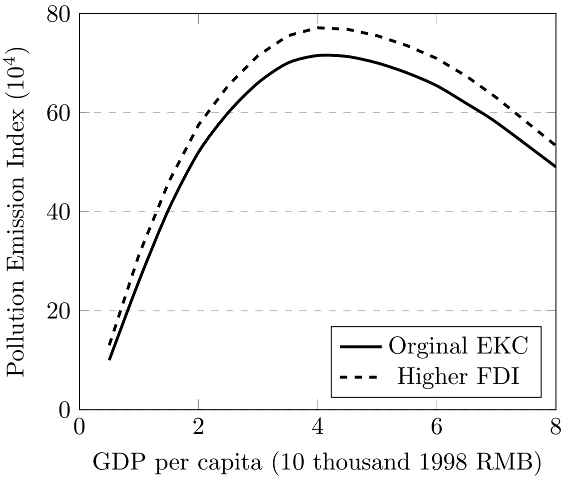
(b) Higher Population Effect



(c) Better Openness Effect



(d) Higher Urbanization Effect



(e) Higher FDI Effect

Figure 3.4: Environment Kuznets Curve: The Role of Population,Openness,Urbanization and FDI

As shown in Figure 3.4 from (b)-(d), higher population,urbanization rate and Foreign Direct Investment results in marginally to moderately higher of ambient pollution pressure levels, while better openness rate results drastically decrease of ambient pollution pressure level. This implies that it might be more effective to focus efforts for controlling pollution pressures on improving the trade volume and gain assistance from other countries who have already experienced a serious pollution situation rather than either on limiting economic growth or controlling population growth.In addition the cost of each option is also relevant, but the cost of openness improvements is more likely to have lower costs and more benefits than the restrictions on economic and population growth.

The another interesting finding from the estimation equation (3.30) is that the elasticity between pollution pressures and income per capita in China are lots of higher than the finding in Shafik (1994) who is the only author have discussed about pollution-income elasticity in his studies. According to Shafik (1994), the method of finding a pollution-income elasticity after an empirical regression followed by calculations as,

$$Linear : \varepsilon = \beta_1 \qquad (3.35)$$

$$Quadratic : \varepsilon = \beta_1 + 2\beta_2 lnY \qquad (3.36)$$

$$Cubic : \varepsilon = \beta_1 + 2\beta_2 lnY + 3\beta_3 (LnY)^2 \qquad (3.37)$$

The elasticity between pollution pressure and income per capita we get into this paper is about 3.01 by using equation (3.36), compared with Shafik(1994) with a elasticity of 1.62 between the pollutant, CO2 and income per capita. Obviously the elasticity is much greater in China's situation which implies that the 1% increase in economic growth will result 3.01% increase in pollution level. This might explain that why the EKC slope is much steeper in China than other developed countries described in Grossman and Krueger (1995), Panayotou (1995) and Shafik (1994). Furthermore, this might also give a better understand that why China's economic growth is accompanied along with a severe pollution pressure. This is as far as one can go with equation (3.30).

3.5.2 Estimation results under different Industrial Structures

Next, the panel regression results of equation (3.34) are reported in Table 3.8. Again, the random-effects estimation was rejected by the Hausman test. Therefore, I focus my discussions on the fixed-effect model results even though I report the results of both versions.

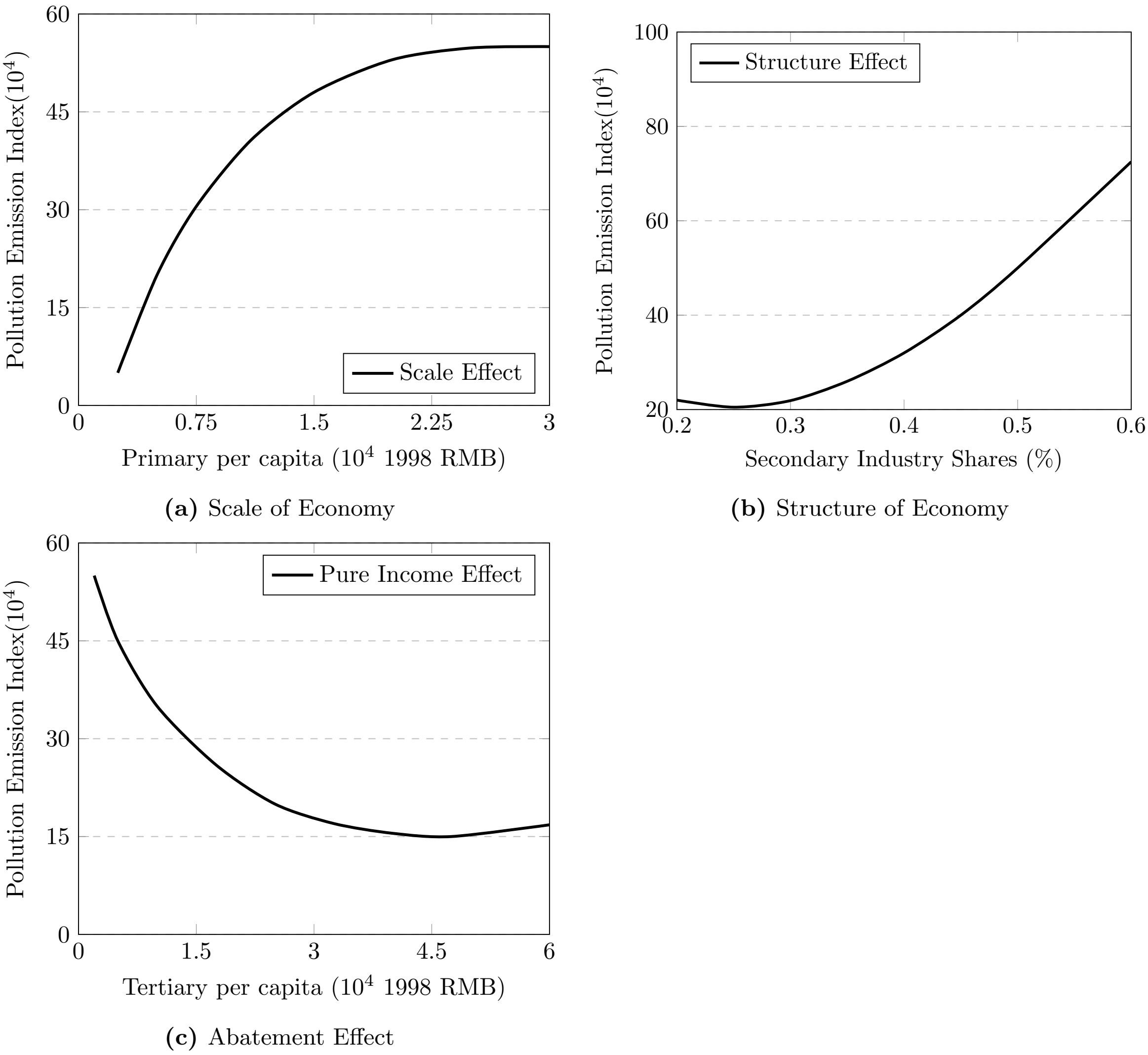
Table 3.8: The estimation result for the relationship between PEI and GDP per capita: The role of Primary,Secondary and Tertiary Industries

Explanatory Variables	Fixed Effects	Random Effects
Constant	65.12963***	64.19598***
	(22.73405)	(.1037955)
$PrimaryPerCapitaofGDP$	10.84306**	11.54042**
	(6.581795)	(6.377973)
$(PrimaryPerCapitaofGDP)^2$	-1.923492*	-1.928079*
	(1.014737)	(1.172002)
$(PrimaryPerCapitaofGDP)^3$	-.1089896**	-.1052019**
	(.0574337)	(.0547613)
$SecondaryIndustryShareofGDP$	1.203029***	1.155031***
	(.2901245)	(.2288988)
$(SecondaryIndustryShareofGDP)^2$	-	-
$(SecondaryIndustryShareofGDP)^3$	-	-
$TertiaryPerCapitaofGDP$	-13.79552***	-13.40431***
	(3.942631)	(3.856301)
$(TertiaryPerCapitaofGDP)^2$	1.581936***	1.589837***
	(.4699309)	(.0167644)
$(TertiaryPerCapitaofGDP)^3$	-.0604234***	-.0616911***
	(.018026)	(.0176807)
Population	-	-
Openness	-.1623446***	-.116456***
	(.0408605)	(.0359067)
Urbanization	.0979915***	.1479261***
	(.0434033)	(.0423771)
Foreign Direct Investments	.0990083***	.0845818***
	(.0304114)	(.0294639)
R^2	0.925	0.922
Hausman Test	-	26.38
Prob> CH2	-	0.0095
N	450	450

* is significant at 10% level; ** is significant at 5% level and *** is significant at 1% level

All variables are the same as in equation (3.30) except the introduction of first,second and tertiary industrial structures, as decomposed into its scale, structure and abatement effects. First of all, it is noteworthy that the overall fitness (R^2)has been improved dramatically from 0.54 to 0.92. Primary industry value added per capita captures the scale effect and it is, as expected, significantly positive associated with ambient pollution pressure levels, but does so at a diminishing rate (Figure 3.5a). It is particularly strong up to about 25,000 RMB per capita and about 3,600 USD by taking 6.8US/RMB as the exchange rate. The expansion of the economy scale in the beginning of the economic growth increases the ambient pressure level in a fast pace, but it does so at a diminishing rate. The cubic term is only marginally significant and does not alter the monotonic relationship within the data range.

The structural effect of the economy represented by industry share has the right signs which represent a generally non-decreasing relationship with ambient pollution levels. It has, however, almost strictly positive increase relationship with the pollution pressure levels. The power and cubic factor of secondary industry share don't have any effectiveness since they are very insignificant and were dropped. A fairly constant section in the beginning for industry shares between 20% and 30%. This is partly due to the fact that the simple industry share term is not statistically significant except as it interacts with income per capita, implying that the pollution emission is not greater in the beginning of the industrialization. However, the larger is the share of industry in GDP, apparently indicating more visibility of pollution emissions are released from industrialization. The pollution pressures increase drastically after the 30% of the industry shares (Figure 3.5b). Hence the most relevant portion of the curve is between industry shares of 20% and 30% since non-decreasing effect represent in this area.



(a) Scale of Economy

(b) Structure of Economy

(c) Abatement Effect

Figure 3.5: The Decomposition of Environmental Kuznets Curve: Primary, Secondary and Tertiary Industry structure Effects.

By controlling both scale and structure effects. The tertiary industry value added per capita works as a pure income effect, and it is, as expected significantly negative relative with pollution pressures until 45,000 RMB of tertiary industry value added per capita (Figure 3.5c). Beyond this point it upturns but the significance of this tail effect is uncertain because of the very few observations at the high end of added value per capita of tertiary industry levels.

By analyzing the decomposition of the EKC in China I found that both first and secondary industries are significantly positively correlated with pollution emissions, whereas the tertiary industry is negatively correlated with pollution pressures. Thus an increase in the share of tertiary industry (abatement effect)of GDP reduces pollution, but the combined effects of both scale and structure of the economy almost balance this abatement effect from the result of table 3.8. This might explain that why the pollution-income elasticity is really high in China. If we intend to prevent that fast pace of the pollution-income relationship, we definitely need to decrease the pollution-income elasticity. Based on the elasticity formula from Shafik(1994) I can calculate the pollution-income elasticity as,

$$\varepsilon_{EY} = \underbrace{\varepsilon_{YP}\varepsilon_{EP}\frac{P}{Y}}_{+} + \underbrace{\varepsilon_{YS}\varepsilon_{ES}\frac{S}{Y}}_{+} + \underbrace{\varepsilon_{YT}\varepsilon_{ET}\frac{T}{Y}}_{-} \tag{3.38}$$

where ε_{EY} is pollution income elasticity, ε_{YP},ε_{YS} and ε_{YT} are the cross elasticizes between income and primary,secondary and tertiary industries,ε_{EP},ε_{ES} and ε_{ET} are the cross elasticizes between pollution and primary,secondary and tertiary industries, P,S and T are primary, secondary and tertiary industries respectively, and Y is income. According the equation (3.38)[15], only the third part represent negative effect given ε_{YP},ε_{YS},ε_{YT},ε_{EP},and ε_{ES} are all greater than zero while $\varepsilon_{ET} < 0$. Thus, the pollution-income elasticity can be reduced by either increase the value of the tertiary industry, pollution-tertiary cross elasticity or income-tertiary cross elasticity considering other things fixed. If we can reduce these variables, the pollution pressure in China could be considerably improved. Besides three effects other variables stay unchanged but the effect of openness becomes less significant under equation (3.34) estimations. This is all results I could generate from equation (3.34).

3.5.3 Across Location Analysis

The further analysis with switching the province specific effect into location dummy variable and this could be a robustness check of my model. By doing this, I divided all 30 provinces into four different location areas: Central Areas, East Areas, North East Areas and West Areas to see if the EKC relationship could be changed with different geographic effects. Among all four different regions, central

[15]See Appendix 1 for the calculation

areas include Shanxi, Henan, Hubei, Hunan, Anhui and Jiangxi provinces, east areas include Beijing, Tianjin, Shanghai, Hebei, Jiangsu, Zhejiang, Shandong, Fujian, Guangdong, and Hainan provinces, north east areas include Liaoning, Jilin and Heilongjiang provinces and west areas include Guangxi, Inner Mongolia, Ningxia, Xinjiang, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu,and Qinghai provinces(Sun, 2013). Basically we estimate the new equation (38) with both regional dummies and the interaction term between location and income per capita. Formally I estimate,

$$\begin{aligned} e_{it} =&\alpha + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 y_{it}^3 + \beta_4 pop + \beta_5 open + \beta_6 ur + \beta_7 fdi \\ &+ \sum_{k=8}^{11} \beta_k D_k + \sum_{k=8}^{11} \beta_{k+4} D_k y_{it} + \gamma_t + u_i \end{aligned} \quad (3.39)$$

where $k = 8$ represents the central areas, $k = 9$ represents the east areas, $k = 10$ represents the north east areas and $k = 11$ represents the west areas. Again, fixed effect estimation is preferred in this equation, while this time we only report the fixed effect estimations through Appendix B3-B6.

The EKC exactly appears with only East and North East areas. With central area effect, the relationship between pollution and income per capita starts to increase in a fast pace from 183 RMB[16] to 10,000 RMB and then increase very slowly after 10,000 RMB until 2,7000 RMB, then starts to rise up again. However, the uptrend strength of rise again is really small. The West areas almost have same situations as Central Areas, while it has a much steeper slope and a even smaller cubic effect. The East area effect and North East area effect are showing a inverted relationships and the turning points are 49,000 RMB and 54,000 RMB respectively. The reason of why the turning point is bigger in north east area effect is because that's the difference between income per capita and its squared effect is bigger in north east area effect than it in east areas. Higher elasticity with a higher turning point implies a higher pollution level eventually in north east areas. All area and area-income interaction effects showed an insignificant result except west area. It is significantly positively correlated with pollution pressures. Since only east and north east exactly follow the EKC hypothesis, the reduction of pollution needs to be considered in these two areas whereas the other two may still need to develop.

The statistical significance of the population found in equation (3.30) and (3.34) survives the robustness check, although it reverses signs.This presumably one area with more people needs to be more considerable about environmental protection. The statistical significance and correct signs of the openness and urbanization variables also survive the robustness check. It can be also said the better openness will reduce pollution more efficiently. The statistical significance of the FDI variable also survives the robustness check, but with reversed signs. This might be explained that the positive spillovers is larger across regions.

[16]The value of log(-4)= 0.0183 and time 10,000 to get 183 RMB showing in Appendix B7 figure B.2(a) and all other income per capitas are also calculated from log values and demonstrated respectively in Figure B.2 through (a)to (d).

3.6 Suggestions and Further Discussion

This chapter investigated the validity of the EKC relationship between pollution index, which I have calculated by PCA and economic growth in China. I found the EKC relationship exist in China's society and the turning point is around 44,000 RMB which is comparable with Panayotou(1995), Shafit(1994) and Grossman (1993). I also found that higher population, urbanization rate and Foreign Direct Investment result in marginally to moderately higher of ambient pollution pressure levels, while better openness rate results drastically decrease of ambient pollution pressure level. It might therefore be more effective to focus efforts for controlling pollution pressures on improving the trade volume and getting a relative assistance from other countries who have already experienced a severe pollution situation rather than either on limiting economic growth or controlling population growth. In addition, the cost of each option is also relevant, the cost of openness improvements is more likely to have lower costs and more benefits than the restrictions on economic and population growth. In addition, I found that the reason why the China has high pollution is because that the elasticity between pollution and GDP per capita is quite high compared to Shafik (1994).

By decomposing the three effects in primary, secondary and tertiary industries, I found that the positive effects between pollution and income per capita from primary and secondary industries are big. However, they can be balanced by the tertiary industry expansions since the increase in the tertiary industry sector will increase the pollution-tertiary elasticity which moderates the pollution-income elasticity. Thus, besides increase openness, increase tertiary sectors are another good method to use to reduce pollution in China, proposed by this chapter.

At last, this chapter has replaced the province specific effect of a regional dummy variable. I divided all 30 provinces into four different location areas: Central Areas, East Areas, North East Areas and West Areas to see if the EKC relationship could be changed with different geographic effects. I found that only the east areas and north east areas present an inverted-U relationship between pollution and income per capita. Since only east and north east exactly follow the EKC hypothesis, the reduction of pollution needs to be considered in these two areas whereas the other two may still need to develop.

Therefore, I conclude that there exists an EKC relationship between pollution emissions and GDP per capita in China between 1998 to 2012. It means that the pollution emission across 30 provinces over all follow the structure of EKC between GDP per capita and polltion emission. The results explain that why that China experiencing a serious pollution along with its economic growth. These results generate much richer results than other studies of pollution-economic growth in China since they only use one pollutant as their pollution indicator, such as Wen et al (2009) who found inverted U-shaped EKC relationship between CO2 emission and income per capita in China from 1989 to 2008's data; Li

(2011) who concluded a N-shaped relationship between CO2 emission and GDP per capita in China from 1995 to 2009's data; etc. Economic development along with a environmental protection seems to be feasible is the essential part generated by this paper

As a result, This chapter suggest that China can reduce its pollution level by increasing openness and Tertiary industry proportions which are the most cost efficient ways for China now. Without understanding these points, it is hard for China to reach its long-run sustainable economic growth equilibrium. China should analyze its own status at the present and makes its own economic path to reach the low carbon economic growth in the future.

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Chapter 4

Individual's Mortality Rate, Economic Growth and Air Pollution Emissions: A Dynamic Panel Cointegration and Causality Analysis for China

4.1 Background

Human capital is a vital factor in economic development. Consumption and production goods, while instantly provided through sophisticated infrastructures, are nevertheless a very difficult process that cannot satisfy demand without some harm to the environment and the human beings at the present.

Pollution which is released from massive consumption and production, negatively influences human health. The impact on human resources, while typically viewed from the level of damage to individual health, could create economic problems that retard social development. At the same time, economic development may rely on processes that create pollution. Factories can create raw materials and products that benefit the society will spew pollutants. Sustainable development, a noble goal for the planet, may not be able to be achieved not only because of the damage to human health, but also because of the economic damage. The results from depressed human capacity, potentially lead corporations to make short term decisions for profitability that will exacerbate existing dire levels of pollution.

Some technology innovations for production processes may solve the problem of environmental degradation, such like wind energy presenting remarkable possibilities for power without harmful byproducts. However, at present, the planet's reliance is on fossil fuel energy, since the new technologies may cost too much. In fact, projections hold that fossil fuels will remain the largest source of energy for the planet in the near future, estimated to be fully 80% of the planet's energy by 2040 (Exxon, 2014). Following centuries of the experiences for the exploration, processing, and dispersal of various forms of fossil fuel forms, transferring fossil fuels into usable power is reliable, and relatively speaking, inexpensive. Yet the provision of power carries considerable waste products, in the exploration and extraction of the fossil fuels, as well as the burning of the fuels. At one time, these were ignored by companies and consumers who demanded power at the beginning of economic development. Yet time has demonstrated that the pollution associated with fossil fuel energy forms has a deleterious impact on the sustainability of human life on the planet.

Human beings have evolved to a point that economic productivity is aligned with existence. Furthermore, productivity is firmly rooted to the use of energy that comes from fossil fuels. Scores of economic sectors rely on energy, and it is likely that a reversal of the use of fossil fuels would cause a considerable economic drop off. Fossil fuel energy use is strongly correlated with economic productivity. Steinberger and Krausmann (2011) explain that "in economic efficiency terms, economic output can be seen as mainly fossil-driven, with rather steady fossil productivity across countries of different incomes". In other words, at least in the contemporary society, economic productivity is strongly correlated with fossil fuel energy consumption. Yet with increasing evidence suggesting that the pollution from fossil fuels have an impact on damaging the environment, and could threaten human existence, the economic productivity could no longer be seen as only having beneficial aspects. Kondrat'ev Krapivin and Varotsos (2003) explained, the use of fossil fuels has a demonstrated impact on global warming patterns, and the warming is resulted from growing CO2 emissions to the atmosphere of products from fossil fuel burning.

Yet in reality, the damage to the human species has been demonstrated to have a causal relationship to CO2 emissions that accompany fossil fuel pollution. Jacobson (2008) established this causation, using an econometric model to demonstrate that the results of continued fossil fuel usage could render 21,600 (7400-39,000) excess CO2-caused annual pollution deaths. The link between economic activity, such as burning fossil fuel and pollution is certain, as is the link to CO2 emissions and deteriorated health outcomes for humans. However, the investigation of long-run and short-run dynamic relationships leaves uncertain among these three variables.

Therefore, It is the purpose of this chapter to investigate the causality and co-integration between three factors: pollution, loss of human capital, and economic growth that could potentially initiate evaluation of the short and the long term economic impact of the consequences of pollution. This study is undertaken by analyzing the panel data form China across 30 provinces from 1995 to 2013. The interaction of these three factors, measured by specific air pollution data (SO2), demographic individual mortality data (IMR), and real Gross Domestic Product (GDP)in China will make it possible to discern future projections and supply evidence that could result in changed production practices in China.

Based on my knowledge, None of studies have been done the research on above mentioned casual relationships. In contrast, there were few papers to study the causality and co-integration between energy consumption, economic growth and pollution emission, e.g.Kraft and Kraft (1978), Stern (1993), Aqeel and Butt (2000), Yuan et al (2008), Ghosh (2010), Binh (2011) and Farhani and Rejeb (2012). Some studies found a long-run relationship between these three factors while other didn't. This chapter will study the long-run and the short-run dynamic relationship between human resource, pollution emission and economic growth based on the studies of testing the causality and co-integration between energy consumption, economic growth and pollution emission. The motivation and result of this study will lead a better understanding of sustainable economic development theory.

The rest of the chapter is organized as follows. Section 2 presents a brief literature reviews. Section 3 describes the data and section 4 methodology and empirical results. Section 5 concludes and states the policy implications of the results.

4.2 Literature Reviews

4.2.1 The relationship between pollution and economic growth

In an effort to illustrate the complex relationship between economic development and environmental damage (and the residual damage to human health), scientists apply the environmental Kuznets curve (EKC[1]). This elaboration of data draws on the work of Simon Kuznets, an economist who theorized that as an economy develops, social inequalities will necessarily increase in the beginning and decrease after a certain level of economic development. This relationship suggested that rather than an increase in social inequalities as the total economy develops, a peak point will emerge when the disparity is very great. However, it is very possible that a growth in the economy will eventually lessen social inequality after an initial disparity (Kuznets, 1955). Kuznets's work is a fundamental principle within

[1]EKC was called Kuznets curve in the beginning and it graphed the hypothesis that as an economy develops, market forces first increase and then decrease economic inequality. It was established by an economist, Simon Kuznets in the 1950s. Later on, The phenomenon has been labeled as Environmental Kuznets Curve by Panayotou (1993) who imposed the environmental pressures on Kuznets curve.

macroeconomic theory, and yet the application of these principles to the environment did not reach a wide audience until Grossman and Krueger (1991) applied Kuznets's principles to environmental factors in their analysis of the future impact of the North American Free Trade Agreement (NAFTA) on the global environment. This paper is the first study on the relationship between environment pollution and economic growth based on the EKC hypothesis. The research indicate a relationship of inverted U-shaped EKC curve between average income and environmental pollution.

The views of Grossman and Krueger (1991) may have been intriguing from a perspective of businesses and of nations that sought to develop global political capital alongside economic capital. However, in reality, the science behind Kuznets's findings, let alone Grossman and Krueger's idea was very limited. This is not to suggest that the findings were not important. It is to suggest that the conclusion that the eventual environmental benefit would emerge from economic growth was not quite as simple as Grossman and Krueger would have hoped. This is why there was a series of empirical studies about EKC has been released. Most of the empirical studies are based on multi-countries, but cross-section analysis assumes that all cross-section countries react identically regardless their different income level, geographical conditions,culture and history (Panayotou, 1993 and 1995; Grossman and Krueger, 1995; Dijkgraaf and Vollebergh, 1998; Hill and Magnani, 2002; etc). However, recently, some researchers test the EKC relationship within an individual country (Firedel and Getzner, 2003; De Bruyn, 2000; Lekkakis, 2000; Stern and Common, 2001; etc). Most of studies found an EKC relationship (inverted U-shape curve) from their empirical results.

4.2.2 The relationship between pollution and human capital

Later on, the relationship between pollution pressures and human capital gained a powerful tool for studying the economic development. The concept of this study is that the pollution may cause the loss of human capital to retard the economic growth in long run. Zivin and Neidell (2012) merged a unique dataset on individual-level daily harvest rates for agricultural workers with data on environmental conditions to assess the impact of ozone pollutant on worker's productivity. They found that a 10 ppb change in average ozone exposure results in a significant and robust 5.5 percent change in agricultural worker productivity. This would echo the findings of Chang et al (2016) who investigated the effect of air pollution on worker productivity in the service sector by focusing on two call centers in China and concluded that higher levels of air pollution decrease worker's productivity by reducing the number of call that workers complete each day.

While using worker's productivity as a human capital health factor of an individual, Tanaka (2015) explored the impact of environmental regulations in China on infant mortality and he found that the infant mortality rate fell by 20 percent in the treatment cities designated with environmental regulation as "Two Control Zones". Several prior studies before this paper have focused on variation in air quality induced by recession (Chay and Greenstone, 2003 a), weekly fluctuations (Currie and Neidell, 2005), wildfires (Jayachandran, 2009), or wind directions (Luechinger, 2014). Chay and Greenstone (2003 b) concluded an outstanding evidence for the linkage between the environmental regulation as "Clean Air Act" of 1970 and infant mortality in U.S. However, whether or how effectively the environmental regulation can improve human health in developing countries remains uncertain. In contrast, Tanaka (2015) solves this uncertainty.

In addition, He (2013), tested the effect of air pollution on cardiovascular mortality evidences from the Beijing Olympic Games. He found that the decreasing current PM10 concentration by 10 percent will save more than 67,000 lives from cardiovascular diseases in the urban areas in China each year. Therefore, the various results provided here proves that pollution pressures are negatively correlated with individuals' health factor. However, the long-run relationship between these two variables leaves uncertain.

4.2.3 The causality between energy consumption, economic growth and pollution emissions

In order to learn the theory of sustainable economic growth, many researchers studied the relationship between energy consumption, economic growth and pollution emissions. Apergis and Payne (2010) have explored the relationship between energy consumption, and real output for 11 countries of the commonwealth of independent states over period 1992 to 2004. They found that in the long-run, energy consumption has a significant positive impact on carbon dioxide emissions while the relationship between real output and carbon dioxide emissions represented an inverted-U shape. They also found a bidirectional causality between energy consumption and CO2 emissions and a bidirectional causality between energy consumption and real GDP per capita in the long-run, whereas, the short-run dynamics revealed a unidirectional direction from energy consumption and real output.

Acaravci and Ozturk (2010), also tested the dynamic relationship between these three variables. They implemented an autoregressive distributed lag bounds co-integration analysis developed by Persaran and Shin (1999) and Persaran et al (2001), along with error correlation based Granger causality models to analyze these relationships for 19 European countries. The results reported an evidence of long-run relationship between carbon dioxide emissions per capita, energy consumption per capita and real GDP per capita only for Denmark, Germany, Greece, Iceland, Italy, Portugal and Switzerland. Furthermore, Wang et al (2011) using the same method to investigate these relationships based on panel data for 28 provinces in China during 1995 t0 2007. The findings echo Acaravci and Ozturk (2010)'s results.

Farhani and Rejeb (2012) applied the panel unit root tests, panel co-integration methods and panel causality test to investigate these relationships for 15 MENA countries covering the annual period from 1973 to 2008. The findings revealed that there is no causal link between GDP and energy consumption while there is a causality between CO2 emissions and energy consumption in the short run and there is a causality running from GDP and CO2 emissions to energy consumption in long-run.

Therefore, from the inspirations of previous studies, this chapter extends the recent works cited above by testing the long-run and short-run dynamics between individual's mortality rate (IMR), economic growth (real GDP) and air pollution emission (SO2) across 30 provinces in China from 1995 to 2013.

4.3 Data Sources and Descriptive Statistics

4.3.1 Data Sources

4.3.1.1 The individuals' mortality rate

The variable of individual mortality rate comes from Public Health Statistical Yearbook of China from 1996 to 2014[2]. This variable is measured at a year level and it is calculated by all-caused rate for a given province per 1,000 people.

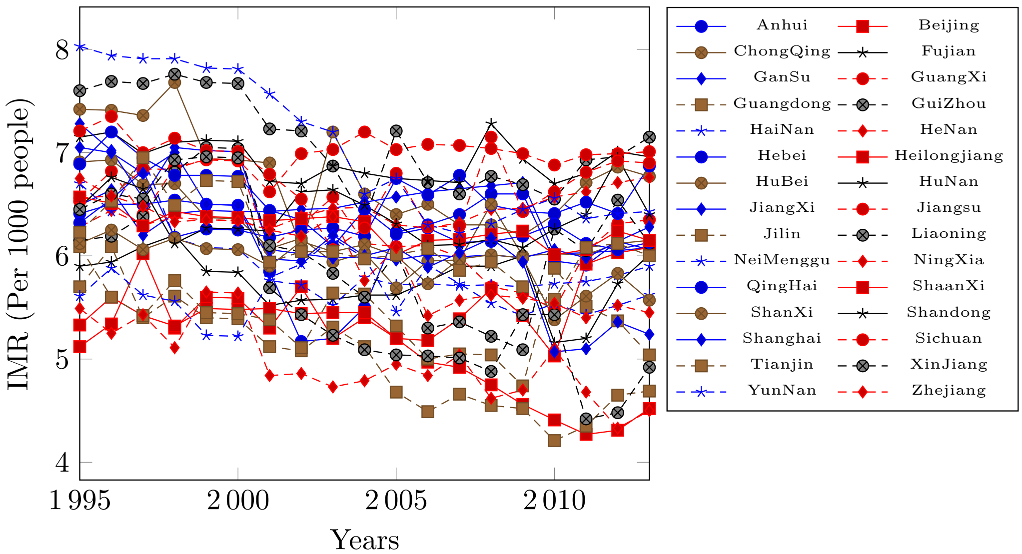

Figure 4.1: Individual's Mortality Rate of 30 Provinces in China (1995-2013).

Figure 4.1 shows the mortality rate across 30 provinces in China. The total evolution of the mortality rate from all 30 provinces seems to follow a downward trend during the period. However, I distinguish

[2]Data source: Department of Public Health of National Bureau Statistic. China Public Health Statistical Yearbook, 1996-2014

that Heibei, Heilongjiang, Hainan, Henan, Hunan, Jiangsu, Shandong and Sichuan present a non-negative evolution of the mortality rate during the study period. Moreover, Heilongjiang, Jiangsu and Shandong provinces, even represent an increasing evolution during the study period. Province Yunnan owns the highest mortality rate in 1995, which is about 8 percent per 1,000 people while provinces Guizhou and Jiangsu own a highest mortality rate in 2013 among other provinces, which is about 7 percent per 1,000 people. Air pollution may not be the only issue to affect the individuals' mortality rate. It may be also caused by the public health institutions availability of the specific province or others. However, since we only study the causality between IMR and air pollution in this chapter, error correction model will absorb these other possibilities affecting the change of mortality rate. This will be discussed in section 4.4.

4.3.1.2 Air pollution emissions

The variable of air pollution emissions - SO2 emissions comes from Other Social Activities and Environmental Protection Statistical Yearbook of China, 1996 to 2014.[3] It covers SO2 emissions from both industry and consumption sides. He, (2013) pointed out the Air Pollution Index (API) score, constructed by WHO,[4] is calculated based on the concentrations of 5 atmospheric pollutants, namely sulfur dioxide (SO2), nitrogen dioxide (NO2), suspended particulates of 10 micrometers or less (PM10), carbon monoxide (CO) and ozone (O3). However, in this paper I only take SO2 as a representation of Air pollution issue for two reasons. First, only SO2 can be found in emission data while others are all concentration data which is from practical measure, and it is improper to be used to analyze the relationship between environmental pressure and economic growth, technically speaking, GDP. This because that concentration data merely reflect the pollution pressure on the monitoring spots, most large cities and the income is usually different from the GDP in these large cities. In addition, many polluting industries move to some undeveloped areas around cities since people pay more attention to more developed cities' environmental quality. This industrial transfer will only affect the concentration data in the monitoring spots but not affect the GDP. Also, weather can easily affect concentration data by the effect is not apparently related with the change of GDP, e.g. rain can shorten the moving distance of pollution in the air but not affect GDP growth (Cao and Wen, 2009).

Second, SO2 emission is highly correlated with the environmental policy in China called Two Control Zones (TCZ) policy, which has been implemented in 1998 in China. The aim of this policy was to reduce the sulfur dioxide (SO2) emissions in the targeted 64 cities across 13 provinces with particularly high air pollution. Therefore, the SO2 emission is the right choice for me to choose upon these points.

[3]Data source: Department of Other Social Activities and Environmental Protection of National Bureau Statistic. China Other Social Activities and Environmental Protection Statistical Yearbook, 1996-2014.

[4]WHO: World Health Organization

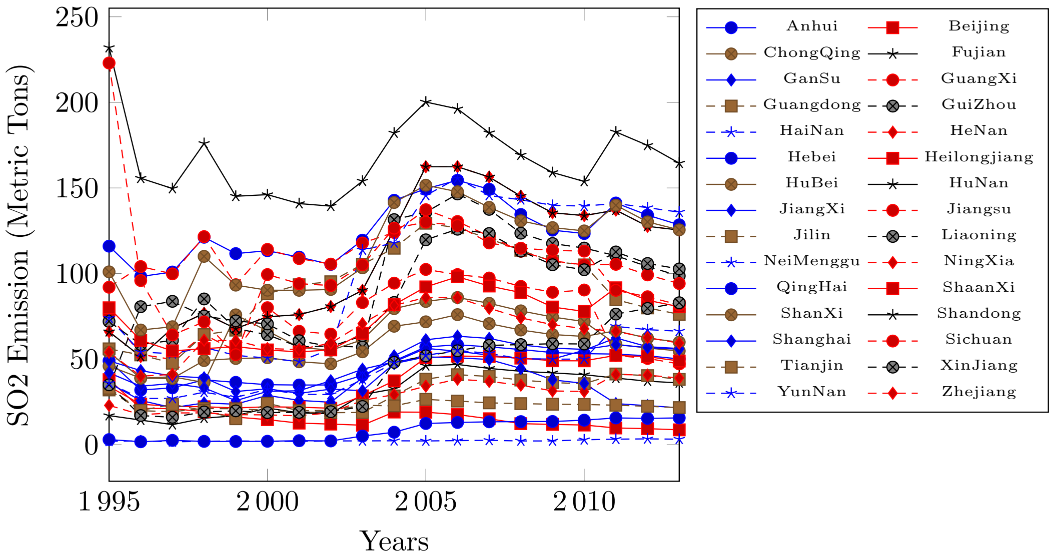

Figure 4.2: SO2 Emission Per Capita of 30 Provinces in China (1995-2013).

Figure 4.2 shows the SO2 emission per capita distributions across 30 provinces in China. Among all provinces, Guangdong, Guizhou, Henan, Hebei, Inner Mongolia,[5] Jiangsu, Shandong, Shanxi and Sichuan provinces have relative high SO2 emission per capita and this is almost match with the province who have a higher mortality rate in section 4.3.1.1. However, the evolution of SO2 emission per capita fluctuates during the study period. This is because of the effects of environmental regulation after 1998.

In 1982, the Environmental Protection Agency (EPA) was established under the Ministry of Urban and Rural Construction whose name has been changed as Ministry of Urban and Rural Construction and Environmental Protection. EPA of China had some authority to issue the environmental protection regulations and guidelines, but it didn't have too much effect at that moment. In 1988, EPA of China raised as an agency directly under the State Council from a bureau under the Ministry of Urban and Rural Construction and Environmental Protection. Its name also changed to National Environmental Protection Agency (NEPA)(Sinkule, 1995). Later, after, in March of 1998, when the time new Primer Rongji, Zhu launched a fundamental reorganization of governmental agencies, NEPA was raised again from a semi-state level to a state level and its name was changed again in State Environmental Protection Administration (SEPA). After this reform, SEPA became the only agency who has increased its official rank. This indicated that Chinese government noticed that environmental protection is an increasing critical issue and paid serious attention to environmental management (Ma, 1998). Because of the changes, the increased focus on the development of the regulatory system, and on monitoring and supervision of environmental performances of various actors became the main responsibilities of the NEPA-SEPA.

[5]Inner Mongolia, known as the Neimonggu province in China.

4.3.1.3 Real GDP distribution

The variable of Gross Domestic Product comes from National Account Statistical Yearbook of China, 1996 to 2014[6]. It is adjusted by the GDP index taking 1995 as the base year. Since economic development in China has made great achievements in these decades, GDP has grown fast. However, the huge amount of population and the different pace of development among regions still cause a weak economic foundation of China. Therefore, continuous economic development, eliminating poverty and improving individual's living standard are still being the main goal of Chinese government.

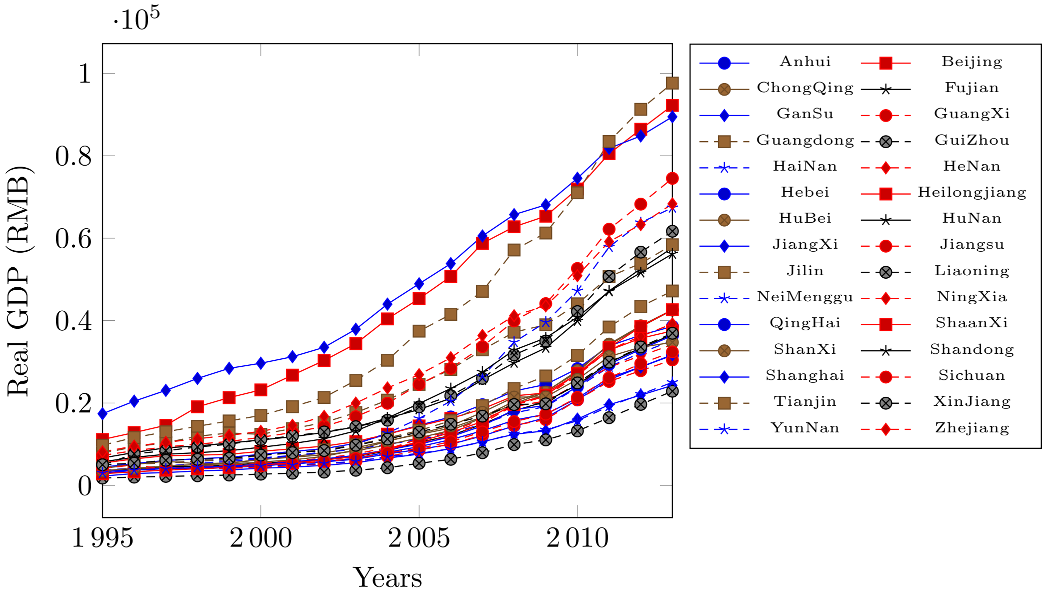

Figure 4.3: Real GDP Per Capita of 30 Provinces in China (1995-2013).

Figure 4.3 describes the real GDP per capita across 30 provinces of China. The trend of the GDP growth is over all an upward sloped relation. Among all provinces, Beijing, Guangdong, Inner Mongolia, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin have the faster evolution of GDP per capita growth. Especially the growth become really sharp after 2002 for provinces of Guangdong, Jiangsu and Hebei.

Since the introduction of economic reforms, China's economy has grown substantially faster than pre-reform period, and, for the most part, has avoided major economic disruptions[7] From 1979 to 2013, China's annual real GDP averaged nearly 10%. This has meant that, on average, China has been able to double the size of its economy in real terms every eight years. The economic growth experiencing three peaks after the reforms from 1979. The First peak was in 1984, about 15% of annual real GDP growth rate. Then it declined until passed the depression period of 1989 and rise again until

[6]Data source: Department of National Account of National Bureau Statistic. China National Account Statistical Yearbook, 1996-2014

[7]China's economic growth declines significantly following the aftermath of the Tiananmen massacre that occurred in June 1989. Several countries, including the United States, imposed trade sanctions against China, causing Chinese economic reforms essentially put on hold. China's real GDP growth rate fell from 11.3% in 1988 to 4.1% in 1989, and declined to 3.8% in 1990. In 1991, Chinese economic reforms were resumed, and several economic sanctions were lifted. As a result, China's rapid economic growth rates have resumed since then.

hit the peak of 1992, about 14.2% of annual real GDP growth rate. Furthermore, it decreased again and hit the recession on 1999, about 7.6% of annual real GDP growth rate, then it increased again from 2000 to 2007 and hit the peak on 2007, about 14.2% of annual real GDP growth rate. The growth was especially faster after 2002 during that period. China's real GDP growth fell from 14.2% in 2007 to 9.6% in 2008 because of the global slowdown in 2008, and hit 9.2% in 2009. In response, the Chinese government implemented a large economic stimulus package and an expansive monetary policy. These measures boosted domestic investment and consumption and helped prevent a sharp economic slowdown in China. From 2009 to 2011, China's real GDP growth averaged 9.6%. China's economy has been slowed in recent years and its real GDP growth rate fell from 10.4% in 2010 to 7.8% in both 2012 and 2013 (Morrison, 2015).

At last the data of total population comes from the Population Statistical Yearbook of China, 1996 to 2014[8].

4.3.2 Descriptive statistics

The most adapted methodology is that we start with a descriptive statistics of these three variables of the 30 provinces in China. We summarize these three variables in a log value in Table 4.1.

Table 4.1: Descriptive Statistics

	LNIMR	**LNSO2**	**LNRGDP**
Panel A:1st and 2nd Moments			
Mean	1.807489	3.858458	9.487885
Maximum	2.083184	5.446737	11.48887
Minimum	1.437463	.5241958	7.49337
Std. Dev.	.1177376	.9553078	.8711004
Panel B: 3rd and 4th Moments			
Skewness	-.5606485	-1.453813	.1641952
Kurtosis	3.297561	5.574496	2.113166
Jarque-Bera	24.25	30.66	54.93
Probabilities	0.0000	0.0000	0.0336
Panel C: Other Information			
Obs	570	570	570
Provinces	30	30	30
Years	19	19	19

[8]Data source: Department of Population of National Bureau Statistic. China Population Statistical Yearbook, 1996-2014.

4.4 Methodology and Results

4.4.1 Panel Unit Root Analysis

Before I process the concrete estimations for the my analysis, I need to check the variables' properties which need to avoid the possibility of spurious regression. This chapter implements six different unit root tests, including Levin-Lin-Chu (LLC) test (Levin et al, 2002), Harris-Tzavalis (HT) test (Harris and Tzavalis, 1999), Breitung test (Breitung, 2000), Im-Pesaran-Shin (IPS) test (Im et al, 2003), ADF-Fisher Chi-square test (Augmentd Dickey Fuller, 1979), and PP-Fisher Chi-square test (Phillips and Perron, 1988) in to evaluate the stationary process of the variables in this chapter.

Conventional unit root tests- Augmented Dickey Fuller (ADF) and Phillips and Perron tests, among others, for individual time series are known to have low power against the alternative of stationarity of the series, particularly for small samples. Recent developments in the literature suggest that panel based unit root tests have higher power than unit root tests on individual time series. Since Panel data provide a larger number of point data that increasing the degrees of freedom and reducing the collinearity between regressors, it allows for more powerful statistical tests and the test statistics asymptotically follow a normal distribution instead of non-conventional distributions. Besides the above mentioned four panel unit root tests (LLC, HT, Breitung and IPS) that I use in this paper, Maddala and Wu (1999), Choi (2001) and Hadri (2000) are also newly developed panel unit root tests for recent developments. By doing these tests, the basic autoregressive model can be expressed as follows:

$$y_{it} = \rho_i y_{it-1} + \mathbf{z'_{it}}\gamma_i + \epsilon_{it} \tag{4.1}$$

where $i = 1, 2, \cdots, N$ represent different sections observed over periods $t = 1, 2, \cdots, T$, $\mathbf{z'_{it}}$ are exogenous variables in the model including any panel fixed effects or individual trend,ρ_i is the autoregressive coefficient, and ϵ_i is a stationary process. If $\rho_i < 1$, y_i is said to be weakly trend-stationary[9]. However, if $\rho_i = 1$, y_i contains a unit root. LLC and Breitung, assume that the ϵ_{it} is $IID(0, \sigma^2_\epsilon)$ and $\rho_i = \rho$ for all i. This implies that the coefficient of y_{it-1} is homogeneous across all cross section units of the panel and that individual processes are cross-sectionally independent. Similarly, HT assumes that ϵ_{it} is independent and identically distributed $IID(0, \sigma^2_\epsilon)$ with constant variance across panels. Equation (1)is often written as

$$\Delta y_{it} = \beta_i y_{it-1} + \mathbf{z'_{it}}\gamma_i + \epsilon_{it} \tag{4.2}$$

[9] y_{it}s here in this paper are $LNIMR$, $LNSO2$ and $LNRGDP$ respectively.

so that the null hypothesis is then $H_0 : \beta_i = 0$ for all i (contains a unit root) versus the alternative $H_a : \beta_i < 0$ (stationary).

LLC and IPS seem to be most popular among the panel unit root tests, where LLC assumes homogeneity in the dynamics of the autoregressive coefficients for all panel members, whereas IPS assumes for heterogeneity in these dynamics. This is a more reasonable proposition because heterogeneity could arise from different locations due to different economic conditions and levels of development.

4.4.1.1 Levin-Lin-Chu (2002) panel unit root test

Levin et al (2002) test is based on the conventional ADF test[10] (Dickey and Fuller, 1979) and found that the panel approach substantially increased power in finite samples when compared with the equation of ADF (1979) test. They proposed a panel-based version of equation that restricts the slope coefficient β_i to be identical across individual sections as following,

$$\Delta y_{it} = \alpha_i + \beta y_{it-1} + \mathbf{z'_{it}}\gamma_i + \sum_{j=1}^{p} \psi_{ij}\Delta y_{it-j} + \varepsilon_{it} \tag{4.3}$$

where Δ is the first difference operator, and ε_{it} is a white-noise disturbance with variance of σ^2.

The LLC test is started by estimating the ADF regressions which are implemented for each individual i, and then the orthogonalized residuals are generated and normalized. This means that after ADF regressions are being estimated, the two orthogonalized residuals are generated by the following two auxiliary regressions:

$$\Delta y_{it} = \sum_{j=1}^{\hat{p}_i} \psi_{ij}\Delta y_{it-j} + \mathbf{z'_{it}}\gamma_i + e_{it} \tag{4.4}$$

$$y_{it-1} = \sum_{j=1}^{\hat{p}_i} \psi_{ij}\Delta y_{it-j} + \mathbf{z'_{it}}\gamma_i + e_{it} + v_{it-1} \tag{4.5}$$

The residuals are saved at $\hat{e}_{it}$ and $\hat{v}_{it-1}$, respectively. To remove heteroscedasticity, the residuals $\hat{e}_{it}$ and $\hat{v}_{it-1}$ are normalized by the regression standard error from the ADF regression. Denote the standard error as

$$\hat{\sigma}_{\varepsilon i} = \sqrt{\sum_{t=\hat{p}_i+2}^{T} \left(\hat{e}_{it} - \hat{\beta}_i\hat{v}_{it-1}\right)^2 / (T - p_i - 1)} \tag{4.6}$$

[10]The Dickey and Fuller (1979) implements a regression equation:

$$\Delta y_{it} = \alpha_i + \beta_i y_{it-1} + \mathbf{z'_{it}}\gamma_i + \sum_{j=1}^{p} \psi_{ij}\Delta y_{it-j} + \varepsilon_{it}$$

it consists to test the null of contain unit root $H_0 : \beta_i = 0$ against the alternative, stationary of y_{it}, $H_a : \beta_i < 0$. The test statistic is calculated as $t_{\beta_i} = \frac{\hat{\beta}_i}{\sigma_{\hat{\beta}_i}}$

By using the standard error in equation (4.6) we can normalize residuals from the estimations of equations (4.4) and (4.5) as,

$$\tilde{e}_{it} = \frac{\hat{e}_{it}}{\hat{\sigma}_{\varepsilon i}} \tag{4.7}$$

$$\tilde{v}_{it-1} = \frac{\hat{v}_{it-1}}{\hat{\sigma}_{\varepsilon i}} \tag{4.8}$$

Next, The ratios of long-run to short-run standard deviations of Δy_{it} are estimated. Denote the ratios and the long-run variances as s_i and σ_{yi}, respectively. Therefore, the ratios are estimated by $\hat{s}_i = \hat{\sigma}_{yi}/\hat{\sigma}_{\varepsilon i}$. Let the average standard deviation ratio be $S_N = (1/N)\sum_{i=1}^{N} s_i$, and let its estimator be $\hat{S}_N = (1/N)\sum_{i=1}^{N} \hat{s}_i$. Afterward, the panel test statistics are calculated. In order to calculate the t statistic and the adjusted t statistic, we estimate the following equation:

$$\tilde{e}_{it} = \beta\tilde{v}_{it-1} + \tilde{\varepsilon}_{it} \tag{4.9}$$

where the total number of the observations is $N\tilde{T}$, with $\bar{\hat{p}} = \sum_{i=1}^{N} \hat{p}_i/N$, and $\tilde{T} = T - \bar{\hat{p}} - 1$.

Levin-Lin-Chu (2002) tested $H_0 : \beta_i = \beta = 0, \forall i$ (contain an unit root) against the alternative of $H_a : \beta_i = \beta < 0, \forall i$ (stationary). The test statistic can be calculated as $t_\beta = \frac{\hat{\beta}}{\sigma_{\hat{\beta}}}$, with OLS estimator $\hat{\beta}$ and standard deviation $\sigma_{\hat{\beta}}$. However, the standard t statistic diverges to negative infinity for the models (4.4) and (4.5). Levin, Lin, and Chu (2002) propose the following adjusted t statistic:

$$t^*_\beta = \frac{t_\beta - N\tilde{T}\hat{S}_N\hat{\sigma}_{\tilde{\varepsilon}}^{-2}\sigma_{\hat{\delta}}\mu^*_{m\tilde{T}}}{\sigma^*_{m\tilde{T}}}, \quad m = 1, 2, 3 \tag{4.10}$$

Where,

$$\hat{\sigma}^2_{\tilde{\varepsilon}} = \left[\frac{1}{N\tilde{T}}\sum_{i=1}^{N}\sum_{t=2+\hat{p}_i}^{T}(\tilde{e}_{it} - \hat{\delta}\tilde{v}_{it-1})^2\right] \tag{4.11}$$

The mean and standard deviation adjustments $(\mu^*_{m\tilde{T}}, \sigma^*_{m\tilde{T}})$ depend on the time series dimension $\tilde{T}$ and model specification m, which can be found in Table 2 of Levin-Lin-Chu (2002).

4.4.1.2 Im-Pesaran-Shin (2003) panel unit root test

In contrast, Im et al (2003) test proposed the mean group approach and used the average of the t_{β_i} which calculated from estimating the ADF (1979) regression to perform the following $Z_{\tilde{t}-bar}$ statistic:

$$Z_{\tilde{t}-bar} = \frac{\sqrt{N}\{\tilde{t}\text{-bar}_{NT} - E\left(\tilde{t}_T\right)\}}{\sqrt{Var\left(\tilde{t}_T\right)}} \implies \mathcal{N}(0,1) \tag{4.12}$$

where $\tilde{t}\text{-bar}_{NT} = \frac{1}{N}\sum_{i=1}^{N} \tilde{t}_{it}$. $E\left(\tilde{t}_T\right)$ and $Var\left(\tilde{t}_T\right)$ are the mean and variance of $\tilde{t}_{iT}$, respectively. The limit is taken as $N \to \infty$ and T is fixed. Their values are simulated for finite samples without a time trend. The $Z_{\tilde{t}bar}$ is also likely to converge to standard normal.

The slope of coefficient β_i, comparing with a constant β in LLC (2002), is the number of lags in the ADF regression and the error terms ε_{it} are assumed to be independently and normally distributed random variables for all i and t with zero means and finite heterogeneous variances σ_i^2. Both β_i and the lag order ψ_{ij} are allowed to vary among cross-sections. The null hypothesis, $H_0 : \beta_i = 0$ for all i, is that each series in the panel contains a unit root versus the alternative hypothesis, $H_a : \beta_i < 0$ for at least one i in the panel is stationary. The test statistic is normally distributed under the null hypothesis and the critical values for given values of N and T are provided in Im et al. (2003).

4.4.1.3 The results from all panel unit root tests

Therefore, by implementing the above panel unit root tests for our three variables: $LNIMR$, $LNSO2$ and $LNRGDP$ we report the results in Table 4.2 below.

Table 4.2: Panel Unit Root Test Results

Method	**LNIMR**		**LNSO2**		**LNRGDP**	
	Statistic	**Prob**	**Statistic**	**Prob**	**Statistic**	**Prob**
LLC-t*						
Log Level Value	-3.7393	0.0001**	-5.7562	0.0000**	0.3778	0.6472
First Difference	-9.0786	0.0000**	-9.8967	0.0000**	-6.8301	0.0000**
HT-z-stat						
Log Level Value	-7.7715	0.0000**	-1.1618	0.1227	1.7193	0.9572
First Difference	-37.3710	0.0000**	-33.0932	0.0000**	-22.6059	0.0000**
Breitung-t-stat						
Log Level Value	-2.5412	0.0055**	-0.3511	0.3627	2.7781	0.9973
First Difference	-14.0445	0.0000**	-6.5128	0.0000**	-5.4631	0.0000**
IPS-$Z_{\tilde{t}-bar}$-stat						
Log Level Value	-3.9652	0.0000**	-0.6850	0.2467	3.3830	0.9996
First Difference	-12.8891	0.0000**	-12.4953	0.0000**	-8.8170	0.0000**
ADF-Fisher-χ^2-stat						
Log Level Value	157.1927	0.0000**	71.5237	0.1127	63.3960	0.3576
First Difference	272.5137	0.0000**	322.250	0.0000**	124.327	0.0000**
PP-Fisher-χ^2-stat						
Log Level Value	78.2885	0.0566	64.7355	0.3149	42.9837	0.9524
First Difference	628.257	0.0000**	362.940	0.0000**	183.356	0.0000**

Note: All six tests examine the null hypothesis of non stationarity aginst the alternative hypothesis of stationarity. Probabilities for ADF-Fisher-type test was computed by using an asymptotic χ^2 distribution. All other tests assumed asymptotic normality. The lag length is selected by using Schwarz information criterion. ** represents statistical significance at the 5% level.

The results from all tests reported in Table 4.2 indicate that the statistics significantly determine that the log level values of all series are non-stationary while all variables are stationary at least at 5% significance level of their first difference, or technically speaking I(1), integrated of order 1.

4.4.2 Panel Cointegration Analysis

After the panel unit root tests, I need to do the further analysis of panel cointegration tests[11] in order to determine whether the regressions are spurious. By doing this, this chapter implements three panel conitegration tests: Pedroni (2004), Kao's (1999) and Johansen's (1988) Fisher. A panel cointegration model which allows for considerable heterogeneity of individual's mortality rate is proposed as following:

$$LNIMR_{it} = \alpha_{1i} + \beta_{1i} LNRGDP_{it} + \delta_{1i} LNSO2_{it} + e_{it} \tag{4.13}$$

where $i = 1, \cdots, N$ and $t = 1, \cdots, T$, α_i is the fixed effect varying across the sections, β and γ are slope coefficients, and all three variables $LNIMR$, $LNSO2$ and $LNRGDP$ are at I(1).

4.4.2.1 Pedroni (2004) panel cointegration test

Pedroni (2004)developed seven different residual based panel cointegratin tests for testing the null hypothesis of no cointegration. There are four within-dimension based statistics: panel-υ, panel-ρ, semi-parametric panel-t and parametric panel-t. These four tests are calculated by summing up the numerator and denominator over N cross sections separately. Moreover, there are three between-dimension-based statistics: group-ρ, semi-parametric group-t and parametric group-t. They are calculated by diving the numerator and the denominator before summing up over N cross-sections. To implement the Pedroni (2004) cointegration test, the independent variables are assumed to be at most I(1). I employ the Pedroni (2004) cointegration technique that allows for individual fixed effects and deterministic trends to test for the long-run relationship among the three variables of IMR, SO2 emission and real GDP of equation (4.13). Pedroni cointegration tests use the regression equation as follows:

$$y_{it} = \alpha_i + \phi_i t + \sum_{j=1}^{m} \beta_{ij} x_{ijt} + e_{it} \tag{4.14}$$

where $i = 1, \cdots, N$ and $t = 1, \cdots, T$. ϕ_i is the slope coefficient of time trend t, β_{ij} are slope coefficients. Both y_{it} and x_{it} are integrated of order one in levels, I(1). Under null hypothesis of no cointegration $H_0 : \rho_i = 0; \forall i$, we estimate the equation of,

$$\hat{e}_{it} = \rho_i \hat{e}_{it-1} + u_{it} \tag{4.15}$$

where ρ_i is the autoregressive term of the estimated residuals and calculate seven statistics as,

[11] The requirement of cointegration tests needs that the variables must be non-stationary at level value but stationary at their first difference.

(i). Panel υ-statistic

$$T^2 N^{3/2} Z_{\hat{\upsilon}_{NT}} = T^2 N^{3/2} (\sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{it-1}^2)^{-1} \tag{4.16}$$

where $\hat{L}_{k1i}^{-2}$ is the inverse function of the long-run variance $\hat{L}_{11i}^2$.[12] In order to calculate the semi-parametric statistics, the regression (4.15) is estimated using the residual of $\hat{e}_{it}$ from the cointegration regression of equation (4.14). By doing this the contemporaneous variance $\hat{s}_i^2$ and the long-run variance $\hat{\sigma}_i^2$ of the error term u_{it} can be calculated. For the derivation of $\hat{\sigma}_i^2$, $4(\frac{T}{100})^{2/9}$ is used as the lag truncation function for the Newey and West kernel estimator[13].

To calculate the parametric statistics, the panel-t and the group-t, are estimated using the residual $\hat{e}_{it}$ with a regression of $\hat{e}_{it} = \rho_i \hat{e}_{it-1} + \gamma_{i1} \Delta \hat{e}_{it-1} + \cdots + \gamma_{ip_i} \Delta \hat{e}_{it-p_i} + u_{it}^*$. At last, the simple variance and the long-run variance of u_{it}^* can be computed as $\hat{s}_i^2$ and $\hat{s}_{NT}^2$, respectively. The lag truncation order of ADF t-statistics can be determined by any lag order selection criterion. Therefore, the following statistic formulas are,

(ii). Panel ρ-statistic

$$T\sqrt{N} Z_{\hat{\rho}_{NT}-1} = T\sqrt{N} \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \hat{e}_{it-1}^2 \right)^{-1} \sum_{i=1}^{N} \sum_{t=1}^{T} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right) \tag{4.17}$$

(iii). Panel-t statistic (Semi-parametric)

$$Z_{t_{NT}} = \left(\tilde{\sigma}_{NT}^2 \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{e}_{it-1}^2 \right)^{-1/2} \sum_{i=1}^{N} \sum_{t=1}^{T} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right) \tag{4.18}$$

(iv). Panel-t statistic (Parametric)

$$Z_{t_{NT}}^* = \left(\tilde{s}_{NT}^{*2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{it-1}^2 \right)^{-1/2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{it-1} \Delta \hat{e}_{it} \tag{4.19}$$

(v). Group-ρ statistic

$$TN^{-1/2} \tilde{Z}_{\hat{\rho}_{NT}-1} = TN^{-1/2} \sum_{i=1}^{N} \left[\left(\sum_{t=1}^{T} \hat{e}_{it-1}^2 \right)^{-1} \sum_{t=1}^{T} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right) \right] \tag{4.20}$$

[12]The long-run variance $\hat{L}_{11i}^2$ is calculated by estimating the first difference regression of equation (4.13) such as, $\Delta LNIMR_{it} = \beta_{1i} \Delta LNRGDP_{it} + \beta_{2i} LNSO2_{it} + \zeta_{it}$ for equation (4.13) as an example. Using the residuals from the differenced regression, the long-run variance $\hat{L}_{11i}^2$ of ζ_{it} is calculated with a Newey and West (1987) estimator as,

$$\hat{L}_{11i}^2 = \frac{1}{T} \sum_{t=1}^{T} \hat{\zeta}_{it}^2 + \frac{2}{T} \sum_{s=1}^{M_i} \left(1 - \frac{s}{M_i + 1} \right) \sum_{t=s+1}^{T} \hat{\zeta}_{it} \hat{\zeta}_{it-s}$$

where M_i is the maximum lags.

[13]Pedroni (1995, 2004) and Newey and West (1994) recommended to use this lag truncation function.

(vi). Group-t statistic (Semi-parametric)

$$N^{-1/2}\tilde{Z}_{t_{NT}} = N^{-1/2}\sum_{i=1}^{N}\left[\left(\hat{\sigma}_i^2\sum_{t=1}^{T}\hat{e}_{it-1}^2\right)^{-1/2}\sum_{t=1}^{T}\left(\hat{e}_{it-1}\Delta\hat{e}_{it}-\hat{\lambda}_i\right)\right] \tag{4.21}$$

(vii). Group-t statistic (Parametric)

$$N^{-1/2}\tilde{Z}^{*}_{t_{NT}} = N^{-1/2}\sum_{i=1}^{N}\left[\left(\hat{s}_i^{*2}\sum_{t=1}^{T}\hat{e}_{it-1}^2\right)^{-1/2}\sum_{t=1}^{T}\hat{e}_{it-1}\Delta\hat{e}_{it}\right] \tag{4.22}$$

where

$$\hat{\lambda}_i = \frac{1}{T}\sum_{s=1}^{M_i}\left(1-\frac{s}{M_i+1}\right)\sum_{t=s+1}^{T}\hat{u}_{it}\hat{u}_{it-s}, \qquad \hat{s}_i^2 = \frac{1}{T}\sum_{t=1}^{T}\hat{u}_{it}^2,$$

$$\hat{\sigma}_i^2 = \hat{s}_i^2 + a\hat{\lambda}_i, \qquad \tilde{\sigma}_{NT}^{*2} = \frac{1}{N}\sum_{i=1}^{N}\hat{L}_{11i}^{-2}\hat{\sigma}_i^2,$$

$$\tilde{s}_i^{*2} = \frac{1}{T}\sum_{t=1}^{T}\hat{u}_{it}^{*2}, \qquad \tilde{s}_{NT}^{*2} = \frac{1}{N}\sum_{i=1}^{N}\tilde{s}_i^{*2}.$$

Between-dimension-based statistics are just the group mean approach extensions of the within-dimension-based ones. After the calculations of the panel cointegration test statistics, the appropriate mean and variance adjustment terms are applied, so the test statistics are asymptotically standard normally distributed as,

$$\frac{\aleph_{NT} - m_1\sqrt{N}}{\sqrt{m_2}} \Rightarrow N(0,1) \tag{4.23}$$

where $\aleph_{NT} = (T^2N^{3/2}Z_{\hat{\nu}_{NT}}, T\sqrt{N}Z_{\hat{\rho}_{NT}-1}, Z_{t_{NT}}, Z^{*}_{t_{NT}}, TN^{-1/2}\tilde{Z}_{\hat{\rho}_{NT}-1}, N^{-1/2}\tilde{Z}_{t_{NT}}, N^{-1/2}\tilde{Z}^{*}_{t_{NT}})$ is the standardized form of the statistic with respect to N and T, and m_1 and m_2 are the moments of the underlying Brownian motion functionals.

4.4.2.2 The results from Pedroni (2004) cointegration test by taking LNIMR as a dependent variable

Now, we make an assumption of unique cointegration equation with $LNIMR$ as dependent variable as of equation (4.13). In Pedroni(2004) test, we regress this equation (4.13) with FMOLS[14] to get the residual. The residual/error term will be tested whether it is stationary. The results in table 4.3 below shows that this cointegration equation results in stationary error term. Since all P-value are lower than 5% significance level and we have to reject the null that there is no cointegration from this equation (4.13), expecting the panel υ-statistic and panel ρ-statistic.

[14]Fully Modified Ordinary Least Squares. It will be defined in Section 4.4.4

Table 4.3: Pedroni (2004)'s residual cointegration test results: *LNIMR* as dependent variable

	Test Statistics	Prob		Test Statistics	Prob
With-dimension			**Between-dimension**		
Panel υ-stat	-0.404313	0.6570			
Panel ρ-stat	-1.530999	0.0629	Group ρ-stat	0.194625	0.5772
Panel PP-stat	-4.70023**	0.0000	Group PP-stat	-7.548955**	0.0000
Panel ADF-stat	-5.377816**	0.0000	Group ADF-stat	-7.730753**	0.0000

Note: The null hypothesis is no cointegration for all variables. Under the null hypothesis tests, all variables are normal distributed in (0, 1). The lag length is selected by Schwarz Information Criterion (SIC). ** represents statistical significance at the 5% level.

4.4.2.3 Kao (1999) panel cointegration test

Kao (1999) developed parametric residual-based panel tests by testing the null hypothesis of no cointegration. He expanded the DF and ADF unit root tests to panel cointegration. Again, all variables are restricted to be at most I(1) in order to implement this test. Here in this paper, I implemented the ADF one for processing equation (13). In the bi-variate case Kao considers the following model:

$$y_{it} = \alpha_i + \beta x_{it} + e_{it} \tag{4.24}$$

$$y_{it} = y_{it-1} + u_{it} \tag{4.25}$$

$$x_{it} = x_{it-1} + \varepsilon_{it} \tag{4.26}$$

where α_i is the fixed effect varying across the cross section observations, β is the slope parameter, and it is assumed to be cross-section invariant (i.e. the cointegrating vector is homogeneous), y_{it} and x_{it} are both at I(1).

Comparing with DF type test, which using the AR(1) represent the regression residuals, the ADF type panel statistic is base on the following AR(p) regression.

$$\hat{e}_{it} = \rho\hat{e}_{it-1} + \gamma_1\Delta\hat{e}_{it-1} + \cdots + \gamma_p\Delta\hat{e}_{it-p} + \nu_{itp} \tag{4.27}$$

Therefore, Kao (1999) formulated the ADF panel test statistic as,

$$ADF = \frac{\frac{\sum_{i=1}^{N}(e_i' Q_i \nu_i)}{s_\nu\sqrt{\sum_{i=1}^{N}(e_i' Q_i e_i)}} + \frac{\sqrt{6N}\hat{\sigma}_\nu}{2\hat{\sigma}_{0u}}}{\sqrt{\frac{\hat{\sigma}_{0\nu}^2}{2\hat{\sigma}_\nu^2} + \frac{3\hat{\sigma}_\nu^2}{10\hat{\sigma}_{0\nu}^2}}} \tag{4.28}$$

with

$$Q_i = I - X_{ip}(X_{ip}'X_{ip})^{-1}X_{ip}' \tag{4.29}$$

and

$$t_{ADF} = \frac{\sum_{i=1}^{N}(e_i' Q_i \nu_i)}{s_\nu \sqrt{\sum_{i=1}^{N}(e_i' Q_i e_i)}} \tag{4.30}$$

where the regressor X_{ip} denotes a matrix of observations on the p regressors ($\Delta\hat{e}_{it-1}$, $\Delta\hat{e}_{it-2}$, $\cdots$,$\Delta\hat{e}_{it-p}$), $\hat{\sigma}^2_{0\nu}$ is a consistent estimator of the long-run conditional variance as, $\sigma^2_{0\nu} = \sigma^2_{0u} - \sigma^2_{0u\varepsilon}\sigma_\varepsilon^{-2}$, and $\hat{\sigma}_\nu$ is a consistent estimator of the contemporaneous variance as, $\sigma^2_\nu = \sigma^2_u - \sigma^2_{u\varepsilon}\sigma_\varepsilon^{-2}$. The term σ^2_{0u} specifies the long-run variance of u_{it}, while $\sigma_{u\varepsilon}$ is the contemporaneous covariance between u_{it} and ε_{it}.

Note that e_i is the vector of observations on $\hat{e}_{it-1}$, and it is as

$$s^2_\nu = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{\nu}^2_{itp}}{NT} \tag{4.31}$$

where $\hat{\nu}_{itp}$ is the estimate value of ν_{itp}. Under the null hypothesis, the panel ADF test of Kao (1999) is also asymptotically, $N(0,1)$ distributed as T and N toward to ∞ sequentially.

4.4.2.4 The results from Kao (1999) cointegration test: LNIMR as a dependent variable

Now, we process a Kao (1999) residual cointegration test for the cointegration equation (4.13). The results in Table 4.4 shows rejection the null of no cointegration at the 5% significance level, which implies the existence of cointegration.

Table 4.4: Kao(1999)'s residual cointegration test results: LNIMR as a dependent variable

Dependent Variables		t-statistic	Prob
LNIMR	**ADF**	-3.007539 **	0.0013

Note: The null hypothesis is no cointegration for all variables. Under the null hypothesis tests, all variables are normal distributed in (0, 1). The lag length is selected by Schwarz Information Criterion (SIC). ** represents statistical significance at the 5% level.

Therefore, there is an evidence that the cointegration exists among these three variables from Kao (1999)'s residual cointegration test.

4.4.2.5 Johasen (1988)-Fisher combined individual panel cointegraion test

Unlike Pedroni and Kao residual test that are useful for bivariate panel cointegration, the Johansen-Fisher panel cointegration test proposed by Maddala and Wu (1999) who use Fisher's result to propose and alternative approach to test the cointegration by combining the tests from individual cross-sections to obtain the test statistics for the full panel. The Johansen-Fisher panel cointegration test is panel version of the individual Johansen cointegratin test. It is based on the aggregates of the p-value of the individual Johansen Maximum eigenvalues and trace statistic. If p_i is the p-value from an individual cointegration test for cross-section i, then under the null hypothesis of the panel we test,

$$-2\sum_{i}^{n}\log(p_i) \Rightarrow \chi^2(2n) \tag{4.32}$$

where $\chi^2(2n)$ is a Chi-square distribution with $2n$ degree of freedom. The χ^2 value is based on Mackinnon-Haug-Michelis (1999) p-values for Johansen's cointegratin trace test and maximum eigenvalue test. In the Johansen-Fisher type panel cointegratin tests, the results heavily depends on the number of lags of the VAR system. Under null hypothesis of trace test, we test, $H_0 : r_0 = r_i \leq r$ for all i from 1 to n versus the alternative hypothesis of $H_a : r_0 > r$ for all i from 1 to n. Under null hypothesis of maximum eigenvalue test, we test, $H_0 : r_0 = r$ for all i and against the alternative hypothesis that $H_0 : r_0 > r$ for all i. The standard rank test statistics are defined in terms of average of the trace statistic for each cross section unit and mean and variance of trace statistics. The results for Johansen-Fisher based panel cointegratin test of equation (13) are presented in Table 4.5 indicate that the null hypothesis of zero cointegration vector is rejected at 5% level of significance, which implies that the variables are cointegrated with at least one cointegrating vector.

Table 4.5: Johansen (1988)-Fisher cointegratin test results

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob	Fisher Stat.* (from max-eigen test)	Prob
None	262.6**	0.0000	194.6**	0.0000
At most 1	127.7**	0.0000	134.2**	0.0000
At most 2	52.41	0.7464	52.41	0.7464

Note: The null hypothesis is no cointegration. p-values are computed using asymptotic Chi-square distribution. ** represents statistical significance at the 5% level. Fisher (1932)'s test applied regardless of the dependent variable.

Therefore, from the above three cointegration tests conducted we can conclude that the variables in our study have a long-run equilibrium relationship among themselves, meaning that individual's mortality rate, SO2 emissions and real GDP (income) move together in the long run.

4.4.3 Panel Causality Analysis

4.4.3.1 Vector Error Correction Model

The above implemented cointegration tests are only able to indicate whether or not the variables are cointegrated and if a long-run relationship exists between them. Since they do not indicate the direction of causality, we need to estimate the two-step panel-based Vector Error Correction Model (VECM) proposed by Engle and Granger (1987). In this test, the error correction term (ECT) is included to the VAR system as an additional variable. The VECM approach well known as the augmented Granger causality test is able to investigate both long and short run causal relationships. The first step is that we estimate the long-run parameters in equation (4.13) by FMOLS in order to obtain the residuals that corresponding to the deviation from long equilibrium and the residuals from equation (4.13) should be I(0). The second step is that we estimate the parameters related to the short-run adjustment. we regress a linear dynamic panel-data error correction models include p lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. The equations that arise for panel Grangeer causality testing are the following as,

$$\Delta LNIMR_{it} = \theta_{1i} + \sum_{k=1}^{p} \theta_{11ik} \Delta LNIMR_{it-k} + \sum_{k=1}^{p} \theta_{12ik} \Delta LNRGDP_{it-k} + \sum_{k=1}^{p} \theta_{13ik} \Delta LNSO2_{it-k} + \lambda_{1i} ECT_{it-1} + u_{1it} \tag{4.33}$$

$$\Delta LNRGDP_{it} = \theta_{2i} + \sum_{k=1}^{p} \theta_{21ik} \Delta LNIMR_{it-k} + \sum_{k=1}^{p} \theta_{22ik} \Delta LNRGDP_{it-k} + \sum_{k=1}^{p} \theta_{23ik} \Delta LNSO2_{it-k} + \lambda_{2i} ECT_{it-1} + u_{2it} \tag{4.34}$$

$$\Delta LNSO2_{it} = \theta_{3i} + \sum_{k=1}^{p} \theta_{31ik} \Delta LNIMR_{it-k} + \sum_{k=1}^{p} \theta_{32ik} \Delta LNRGDP_{it-k} + \sum_{k=1}^{p} \theta_{33ik} \Delta LNSO2_{it-k} + \lambda_{3i} ECT_{it-1} + u_{3it} \tag{4.35}$$

or we can write equations (4.33), (4.34) and (4.35) into Matrix form as,

$$\begin{bmatrix} \Delta LNIMR_{it} \\ \Delta LNRGDP_{it} \\ \Delta LNSO2_{it} \end{bmatrix} = \begin{bmatrix} \theta_{1i} \\ \theta_{2i} \\ \theta_{3i} \end{bmatrix} + \sum_{k=1}^{p} \begin{bmatrix} \theta_{11ik} & \theta_{12ik} & \theta_{13ik} \\ \theta_{21ik} & \theta_{22ik} & \theta_{23ik} \\ \theta_{31ik} & \theta_{32ik} & \theta_{33ik} \end{bmatrix} \begin{bmatrix} \Delta LNIMR_{it-k} \\ \Delta LNRGDP_{it-k} \\ \Delta LNSO2_{it-k} \end{bmatrix} + \begin{bmatrix} \lambda_{1i} \\ \lambda_{2i} \\ \lambda_{3i} \end{bmatrix} ECT_{it-1} + \begin{bmatrix} u_{1it} \\ u_{2it} \\ u_{3it} \end{bmatrix} \tag{4.36}$$

where Δ denotes the first differences, θ_{mit} $(m = 1, 2, 3)$ represents the fixed province effect, $k = 1, \cdots, p$ is the optimal lag length determined by the Schwarz Information Criterion (SIC)[15], and ECT_{it-1} is the estimated lagged error correction term derived from the long-run cointegrating relationship of equation (4.13). Where $ECT_{it} = LNIMR_{it} - \hat{\beta}_i LNRGDP - \hat{\delta}_i LNSO2 - \hat{\alpha_i}$. The parameter of λ_{mi} $(m = 1, 2, 3)$ is the adjustment coefficient and the error term u_{mit}'s $(m = 1, 2, 3)$ are assumed to be white noise and uncorrelated with zero means.

The Wald χ^2-statistic is applied here to examine the direction of any causal relationship between the three variables in short-run aspects. The economic growth does not Granger cause individual's mortality rate in the short-run, if and only if all the coefficients θ_{12ik}'s for all k are not significantly different from zero (i.e. H_0: $\theta_{12ik} = 0$ versus $H_a : \theta_{12ik} \neq 0$) in equation (4.36). Similarly, people's

[15]Schwarz Information Criterion is known as Bayesian Information Criterion (BIC) and it is formally defined as , $BIC = -2ln\hat{L} + kln(n)$, where $\hat{L}$ = the maximized value of the likelihood function of the model M, k =the number of free parameters to be estimated, and n =the number of data points in the observed data x.

mortality rate does not Granger cause economic growth in short-run if all the coefficients θ_{21ik}'s for all k are not significantly different form zero (i.e. H_0: $\theta_{21ik} = 0$ versus $H_a : \theta_{21ik} \neq 0$) in equation (4.38) and so on so forth. The coefficients of ECT indicates the presence of a long-run equilibrium relationship among the variables. Comparing the Wald χ^2-test for determining the short-run causality for variables, the long-run causality is established through the significance of the lagged error correction term based on the t-statistic.

4.4.3.2 The results of panel causality test

The short-run and long-run Granger causality test results are reported in Table 4.6 for equation (4.36). From the results in Table 4.6, We find the short-run Granger causal relationship from LNRGDP to LNIMR at 5% level of significance. In accordance with this result, we note that individual's mortality rate is influenced by economic growth but not SO2 emission. Furthermore,the results also shows that there is a short-run Granger causal relationship from LNSO2 to LNRGDP at 5% level of significance. This implies that an increase of SO2 emission will stimulate economic growth even in a short period. However, the short-run Granger causal relationship moving toward from LNRGDP to LNSO2 is not existed. This implies that the change of economic growth may not necessary change the value of SO2 emission on the other hand. As a result, we found an unidirectional causal relationship from economic growth to individual's mortality rate and a unidirectional causal relationship moving toward from SO2 emissions to economic growth in short-run.

Table 4.6: Panel Causality Test Results

Dependent Variables	**Sources of Causality Tests (Independent Variables) F-Statistic**			**t-stat**
		Short-run		**Long-run**
	ΔLNIMR	**ΔLNRGDP**	**ΔLNSO2**	**ECT**
ΔLNIMR				
Test statistic	-	19.19914**	4.608274	-2.041306**
Prob		(0.0002)	(0.2028)	(0.0414)
Direction of Causality	-	RGDP $\longrightarrow$ IMR	No	RGDP and SO2 $\longrightarrow$ IMR
ΔLNRGDP				
Test statistic	0.945358	-	37.180810**	3.503360**
Prob	(0.8145)		(0.0000)	(0.0005)
Direction of Causality	No	-	SO2 $\longrightarrow$ RGDP	IMR and SO2 $\longrightarrow$ RGDP
ΔLNSO2				
Test statistic	1.085829	4.319922	-	-0.373280
Prob	(0.5811)	(0.1153)		(0.7090)
Direction of Causality	No	No	-	No

Note: ** represents statistical significance at the 5% level. Short-run causality is determined by the statistical significance of the Wald-χ^2-statistics associated with the right hand side variables. Long-run causality is tested by the statistical significance of error correction term using a t-statistic.

In the long run, evidence of long-run Granger causality moving toward from economic growth and SO2 emission to individual's mortality rate is observed at 5% level of significance. Similarly, the long-run Granger causality moving toward from individual's mortality rate and SO2 emission to economic growth is observed at 5% level of significance as well. However, the Long-run Granger causality fail to exist from individual's mortality rate and economic growth to SO2 emission at 5% level of significance. In other words, there is a bidirectional causal relationship between individual's mortality rate and economic growth in long-run. These results imply that individual's mortality rate and economic growth could play an important adjustment factor as the system departs from the long-run equilibrium.

After establishing the cointegration and the direction of causality in the long-run, I now examine the long-run elasticity's of the impact of economic growth and SO2 emissions on individual's mortality rate. By doing this I both fully modified OLS (FMOLS) and dynamic OLS (DOLS) proposed by Pedroni (2001) for further analyses.

4.4.4 FMOLS and DOLS Estimations

There are various modern econometric techniques to investigate the existence of a long-run relationship among variables for estimating a coinegration vector using panel data. Pedroni (2000, 2001,2004) approach, Chiang and Kao (2000, 2002) approach and Breitung (2002) approach. The various estimators include with and between-group estimations in both fully modified OLS (FMOLS) and dynamic OLS (DOLS) estimators. In this study, I implement both between-group (Group-mean) FMOLS and DOLS estimation approaches to investigate the long-run relationship between individual's mortality rate, economic growth and air pollution pressure.

The reasons that I chosen between-dimension group-mean estimators over within-dimension pooled estimators are explained by Pedroni (2000):

First, the form of pooled data in the between-dimension estimators allows for greater flexibility in the presence of heterogeneity of the cointegrating vectors. The test statistics from within-dimension estimators are designed to test $H_0 : \beta_i = \beta_0$ for all i against $H_a : \beta_i = \beta_a \neq \beta_0$, where the value of β_a is identical for all i. In contrast, the test statistics from between-dimension estimators are designed to test $H_0 : \beta_i = \beta_0$ for all i against $H_a : \beta_i =\neq \beta_0$ for all i, so that the values of β_i are not constructed to be same under alternative hypothesis. This is an important advantage of application because it is hard to believe that if the cointegration slopes are not equal, they should take some other arbitrary common value. Second, the point estimations of the between-dimension group mean estimators have a more useful interpretation in the event of true cointegrating vectors which are heterogeneous. This is because when the true cointegrating vectors are heterogeneous, it provides the mean value of cointegrating vectors while the within-dimension estimator provides the average regression coefficient. Third, The test statistics constructed from between-dimension estimators appear to have an advantage under null hypothesis when the cointegrating vector is homogeneous. Pedroni (2000) shows that they exhibit relatively lower distortions in small sample than within-dimension estimators.

4.4.4.1 FMOLS estimators

FMOLS method was originally introduced and developed by Philips and Hansen (1990) for the purpose to estimate a single cointegration relationship that has a combination of I(1). According to Stock (1987), if there is a cointegration relationship exists between non-stationary variables we could get a super consistent estimation if we apply the OLS method. The conclusion makes the estimation of cointegrating relationship become easy, therefore become wildly used in the field of empirical study. However, further studies show there are two major disadvantages for using OLS method. First, although OLS will prove super consistent estimate, based on Monte Caro experiment by Banerjee (1986), ignoring short term dynamics will cause a larger limit sample bias. Second, generally the distribution of the OLS estimations is not standard, could be easily affected by noise and therefore leads to failure of standard testing procedure.

The FMOLS method utilizes Kernel estimators of the Nuisance parameters that affect the asymptotic distribution of the OLS estimator. Therefore, in order to achieve asymptotic efficiency, FMOLS is a non-parametric approach to deal with modification for serial correlation effects and test which solve the endogeneity in the regressors that result from the existence of the cointegration relationship of the least squares.

Consider the following fixed effects cointegrated system for a panel of $i = 1, \cdots, N$ members,

$$y_{it} = \alpha_i + \beta_i x_{it} + e_{it} \tag{4.37}$$

$$x_{it} = x_{it-1} + u_{it} \tag{4.38}$$

where y_{it} and x_{it} are cointegrated with slope coefficient β_i, which may or may not be homogeneous across section i if both y_{it} and x_{it} are I(1). The term α_i allows the cointegrating relationship to include member specific fixed effects. Also, x_{it} can in general be an m dimensional vector of regressors, which are not cointegrated with each other since we are not allowed for exogeneity of the regressors. The term e_{it} is the at I(0) and the term $u_{it} = x_{it} - x_{it-1} = \Delta x_{it}$.

We consider vector error process $w_{it} = (e_{it}, \Delta x_{it})$, is stationary with asymptotic covariance matrix Ω_i. Thus the long-run covariance matrix Ω_i of w_{it} can be defined as

$$\Omega_i = \lim_{T \longrightarrow \infty} E\left[T^{-1}(\sum_{t=1}^{T} w_{it})(\sum_{t=1}^{T} w_{it})'\right] = \begin{bmatrix} \Omega_{11i} & \Omega'_{21i} \\ \Omega_{12i} & \Omega_{22i} \end{bmatrix} \tag{4.39}$$

where Ω_{11i} is the scalar long run variance of the residual e_{it}, Ω_{22i} is the $m \times m$ long run covariance among u_{it}, and Ω_{21i} is a $m \times 1$ vector that gives the long-run covariance between the residual e_{it} and each of the u_{it}. Also Ω_i can be decomposed into

$$\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i' \tag{4.40}$$

where Ω_i^0 is the contemporaneous covariance[16] and Γ_i is a weighted sum of autocovariance. The group-mean FMOLS estimator[17] is constructed by making corrections for endogeneity and serial correlation to the OLS estimator and is defined as:

$$\hat{\beta}_{GFM} = \frac{1}{N}\left[\sum_{i=1}^{N}\sum_{t=1}^{N}(x_{it}-\bar{x}_i)(x_{it}-\bar{x}_i)'\right]^{-1}\left[\sum_{i=1}^{N}\left(\sum_{t=1}^{N}(x_{it}-\bar{x}_i)\hat{y}_{it}^{+} - T\hat{\Lambda}_i\right)\right] \tag{4.41}$$

where $\hat{\Lambda}_i$ is the serial correlation correction term and it is defined as,

$$\hat{\Lambda}_i = \hat{\Gamma}_{21i} + \hat{\Omega}_{21i}^0 - \frac{\hat{\Omega}_{21i}}{\hat{\Omega}_{22i}}(\hat{\Gamma}_{22i} + \hat{\Omega}_{22i}^0) \tag{4.42}$$

and y_{it}^{+} is the transformed variable of y_{it} to achieve the endogeneity correction and it can be defined as,

$$y_{it}^{+} = y_{it} - \frac{\hat{\Omega}_{21i}}{\hat{\Omega}_{22i}}\Delta x_{it} \tag{4.43}$$

and T is the number of time periods. More interestingly, Between dimension group-mean FMOLS estimator can also be written based on the within-dimension pooled FMOLS estimator as,

$$\hat{\beta}_{GFM} = \frac{\sum_{i=1}^{N}\hat{\beta}_{FMi}}{N} \tag{4.44}$$

where $\hat{\beta}_{FMi}$ is the within-dimension pooled FMOLS estimator and the t-statistic of group-mean FMOLS is calculated also based on the t-statistic of pooled FMOLS as,

$$t_{\hat{\beta}_{GFM}} = \frac{\sum_{i=1}^{N} t_{\hat{\beta}_{FMi}}}{\sqrt{N}} \tag{4.45}$$

with

$$t_{\hat{\beta}_{FMi}} = (\hat{\beta}_{FMi} - \beta_0)\left[\Omega_{11i}^{-1}\sum_{t=1}^{T}(x_{it}-\bar{x}_i)(x_{it}-\bar{x}_i)'\right]^{\frac{1}{2}} \tag{4.46}$$

[16]See details from Pedroni (2000) and Chiang and Kao (2000).

[17]The simplicity form of group-mean FMOLS can be written as, $\hat{\beta}_{GFM} = (X'X)^{-1}(X'Y^{+} - T\hat{\Lambda})$

4.4.4.2 DOLS estimators

The serial correlation and the endogeneity can also be corrected by using the panel DOLS estimators. In the DOLS framework, the long-run regression is augmented by lead and lagged differences of the explanatory variables to control for the endogenous feedback (Saikkonen, 1991). Moreover, by including the past and the future values of the differenced I(1) regressors, DOLS estimator uses parametric adjustment to the errors in order to obtain an unbiased estimator of the long-run parameters. In particular, we look at equation of,

$$y_{it} = \alpha_i + \beta_i x_{it} + \sum_{k=-q_i}^{q_i} \gamma_{ik} \Delta x_{it-k} + v_{it} \tag{4.47}$$

Using regression (4.47), Pedroni (2000, 2001) constructs his group-mean DOLS panel estimator as follows,

$$\hat{\beta}_{GD} = \frac{1}{N}\left[\sum_{i=1}^{N}\left(\sum_{t=1}^{T} z_{it} z_{it}'\right)^{-1}\left(\sum_{t=1}^{T} z_{it}\tilde{y}_{it}\right)\right] \tag{4.48}$$

where z_{it} is the $(2(q+1)\times 1)$ vector of regressors and

$$z_{it} = (x_{1it} - \bar{x}_{1i}, \cdots, x_{kit} - \bar{x}_{ki}, \Delta x_{1it-p}, \cdots, \Delta x_{kit-p}, \Delta x_{kit+p}) \tag{4.49}$$

here $\tilde{y}_{it} = y_{it} - \bar{y_i}$, $\bar{x_{1i}} = \frac{\sum_{t=1}^{T} x_{1it}}{T}$ and so on so forth. The long-run variance of the residuals from the DOLS is defined as,

$$\sigma_i^2 = \lim_{T\longrightarrow\infty} E\left[T^{-1}\left(\sum_{t=1}^{T}\hat{v}_{it}\right)^2\right] \tag{4.50}$$

Again Between dimension group-mean DOLS estimator can also be written based on the within-dimension pooled DMOLS estimator as,

$$\hat{\beta}_{GD} = \frac{\sum_{i=1}^{N}\hat{\beta}_{Di}}{N} \tag{4.51}$$

where $\hat{\beta}_{Di}$ is the within-dimension pooled DOLS estimator and the t-statistic of group-mean DOLS is calculated also based on the t-statistic of pooled DOLS as,

$$t_{\hat{\beta}_{GD}} = \frac{\sum_{i=1}^{N} t_{\hat{\beta}_{Di}}}{\sqrt{N}} \tag{4.52}$$

with

$$t_{\hat{\beta}_{Di}} = (\hat{\beta}_{Di} - \beta_0)\left(\sigma_i^{-2}\sum_{t=1}^{T} z_{it}z_{it}'\right)^{\frac{1}{2}} \tag{4.53}$$

4.4.4.3 The results from group-mean FMOLS and GOLS estimations

The model of this chapter are based on the regression between three variables, $LNIMR$, $LNRGDP$, and $LNSO2$ in equation (4.13) for FMOLS. In addition, I estimate the following model where the individual's mortality rate and the economic growth slopes β_i as well as the individual's mortality rate and SO2 emission slopes δ_i may or may not be homogeneous across i for DOLS.

$$LNIMR_{it} = \alpha_i + \beta_i LNRGDP_{it} + \delta_i LNSO2_{it} + \sum_{k=-q_i}^{q_i} \gamma_{ik}\Delta LNRGDP_{it-k} + \sum_{k=-q_i}^{q_i} \phi_{ik}\Delta LNSO2_{it-k} + \varepsilon_{it} \tag{4.54}$$

FMOLS and DOLS estimation results of long-run elasticity are reported in Table 4.7 to establish cointegration in the long-run both with and without time dummy. This table reports not only the full panel results, but also the results for different economic division areas of China which followed by Wei (2009). There are four division regions: center areas, east areas, north-east areas and west areas. Among all four different areas, center areas include Anhui, Henan, Hubei, Hunan, Jiangxi and Shanxi provinces; east areas include Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Shangdong,Shanghai, Tianjing and Zhejiang provinces; north-east areas include Heilongjiang, Jilin and Liaoning provinces; west areas include Congqing, Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Xinjiang, and Yunnan provinces.

Starting with the relationship moves from RGDP to IMR among different region estimations, all long-run elasticity between RGDP and IMR shows a long-run significant negative relationship between these two variables in both with and without time dummy estimations. This implies that improving of living standard for individuals will mitigate the mortality rate for people among all four regions. The panel results also overwhelming show a significant negative relationship between individual's mortality rate and economic growth. It shows that if 1% change in real GDP will lead to a 0.083% decline in the individual's mortality rate under without time dummy estimation and if 1% change in real GDP will lead to a 0.107% decline in individual's mortality under with time dummy estimation.

For the relationship between individual's mortality rate and SO2 emission, we see a significant long-run positive relationship exist for all regions except the FMOLS estimation results for both center areas and north-east area. These results imply that the air pollution hurts the individual's health condition in long-run and the environmental protection policy are needed to be reinforced.

Table 4.7: FMOLS and DOLS Estimation Results for 30 Provinces (LNIMR as Dependent Variable)

	LNRGDP		LNSO2	
Divisions	**FMOLS**	**DOLS**	**FMOLS**	**DOLS**
Center Area Results				
Without Time Dummies Between	-0.130445**	-0.148945**	0.133622	0.209702**
	[-10.554897]	[-14.313333]	[1.052008]	[3.990166]
With Time Dummies Between	-0.14162**	-0.228832**	0.189200	0.237221**
	[-4.946852]	[-4.289159]	[0.711205]	[2.617133]
East Area Results				
Without Time Dummies	-0.042512**	-0.058238**	0.074966**	0.118354**
	[-10.74994]	[-4.748004]	[4.903590]	[2.05316]
With Time Dummies Between	-0.037968**	-0.124960**	0.071610**	0.238655**
	[-3.122854]	[-6.044131]	[3.124805]	[3.888447]
North-East Area Results				
Without Time Dummies Between	-0.130445**	-0.148967**	0.073620	0.209702**
	[-10.554657]	[-14.315491]	[1.052008]	[3.990166]
With Time Dummies Between	-0.141620**	-0.228832**	0.018920	0.237221**
	[-4.946852]	[-4.289159]	[0.711205]	[2.617133]
West Area Results				
Without Time Dummies Between	-0.028861**	-0.040052**	0.084687**	0.091300**
	[-2.679586]	[-2.301122]	[4.79592]	[2.093627]
With Time Dummies Between	-0.107254**	-0.163939**	0.701550**	0.322560**
	[-3.495442]	[-2.357037]	[4.916141]	[3.702122]
Panel Results				
Without Time Dummies Between	-0.083066**	-0.0990505**	0.091723**	0.157265**
	[-8.634770]	[-8.919487]	[2.950886]	[3.031780]
With Time Dummies Between	-0.107115**	-0.186640**	0.245320**	0.258914**
	[-4.128000]	[-4.244871]	[2.365839]	[3.206209]

Note: t-statistics are for $H_0 : \beta_i = 0$. ** represents statistical significance at the 5% level.

4.5 Further Discussion and Policy Implication

The principal purpose of this chapter is to seek for the linkages among individual's mortality rate, economic growth and air pollution emission in China. In order to achieve my goal, I have employed panel unit root tests, panel cointegration tests and panel causality test by using the data across 30 provinces in China. From the panel cointegration tests, I found that there is a long-run cointegration relationship between individual's mortality rate, economic growth and air pollution emission.

From the panel causality analysis, by implementing a vector error correction model, I found a unidirectional short-run causal relationship moving toward from real GDP to individual's mortality rate and a unidirectional short-run relationship from SO2 emission to real GDP. However, there was no other short-run causal relationship being found. In the long-run, I found a bidirectional relationship between individual's mortality rate and economic growth, which means that individual's mortality rate and real GDP are played as an important adjustment factor for long-run equilibrium.

In order to get a better understanding of the relationship among individual's mortality rate, economic growth and air pollution pressure, I further analyze the long-run elasticity which are estimated by both FMOLS and DOLS. The panel results both from without and with time dummies show a significant negative relationship between the individual's mortality rate and real GDP at 5% significance level. However, there is a positive long-run relationship between individual's mortality rate and SO2 emission from a 5% significance level of panel results. In addition, I divide 30 provinces into four different economic regions in china according to Wei (2009) to investigate if the panel results hold for different regions. The results show a significant negative long-run relationship between individual's mortality rate and real GDP for all four regions as well as full panel. On the other hand, there is a significant positive relationship between individual's mortality rate and SO2 emission except FMOLS results from both center area and north-east area.

These empirical results from this chapter provide a better understanding for policy makers of human mortality-economic growth nexus human mortality-air pollution emission nexus to formulate economic growth as well as environmental protection policies in China. The policy makers in China need to consider whether development first and environmental protection second is suitable for China's economic growth. In this Chapter, the short-run causal result tells us that China doesn't need to consider about the reducing SO2 emission, but focus on doing economic growth first since SO2 emission doesn't affect the individual's mortality rate in short-run. However, in the long-run, environmental protection is definitely to be needed in order to achieve a long-run sustainable equilibrium for China.

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Chapter 5

Conclusion

In this dissertation, I have successfully implemented a two-period OLG model to illustrate that how important is individual's health affected by pollution pressure related to long-run economic growth. Simply I assumed that an individual could get sickness under pollution with probabilities. With this probability concept, I developed the optimal condition of choosing pollution abatement investment for individuals. I concluded when the marginal benefit of abatement is greater or equal than the marginal cost of the abatement, individuals start to invest this abatement, otherwise they won't invest. There are two implications under this optimal condition: (i) individuals will only invest in environmental protection only if the abatement investment makes a positive returns and (ii) individuals will only invest in this environmental protection only if they achieve a given level of consumption. This is totally match up with the ideas of Lieb (2004) who has categorized that the environmental protection as a luxury good.

By doing dynamic analysis, I found that the pollution abatement is not a key factor for a poor country starting its economy at a relatively low capital per worker to achieve its long-run equilibrium, since it has a low capital endowment in the beginning of the economic. This thesis suggested that gaining enough capital accumulation first would be the key trigger for a poor country to achieve a robust growth. In the contrary, a rich country starting its economy at a relatively high capital endowment on the other hand, with an active pollution abatement will eventually achieve its long-run sustainable equilibrium. Otherwise, without pollution abatement, the economy growth of it converges to a long-run equilibrium with zero growth rate or a permanent cycle around one level of steady state. This is also reviewed by a turning point $\tilde{k}$ theory.

I also found some other important implications from my model. The implication such like, a poor country starting its economy at a low capital per worker cannot afford pollution and will converge to a poverty trap all the time. The key effort of it to get out of this poverty trap is capital accumulation first rather than a pollution abatement. These are all findings in chapter two.

In chapter three, Based on the drawbacks of using only one single pollutant as an indicator of environmental degradation from previous studies, I used Principle Component Analysis to create a Pollution Emission Index (PEI) base on 7 different pollutants across 30 provinces in China. I investigated the validity of EKC relationship between pollution index and economic growth in China both from GDP per capita and industry structures. The empirical findings in this chapter provide a new understanding of the relationship between pollution and economic growth in China. I found that the EKC relationship exists in China's society and the turning point is about 44,000 RMB, which is comparable with Panayotou(1995), Shafit(1994) and Grossman (1993). I also found that higher population, urbanization rate and Foreign Direct Investment results in marginally to moderately higher of ambient pollution pressure levels, while better openness rate results drastically decrease of ambient pollution pressure level.

I concluded that it might therefore be more effective to focus efforts for controlling pollution pressures by improving the connections with outsiders and increasing trade volumes rather than either on limiting economic growth or controlling population growth. Furthermore, the cost of each option is also relevant, the cost of openness improvements is more likely to have lower costs and more benefits than the restrictions on economic and population growth.

In addition, I divided all 30 provinces into four different location areas: Central Areas, East Areas, North East Areas and West Areas to test if the EKC relationship is valid in different geographic locations. Only the eastern areas and north east areas effects result an inverted-U relationship between pollution and income per capita and the turning points are 49,000 RMB and 54,000 RMB respectively which are larger than the turning point of an overall EKC. This explains why more pollution pressures affect east and north east areas in China often than other areas, since higher elasticity and higher turning point results in higher pollution pressures.

The principal purpose of chapter 4 is to seek for the linkages among individual's mortality rate, economic growth and air pollution emission in China from 1995 to 2013. In order to reach my goal, I have employed panel unit root tests, panel cointegration tests and panel causality test. Panel unit tests worked as a tool to check if every variable is first difference stationary in order to avoid spurious regression problem. From the panel cointegration tests, I found that there are long-run cointegration relationships between all three variables of individual's mortality rate, economic growth and air pollution emission.

From the panel causality analysis by implementing a vector error correction model, I found a unidirectional short-run causal relationship moving toward from real GDP to individual's mortality rate and a unidirectional short-run relationship from SO2 emission to real GDP while there were no other short-run causal relationship being found. In the long-run, I found a bidirectional relationship between individual's mortality rate and economic growth which means that individual's mortality rate and real GDP are play as an important adjustment factor for long-run equilibrium. I further analyzed the long-run elasticity which are estimated by both FMOLS and DOLS. The panel results reported from both without and with time dummies show a significant negative relationship between individual's mortality rate and real GDP at 5% significance level. However, there is a positive long-run relationship between individuals' mortality rate and SO2 emission at a 5% significance level of panel results. Furthermore, I divided 30 provinces of China into four different economic regions according to Wei (2009) and tested if the panel results hold for each region in China. The results from both without and with time dummies show a significant negative long-run relationship between individual's mortality rate and real GDP for all four regions. However, there is a significant positive relationship between individual's mortality rate and SO2 emission except FMOLS results from both center area and north-east area.

From the evidences from China, we know that Pollution damages the lifespan of people's health, but it is also an indicator of economic development. In order for their economic growth, countries need to produce goods and release pollution emissions. On the other hand, pollution affects individuals' health conditions negatively and without a standard labor quality, our economy may not reach its long-run sustainable equilibrium. This is a miserable cycle that many countries are facing now, especially for developing countries. A country, like China, is struggling between choosing economic development and environmental protection, the government needs to choose the right path for China's economic growth. Without understanding this point, it is hard for China to achieve its long-run sustainable equilibrium. This thesis suggested that China should analyze its own status at the present and makes a most cost efficient way for its economic path in order to achieve the low carbon economic growth in the future.

Appendix A

Appendix for Chapter 2

A.1 Proof of Equation (32)

Recall equation (28),in order to find Marginal Benefit of the abatement we take derivatives respect to a_t in π_t and keep V^S and V^H as constants and therefore,

$$MB = \frac{\partial U_t}{\partial a_t} = -\pi'(a_t)(V_t^{H*} - V_t^{S*}) \quad (A.1.1)$$

For Marginal Cost of Abatement we holding π_t as a constant and take derivatives respect to V^{H*} and V^{L*} , then we have

$$MC = -\frac{\partial U_t}{\partial a_t} = \pi_t\Big(-\frac{\partial V^{S*}}{\partial a_t}\Big) + (1-\pi_t)\Big(-\frac{\partial V^{H*}}{\partial a_t}\Big) \quad (A.1.2)$$

Therefore, the optimal condition is $MBA \geq MCA$, formally as

$$-\pi'(a_t)(V_t^{H*} - V_t^{S*}) \geq \pi_t\Big(-\frac{\partial V^{S*}}{\partial a_t}\Big) + (1-\pi_t)\Big(-\frac{\partial V^{H*}}{\partial a_t}\Big) \quad (A.1.3)$$

Where

$$-\frac{\partial V^{H*}}{\partial a_t} = \frac{1+\beta}{w_t - a_t} \quad (A.1.4)$$

and

$$-\frac{\partial V^{S*}}{\partial a_t} = \frac{\theta[1+\beta\phi(h_t)]}{(1-\delta)w_t - a_t} + \theta\beta\phi'(h_t)g_t^c(E - \frac{P_t}{1+a_t})^{d-1}\frac{P_t}{(1+a_t)^2}ln[(1-\delta)w_t - a_t] \quad (A.1.5)$$

Then, plug equations (A.1.4) and (A.1.5) both together into (A.1.3) we get equation (32).

A.2 Proof Lemma 1.

From equation (39)we have,

$$J(k_t) = \frac{f(k_t)}{k_t} = b\left\{\frac{\beta\phi\{(\tau A k_t)^c(E-\gamma A k_t)^d\}}{1+\beta\phi\{(\tau A k_t)^c(E-\gamma A k_t)^d\}}[(1-\delta)(1-\alpha)A]\right\}$$
$$+ (1-b)\left\{\frac{\beta}{1+\beta}[(1-\alpha)A]\right\} \qquad (A.2.1)$$

It is clear that any interior steady state must satisfy $J(\hat{k*}) = 1$ and this implies that $\hat{k} = f(\hat{k*})$ for all three country status by assuming $b = 1$,by simplified the case, because $(1-b)\frac{\beta}{1+\beta}[(1-\alpha)A]$ is constant toward to k_t. From the above equation (A.2.1), we have $J(0) = 0$ and since equation (19), we have $J(k_t) = 0$ for $\forall k_t \geq \frac{E}{\gamma A}$. This condition is realized as when $E - D_t \leq 0$ then $J(k_t) = 0$ this implies that $E - \gamma A k_t \leq 0$, since no abatement, and therefore we have $k_t \geq \frac{E}{\gamma A}$.Thus there must be at least one $\hat{k*}$ such that $J(\hat{k*}) \geq 1$. If this condition holds, there will be at least two interior steady states. If not there will not be any interior equilibria exist. Figure 3 illustrate this situation,

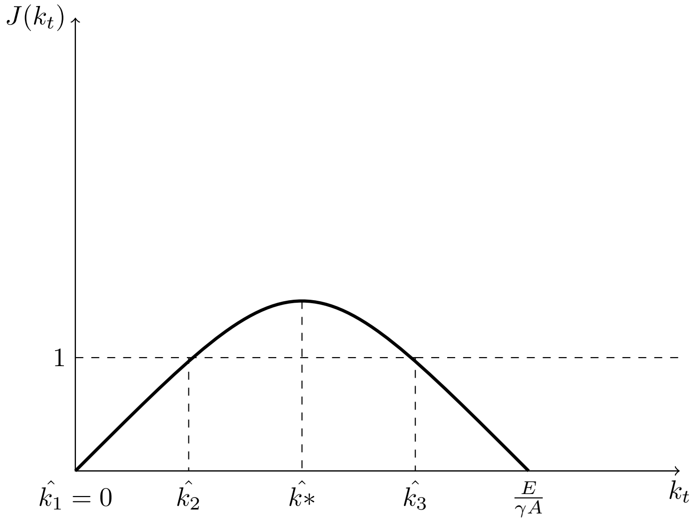


Figure A.1: Interior Solutions require $J(\hat{k^*}) > 1$

By doing derivatives respect to k_t in equations (A.2.1)

$$J'(k_t) = b(1-\delta)(1-\alpha)A\frac{\beta\phi'(h_t)}{[1+\beta\phi'(h_t)\phi_t]^2}\frac{\partial h_t}{\partial k_t} \qquad (A.2.2)$$

Therefore, for $0 \leq k_t \leq \frac{E}{\gamma A}$, the sign of all $J'(k_t)$ depends on the sign of $\frac{\partial h_t}{\partial k_t}$. and without pollution abatement h_t becomes as,

$$h_t = (\tau A k_t)^c(E-\gamma A k_t)^d \qquad (A.2.3)$$

Therefore,

$$\frac{\partial h_t}{\partial k_t} = (\tau A k_t)^c (E - \gamma A k_t)^d \Big(\frac{c}{k_t} - \frac{d\gamma A}{E - \gamma A k_t} \Big) \qquad (A.2.4)$$

which means that $\frac{\partial h_t}{\partial k_t} \geq 0$ iff $\frac{c}{k_t} - \frac{d\gamma A}{E - \gamma A k_t} \geq 0$ then we have, $k_t \leq \frac{c}{c+d} \frac{E}{\gamma A} \equiv \hat{k*}$ Therefore there exists a unique $\hat{k*} \in (0, \frac{E}{\gamma A})$, such that,

$$J'(k_t) \begin{cases} > 0, & \text{if} k_t < \hat{k*} \\ = 0, & \text{if} k_t = \hat{k*} \\ < 0, & \text{if} k_t > \hat{k*} \end{cases} \qquad (A.2.5)$$

and this $\hat{k*}$ should equal to $\tilde{k}$ I have got in section 4. They both around 2.5 if we use the value provided in table to calculate it.

$J(\hat{k*})$ is a global maximum. Particularly,we can solve,

$$\begin{aligned} h_t &= (\tau A \hat{k*})^c (E - \gamma A \hat{k*})^d \\ &= \Big(\frac{c\tau}{\gamma} \Big)^c d^d \Big(\frac{E}{c+d} \Big)^{c+d} \equiv \Lambda \qquad (A.2.6) \end{aligned}$$

Therefore if (A.2.5) holds, there will be two interior steady states equilibria exist such that $\hat{k_3} > \hat{k_2} > 0$ and $\hat{k_3} > \hat{k*}$, i.e $J'(\hat{k_2}) > 0$ and $J'(\hat{k_3}) < 0$.

Since $J(k_t) = \frac{f(k_t)}{k_t}$ for all cases, then we have,

$$\begin{aligned} J'(k_t) &= \frac{f'(k_t)}{k_t} - \frac{f(k_t)}{k_t^2} \\ &= \frac{f'(k_t)k_t - f(k_t)}{k_t^2} \qquad (A.2.7) \end{aligned}$$

Given (A.2.7), $J'(\hat{k_2}) > 0$ implies that,

$$\frac{f'(\hat{k_2})\hat{k_2} - f(\hat{k_2})}{\hat{k_2}^2} > 0$$

or

$$f'(\hat{k_2}) > 1$$

thus $\hat{k_2}$ is unstable, since $J(\hat{k_2}) = 1$ according to figure 3.

Same here for $\hat{k_3}$, since $J'(\hat{k_3}) < 0$ and $f'(\hat{k_3}) < 1$, but $\hat{k_3}$'s stability depends on

$$\hat{k_3} = \begin{cases} long - runstable, & \text{if} - 1 < f'(\hat{k_3}) < 1 \\ unstable, & \text{if} f'(\hat{k_3}) < -1 \end{cases} \qquad (A.2.8)$$

In our preceding analysis, we have noticed that $f(0) = 0$. This indicate that $\hat{k_1} = 0$ is a steady state. Since equation (A.2.7), we can get

$$f'(k_t) = J'(k_t)k_t + J(k_t) \qquad (A.2.9)$$

since $\hat{k_1} = 0$ and $\lim_{k_t \to 0}\left(\frac{\partial h_t}{\partial k_t}k_t\right) = 0$ and $J'(\hat{k_1})\hat{k_1} = 0$, then $f'(\hat{k_1}) = f(0) = 0$,i.e $\hat{k_1} = 0$ is a super-stable equilibrium.

A.3 Proof of Proposition 1

By following Lemma 1, $\hat{k_1} = 0$ is stable and $\hat{k_2} > 0$ is unstable. Hence for any k_0 such that $k_0 < \hat{k_2}$, it is that $k_{t+1} = f(k_t) < k_t$. This implies that the economy's capital per worker falls and converges to a poverty trap at $\hat{k_1} = 0$. This is the only solution for a low polluted country without pollution abatement.

A.4 Proof of Proposition 2

The first part of the Proposition 2 consider that $\hat{k_3}$ is asymptotically stable or satisfies that $-1 < f'(\hat{k_3}) < 1$. Given $\hat{k_3} > \hat{k_2} > 0$ and $k_0 > \hat{k_2}$, the economy starts rise until it reaches $\hat{k*}$ and then it falls after $\hat{k*}$.Also, the transitional dynamics implies that $\lim_{t\to\infty} k_t = \hat{k_3}$. Since we have $\rho_{t+1} = \frac{k_{t+1}}{k_t} - 1$, and thus,

$$\begin{aligned}
\lim_{t\to\infty} \rho_{t+1} &= \lim_{t\to\infty}\left(\frac{k_{t+1}}{k_t}\right) - 1 \\
&= \lim_{t\to\infty}\left(\frac{f(k_t)}{k_t}\right) - 1 \\
&= \lim_{t\to\infty} J(k_t) - 1 \\
&= J(\hat{k_3}) - 1 = 1 - 1 = 0 \qquad (A.4.1)
\end{aligned}$$

The second part of Proposition 2 considers that $\hat{k_3}$ is an unstable equilibrium or it is the case that $f'(\hat{k_3}) < -1$. It is well known that if the transition equation is non-monotonic and its slope at the steady state is negative and sufficiently steep. Then there exists periodic equilibria, denoted as $\bar{k_\omega}$, where $\omega = 1, 2, \cdots, i-1, i, i+1, \cdots, t$ such that $\bar{k_1} < \bar{k_2} \cdots < \bar{k}_{i-1} < \bar{k_i} < \hat{k_3} < \bar{k}_{i+1} < \cdots < \bar{k_\omega}$ then we have

$$f(k_t) \begin{cases} > k_t, & \text{for} \omega \in [1, i] \\ < k_t, & \text{for} \omega \in (i, t] \end{cases} \qquad (A.4.2)$$

Therefore if there is a $k_0 > \hat{k_2}$, the capital stock passes repeatedly through the points $\bar{k}_\omega$ and the economy converge to a n-period cycle equilibria for a rich country.

A.5 Proof of Lemma 2

With a pollution abatement, we need to consider about equation (36) now,we have,

$$J(k_t) = \frac{f(k_t)}{k_t} = \pi(k_t)\Big\{\frac{\beta\phi\{(\tau Ak_t)^c(E - \frac{\gamma Ak_t}{1+a(1-\alpha)Ak_t})^d\}}{1+\beta\phi\{(\tau Ak_t)^c(E - \frac{\gamma Ak_t}{1+a(1-\alpha)Ak_t})^d\}}[(1-\delta)(1-\alpha)(1-a)A]\Big\}$$
$$+ [1-\pi(k_t)]\Big\{\frac{\beta}{1+\beta}[(1-\alpha)(1-a)A]\Big\} \quad (A.5.1)$$

Again, if $k_t = 0$ then $J(k_t) = 0$ since $\frac{\beta}{1+\beta}[(1-\alpha)(1-a)A$ is a constant of k_t. By simplicity, we can ignore its effect. In addition, $J(\infty) = (1-\alpha)(1-a)A\frac{\beta}{1+\beta}$. Also,an interior steady state must satisfies that $J(\hat{k}) = 1$ where $\hat{k} = f(\hat{k})$. By doing derivatives respect to k_t in equations (A.5.1), we have,

$$J'(k_t) = \Big\{\pi'(k_t)(1-\delta)(1-\alpha)(1-a)A\frac{\beta\phi(h_t)}{1+\beta\phi(h_t)} - \pi'(k_t)(1-\alpha)(1-a)A\frac{\beta}{1+\beta}\Big\}$$
$$+ \pi(k_t)(1-\delta)(1-\alpha)(1-a)A\frac{\beta\phi'(h_t)}{[1+\beta\phi'(h_t)\phi_t]^2}\frac{\partial h_t}{\partial k_t} \quad (A.5.2)$$

where the term $\pi'(k_t)(1-\delta)(1-\alpha)(1-a)A\frac{\beta\phi(h_t)}{1+\beta\phi(h_t)} - \pi'(k_t)(1-\alpha)(1-a)A\frac{\beta}{1+\beta}$ is always greater than zero by assumption, since the effect of $\pi'(k_t)$ will be cancel out.
Therefore, the sign of (A.5.2) is only depends on $\frac{\partial h_t}{\partial k_t}$ and as therefore all, now we consider that,

$$h_t = (\tau Ak_t)^c\Big(E - \frac{\gamma Ak_t}{1+a(1-\alpha)Ak_t}\Big)^d \quad (A.5.3)$$

By differentiating k_t in equation (A.5.3) we have,

$$\frac{\partial h_t}{\partial k_t} = (\tau Ak_t)^c\Big(E - \frac{\gamma Ak_t}{1+a(1-\alpha)Ak_t}\Big)^d\Big[\frac{c}{k_t} - \frac{d\gamma A}{[1+a(1-\alpha)Ak_t]^2}\frac{1}{\frac{\gamma Ak_t}{1+a(1-\alpha)Ak_t}}\Big] \quad (A.5.4)$$

Clearly $\frac{\partial h_t}{\partial k_t} \geq 0$ iff,

$$\Omega \equiv \frac{d\gamma A}{[1+a(1-\alpha)Ak_t]^2}\frac{1}{\frac{\gamma Ak_t}{1+a(1-\alpha)Ak_t}} \geq 0 \quad (A.5.5))$$

or we have

$$k_t^2 + \frac{(a(1-\alpha)E-\gamma) + (a(1-\alpha)E - \frac{\gamma d}{c})}{(a(1-\alpha)E-\gamma)a(1-\alpha)A}k_t + \frac{E}{(a(1-\alpha)E-\gamma)a(1-\alpha)A^2} \geq 0 \quad (A.5.6)$$

As long as the restriction $aE > \gamma$ the above equation (A.2.5) holds, and therefore, $J'(k_t) > 0, \forall k_t$ holds. Thus, there is only one interior steady state $\hat{k_2}$ with $J'(\hat{k_2}) \geq 0$ and by given condition (A.2.7), we can easily show that $f'(\hat{k_2}) >$ as same as preceding proof. Therefore $\hat{k_2}$ is unstable. Moreover, $\hat{k_1} = 0$ is a stable steady state here.

Recall equation (A.2.9) above, we have, $\lim_{k_t \to 0} \Omega(k_t)k_t = 0$ and $J'(\hat{k_1})\hat{k_1} = 0$ then $f'(\hat{k_1}) = f(0) = 0$, i.e $\hat{k_1} = 0$ is a super-stable equilibrium.

A.6 Proof of Proposition 3

The Proof of Proposition 3 is exactly same follow the proof of proposition 1 for a country who starts its economy from a relative low capital per worker.

A.7 Proof of Proposition 4

By using (A.5.1) above, we can get the growth rate as,

$$\begin{aligned}1 + \rho_{t+1} = \frac{k_{t+1}}{k_t} = & \pi(k_t)\left\{\frac{\beta\phi\{(\tau A k_t)^c(E - \frac{\gamma A k_t}{1+a(1-\alpha)Ak_t})^d\}}{1 + \beta\phi\{(\tau A k_t)^c(E - \frac{\gamma A k_t}{1+a(1-\alpha)Ak_t})^d\}}[(1-\delta)(1-\alpha)(1-a)A]\right\} \\ & + [1 - \pi(k_t)]\left\{\frac{\beta}{1+\beta}[(1-\alpha)(1-a)A]\right\} \quad (A.7.1)\end{aligned}$$

For the economy with pollution abatement:
Since we have the definition such that $k_{t+1} > k_t$ then $1 + \rho_{t+1} > 1$ as long as $k_0 > \hat{k_2}$, and this is the satisfaction for existing a long-run equilibrium.

Therefore equation (A.7.1) can be write as

$$k_{t+1} = (1 + \rho_{t+1})k_t$$

or

$$k_t = \Pi_{n=0}^{t}(1 + \rho_n)k_0 \quad (A.7.2)$$

Since we verify that $\lim_{t\to\infty} k_t = \infty$ and the property of $\pi(\infty) = 0$, we have result for equation (A.7.2) as

$$
\begin{aligned}
\lim_{t\to\infty}\rho_{t+1} &= \lim_{tto\infty}\Bigg[\pi(k_t)\left\{\frac{\beta\phi\{(\tau Ak_t)^c(E-\frac{\gamma Ak_t}{1+a(1-\alpha)Ak_t})^d\}}{1+\beta\phi\{(\tau Ak_t)^c(E-\frac{\gamma Ak_t}{1+a(1-\alpha)Ak_t})^d\}}[(1-\delta)(1-\alpha)(1-a)A]\right\} \\
&+[1-\pi(k_t)]\left\{\frac{\beta}{1+\beta}[(1-\alpha)(1-a)A]\right\}-1\Bigg] \\
&=\pi(k_\infty)\left\{\frac{\beta\phi\{(\tau Ak_\infty)^c(E-\frac{\gamma Ak_\infty}{1+a(1-\alpha)Ak_\infty})^d\}}{1+\beta\phi\{(\tau Ak_\infty)^c(E-\frac{\gamma Ak_\infty}{1+a(1-\alpha)Ak_\infty})^d\}}[(1-\delta)(1-\alpha)(1-a)A]\right\} \\
&+[1-\pi(k_\infty)]\left\{\frac{\beta}{1+\beta}[(1-\alpha)(1-a)A]\right\}-1 \\
&=\frac{\beta}{1+\beta}[(1-\alpha)(1-a)A]-1=\hat{\rho} \qquad (A.7.3)
\end{aligned}
$$

Therefore, by assumption 1, $\frac{\beta}{1+\beta}[(1-\alpha)(1-a)A] > 1 = \hat{\rho}$ always hold. This implies that $1+\hat{\rho}$ is always greater than 1 and $\hat{\rho}$. The economy starting with relative high capital per worker will converge to a asymptotically BGP where the capital and output per-worker grows at a rate $\hat{\rho}$. Therefore, there will be a long-run sustainable growth exist showing in Figure 4,

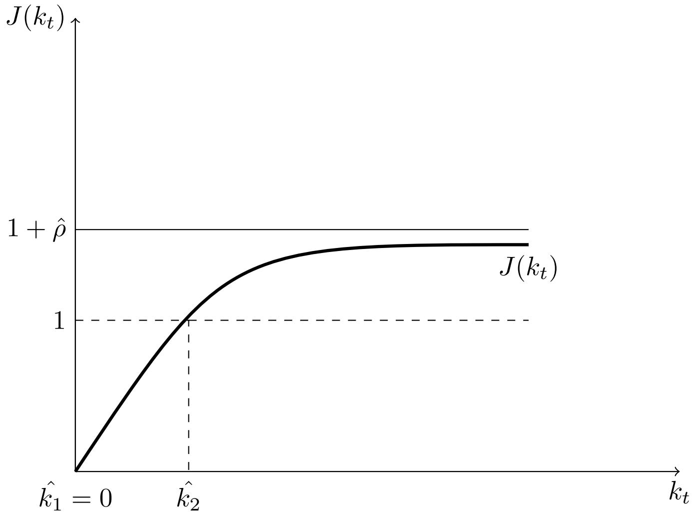


Figure A.2: Long-run sustainable growth

Appendix B

Appendix for Chapter 3

B.1 The calculation of Pollution-Income Elasticity:

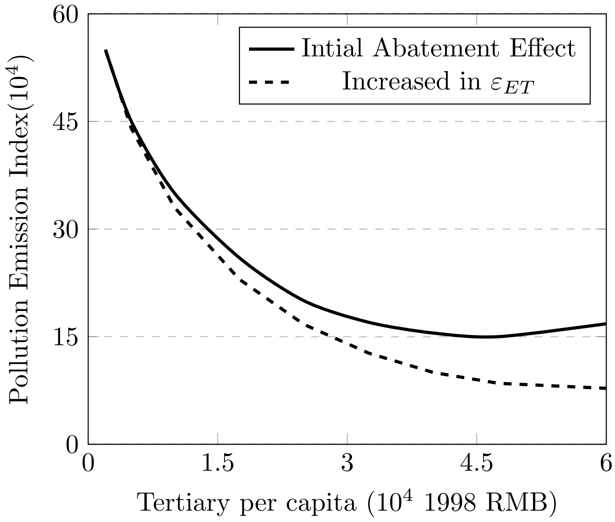
Equation (3.38) calculation: Let P, S and T be functions of Y such as $P = P(Y)$,$S = S(Y)$ and $T = T(Y)$ and according the equation (3.34) and equation (3.37) from Shafik (1994),

$$
\begin{aligned}
\varepsilon_{EY} = & \frac{\partial P}{\partial Y} \underbrace{[\frac{\beta_1}{P} + 2\beta_2 LnP + 3\beta_3 (Ln_P)^2]}_{\varepsilon_{EP}} + \frac{\partial S}{\partial Y} \underbrace{[\frac{\beta_4}{S} + 2\beta_5 LnS + 3\beta_6 (Ln_S)^2]}_{\varepsilon_{ES}} \\
& + \frac{\partial T}{\partial Y} \underbrace{[\frac{\beta_7}{T} + 2\beta_8 LnT + 3\beta_9 (Ln_T)^2]}_{\varepsilon_{ET}} \\
& = \underbrace{\frac{\partial P}{\partial Y}\frac{Y}{P}}_{\varepsilon_{YP}} \frac{P}{Y}\varepsilon_{EP} + \underbrace{\frac{\partial S}{\partial Y}\frac{Y}{S}}_{\varepsilon_{YS}} \frac{S}{Y}\varepsilon_{ES} + \underbrace{\frac{\partial T}{\partial Y}\frac{Y}{T}}_{\varepsilon_{YT}} \frac{T}{Y}\varepsilon_{ET} \\
& = \underbrace{\varepsilon_{YP}\varepsilon_{EP}\frac{P}{Y}}_{+} + \underbrace{\varepsilon_{YS}\varepsilon_{ES}\frac{S}{Y}}_{+} + \underbrace{\varepsilon_{YT}\varepsilon_{ET}\frac{T}{Y}}_{-}
\end{aligned}
$$

B.2 The abatement effect of increase in Tertiary Industry:

The abatement effect of increase in Tertiary Industry (T) caused increase in pollution-tertiary elasticity.

Figure B.1: Abatement Effect with an increase pollution-tertiary elasticity



B.3 Central Areas Results:

Table B.1: The estimation result for the relationship between PEI and GDP per capita: The role of Central Areas VS other Areas

Explanatory Variables	Central Areas (Fixed Effects)	Other Areas (Fixed Effects)
Constant	39.34619***	35.26475***
	(3.423345)	(3.623628)
$GDPPerCapita$	7.471455***	8.068015***
	(.6265453)	(.6264944)
$(GDPPerCapita)^2$	-1.413453***	-1.525439***
	(.3196059)	(.3130963)
$(GDPPerCapita)^3$	.6665462*	.5961054*
	(.3249738)	(.3186937)
Population	-1.18156***	-.8923272***
	(.2070005)	(.2175974)
Openness	-1.256737***	-1.308033***
	(.2697905)	(.2839593)
Urbanization	1.160753***	1.575761***
	(.3966971)	(.4125495)
Foreign Direct Investments	-1.037305***	-.8366587***
	(.2239762)	(.2324824)
Central Areas	-.5228356*	-
	(.3406434)	
East Areas	-	-
North East Areas	-	-.7844904*
		(.4996715)
West Areas	-	1.140314***
		(.3709975)
(Central Areas)(GDP per capita)	-	-
		-
(East Areas)(GDP per capita)	-	-
(North East Areas)(GDP per capita)	-	-
(West Areas)(GDP per capita)	-	-
R^2	0.6765	0.6863
Hausman Test	-	-
Prob> CH2	-	-
N	450	450

* is significant at 10% level; ** is significant at 5% level and *** is significant at 1% level

B.4 East Areas Results:

Table B.2: The estimation result for the relationship between PEI and GDP per capita: The role of East Areas VS other Areas

	East Areas	Other Areas
Explanatory Variables	(Fixed Effects)	(Fixed Effects)
Constant	40.66562***	35.01585***
	(3.314436)	(3.624268)
$GDPPerCapita$	7.603833***	8.068015***
	(.6251151)	(.6264944)
$(GDPPerCapita)^2$	-1.544271***	-1.525439***
	(.3189353)	(.3130963)
$(GDPPerCapita)^3$	-	.5961054*
		(.3186937)
Population	–1.313748***	-.8923272***
	(.1937812)	(.2175974)
Openness	-1.118134***	-1.308033***
	(.2889408)	(.2839593)
Urbanization	1.051972***	1.575761***
	(.3986369)	(.4125495)
Foreign Direct Investments	-1.044093***	-.8366587***
	(.23205)	(.2324824)
Central Areas	-	-
	-	-
East Areas	-	-
North East Areas	-	-
West Areas	-	1.389211***
		(.5240557)
(Central Areas)(GDP per capita)	-	-
		-
(East Areas)(GDP per capita)	-	-
(North East Areas)(GDP per capita)	-	-
(West Areas)(GDP per capita)	-	-
R^2	0.6746	0.6863
Hausman Test	-	-
Prob> CH2	-	-
N	450	450

* is significant at 10% level; ** is significant at 5% level and *** is significant at 1% level

B.5 North-East Areas Results:

Table B.3: The estimation result for the relationship between PEI and GDP per capita: The role of North East Areas VS Other Areas

	North East Areas	Other Areas
Explanatory Variables	(Fixed Effects)	(Fixed Effects)
Constant	40.81193***	34.48026***
	(3.262971)	(3.611488)
$GDPPerCapita$	7.906486***	8.068015***
	(.6295705)	(.6264944)
$(GDPPerCapita)^2$	-1.600453***	-1.525439***
	(.3201242)	(.3130963)
$(GDPPerCapita)^3$	-	.5961054*
		(.3186937)
Population	-1.234202***	-.8923272***
	(.1963872)	(.2175974)
Openness	-1.259001***	-1.308033***
	(.2639662)	(.2839593)
Urbanization	1.350442***	1.575761***
	(.4145562)	(.4125495)
Foreign Direct Investments	-1.10972***	-.8366587***
	(.2208429)	(.2324824)
Central Areas	-	.7844904*
		(.4996715)
East Areas	-	-
North East Areas	-.7813639*	-
	(.5300816)	
West Areas	-	1.924804***
		(.5111543)
(Central Areas)(GDP per capita)	-	-
(East Areas)(GDP per capita)	-	-
(North East Areas)(GDP per capita)	-	-
(West Areas)(GDP per capita)	-	-
R^2	0.6782	0.6863
Hausman Test	-	-
Prob> CH2	-	-
N	450	450

* is significant at 10% level; ** is significant at 5% level and *** is significant at 1% level

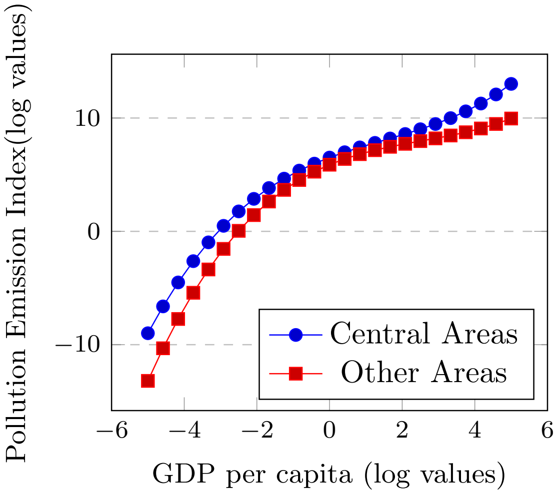
B.6 West Areas Results:

Table B.4: The estimation result for the relationship between PEI and GDP per capita: The role of West Areas VS Other Areas

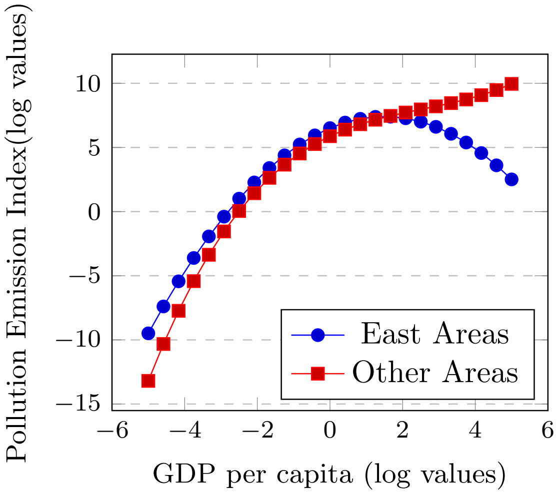
Explanatory Variables	West Areas (Fixed Effects)	Other Areas (Fixed Effects)
Constant	34.90751***	36.40507***
	(3.636269)	(3.473183)
$GDPPerCapita$	7.779112***	8.068015***
	(.6771811)	(.6264944)
$(GDPPerCapita)^2$	-1.485685***	-1.525439***
	(.3167962)	(.3130963)
$(GDPPerCapita)^3$	.651704*	.5961054*
	(.3821825)	(.3186937)
Population	-.9165884***	-.8923272***
	(.2174895)	(.2175974)
Openness	-1.255244***	-1.308033***
	(.2706777)	(.2839593)
Urbanization	1.404579***	1.575761***
	(.3979057)	(.4125495)
Foreign Direct Investments	-.8254747***	-.8366587***
	(.2304528)	(.2324824)
Central Areas	-	-1.140314***
		(.3709975)
East Areas	-	-1.389211***
		(.5240557)
North East Areas	-	-1.924804***
		(.5111543)
West Areas	1.300793***	-
	(.3421463)	
(Central Areas)(GDP per capita)	-	-
(East Areas)(GDP per capita)	-	-
(North East Areas)(GDP per capita)	-	-
(West Areas)(GDP per capita)	-	-
R^2	0.6851	0.6863
Hausman Test	-	-
Prob> CH2	-	-
N	450	450

* is significant at 10% level; ** is significant at 5% level and *** is significant at 1% level

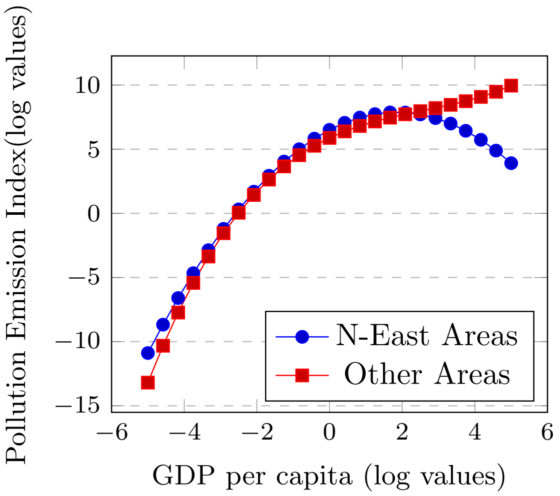
B.7 The Graphs for Different Region Effects:



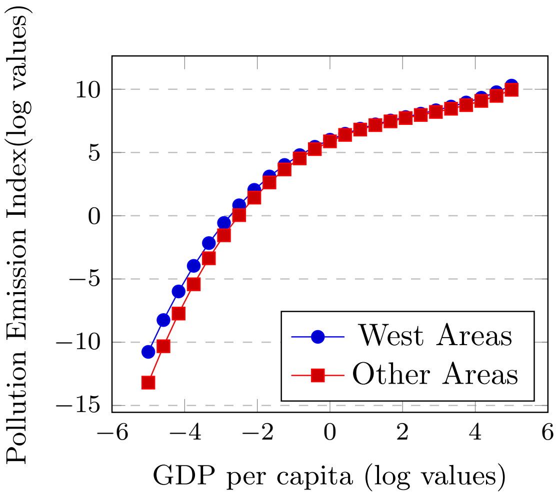
(a) Central Areas VS Other Areas



(b) East Areas VS Other Areas



(c) North East Areas VS Other Areas



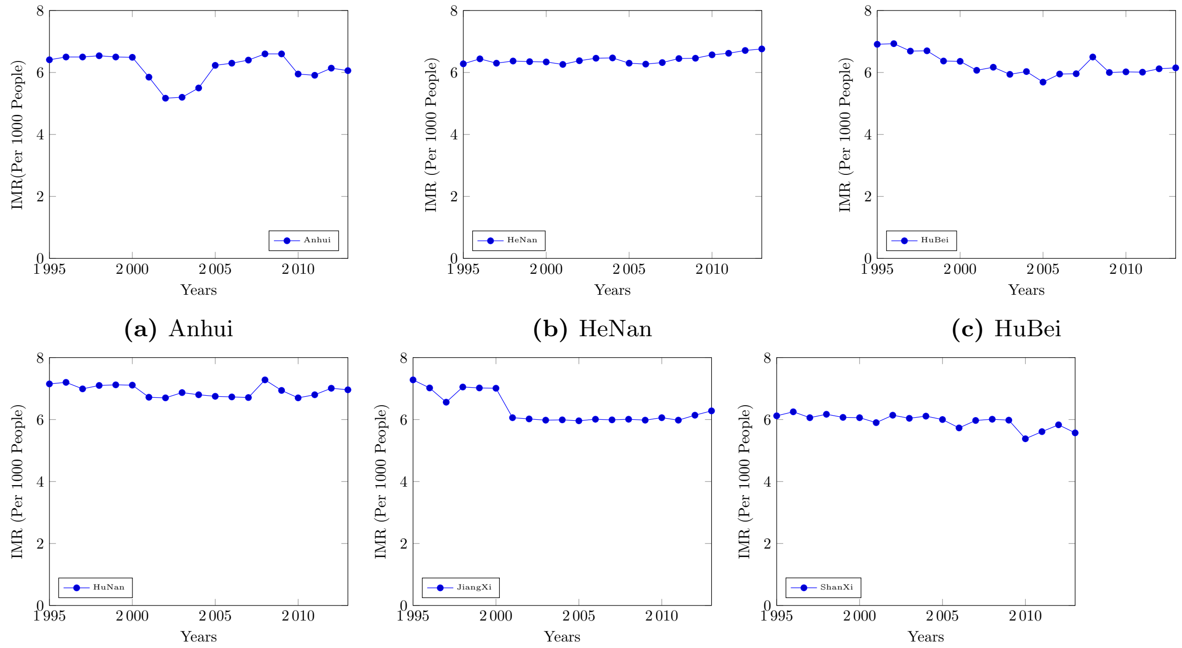
(d) West Areas VS Other Areas

Figure B.2: The relationship between pollution pressure and income per capita: The Role of Central, East, North East and West Areas

Appendix C

Appendix for Chapter 4

C.1 The IMR for Central Areas in China:

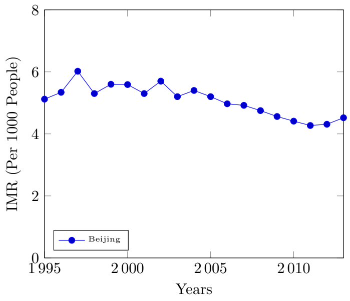


(a) Anhui (b) HeNan (c) HuBei

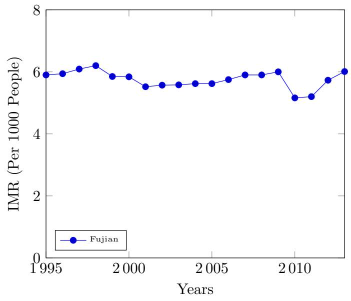
(d) HuNan (e) JiangXi (f) ShanXi

Figure C.1: The Individual's Mortality Rate for each province of Central Areas in China.

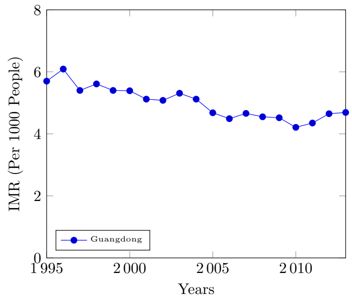
C.2 IMR for East Areas in China:



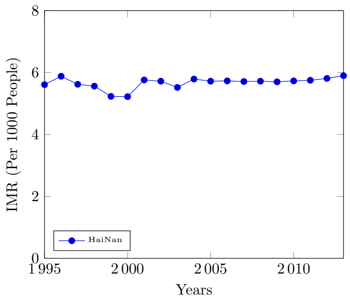
(a) Beijing



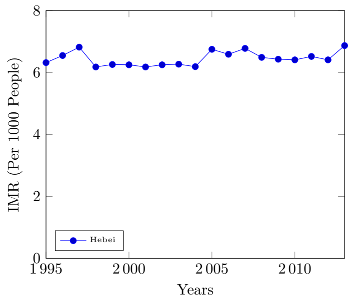
(b) Fujian



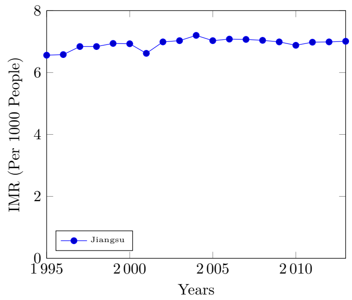
(c) Guangdong



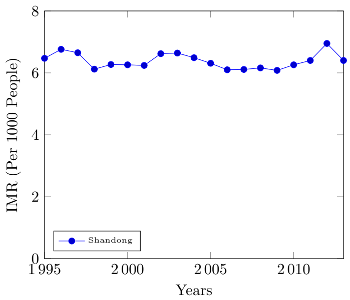
(d) HaiNan



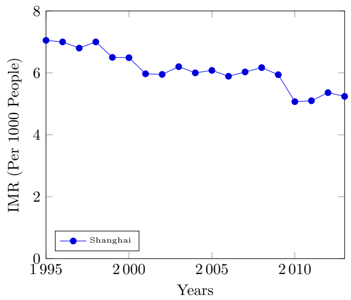
(e) Hebei



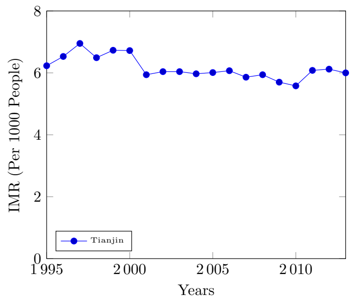
(f) Jiangsu



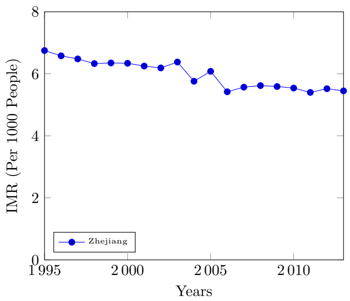
(g) Shandong



(h) Shanghai



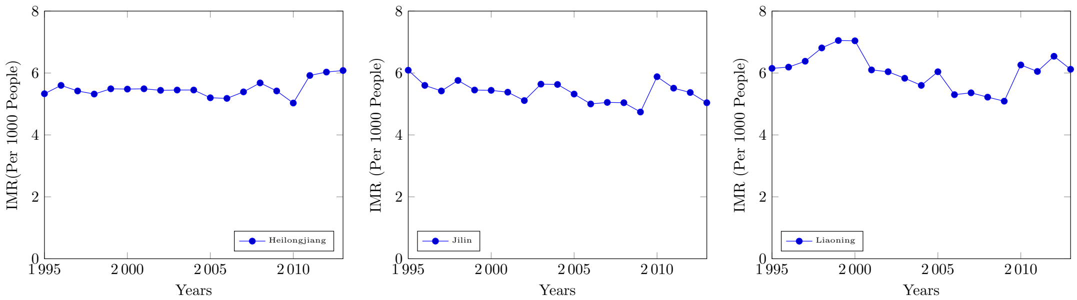
(i) Tianjin



(j) Zhejiang

Figure C.2: The Individual's Mortality Rate for each province of East Areas in China.

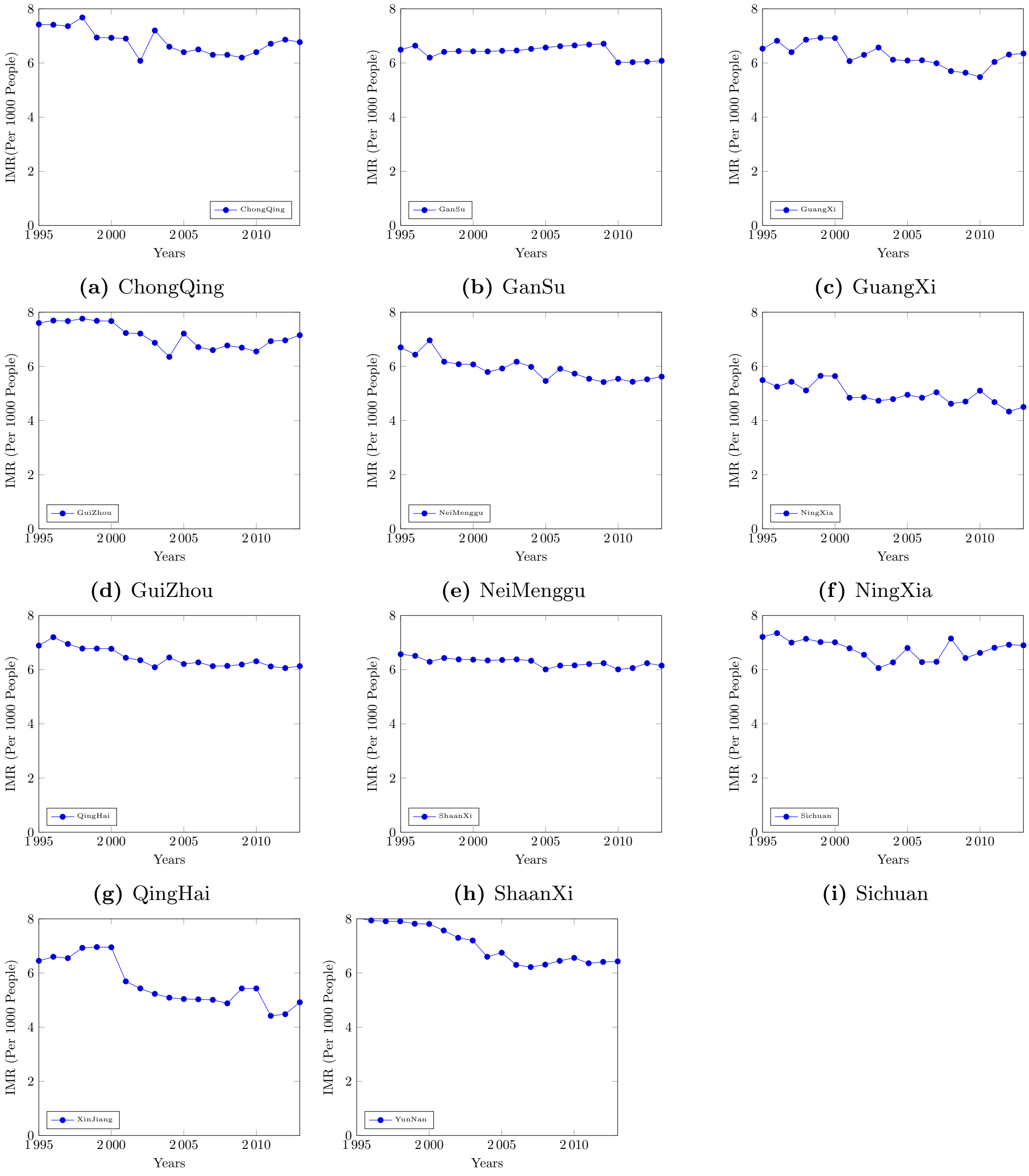
C.3 The IMR for Northeast Areas in China:



(a) Heilongjiang **(b)** Jilin **(c)** Liaoning

Figure C.3: The Individual's Mortality Rate for each province of Northeast Areas in China.

C.4 The IMR for West Areas in China:



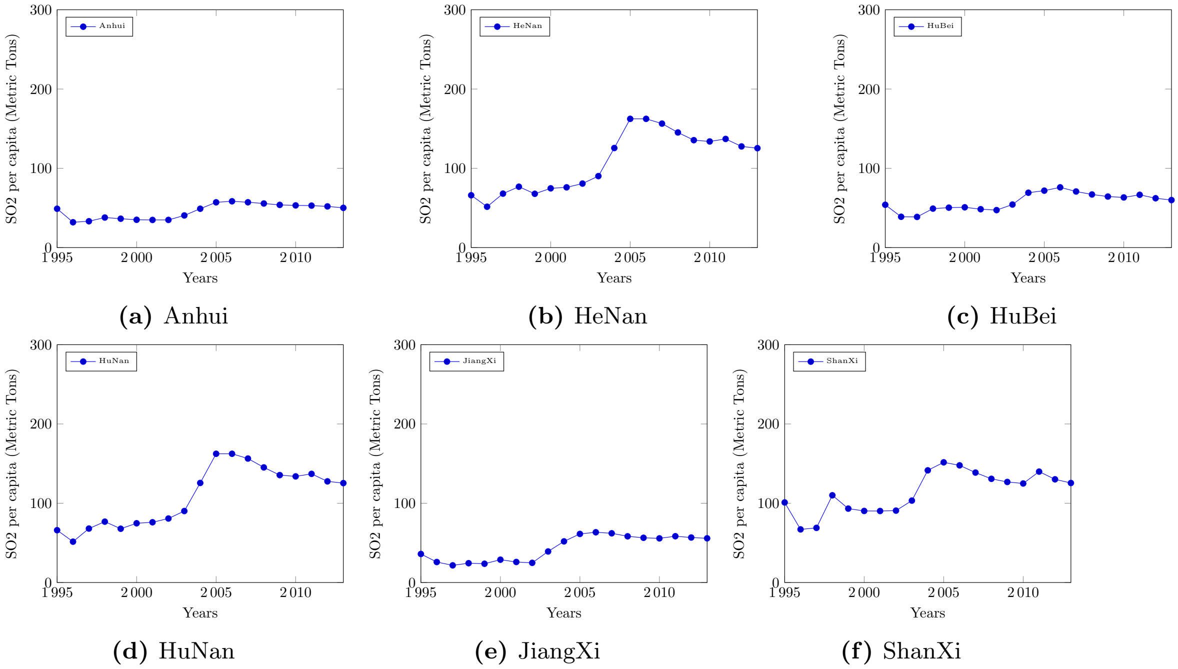
(a) ChongQing **(b)** GanSu **(c)** GuangXi

(d) GuiZhou **(e)** NeiMenggu **(f)** NingXia

(g) QingHai **(h)** ShaanXi **(i)** Sichuan

(j) XinJiang **(k)** YunNan

Figure C.4: The Individual's Mortality Rate for each province of West Areas in China.



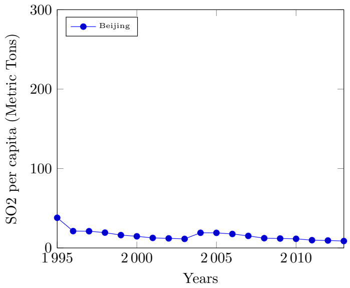
(a) Anhui **(b)** HeNan **(c)** HuBei

(d) HuNan **(e)** JiangXi **(f)** ShanXi

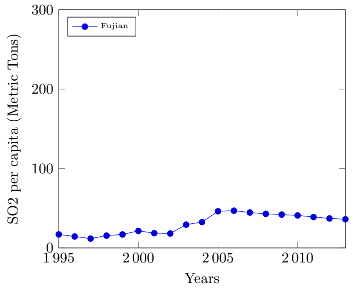
Figure C.5: The SO2 Emission per capita for each province of Central Areas in China.

C.5 The SO2 Emissions for Central Areas in China:

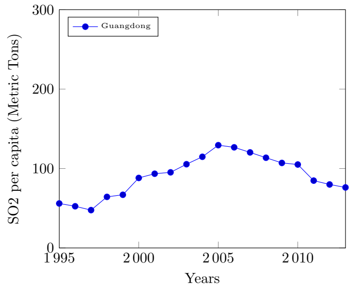
C.6 SO2 Emissions for East Areas in China:



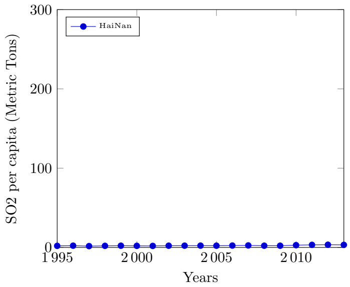
(a) Beijing



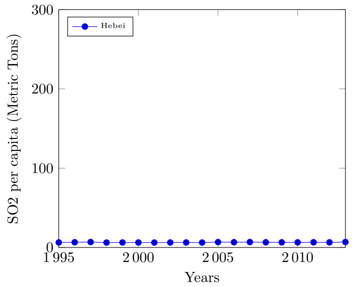
(b) Fujian



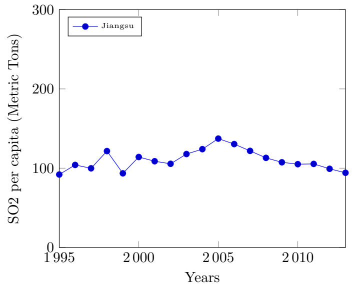
(c) Guangdong



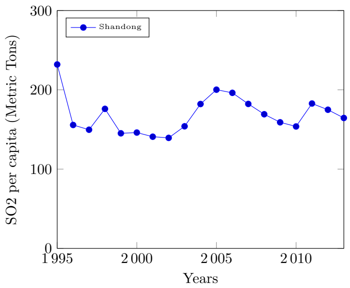
(d) HaiNan



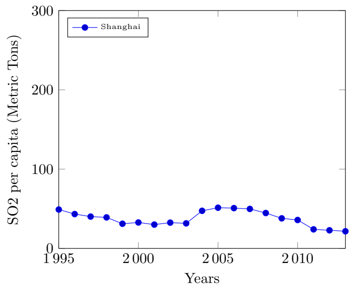
(e) Hebei



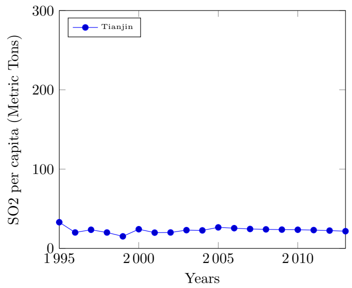
(f) Jiangsu



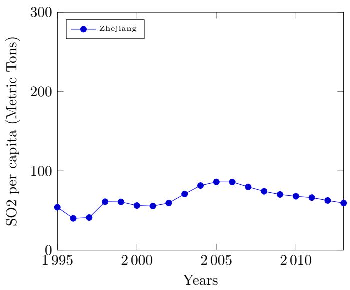
(g) Shandong



(h) Shanghai



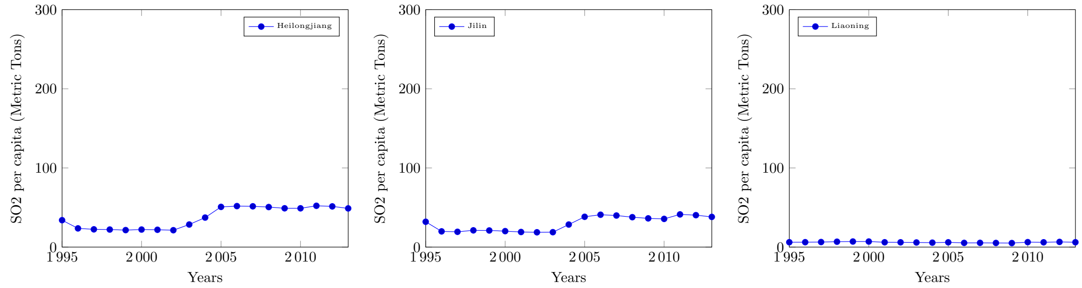
(i) Tianjin



(j) Zhejiang

Figure C.6: The SO2 Emission per capita for each province of East Areas in China.

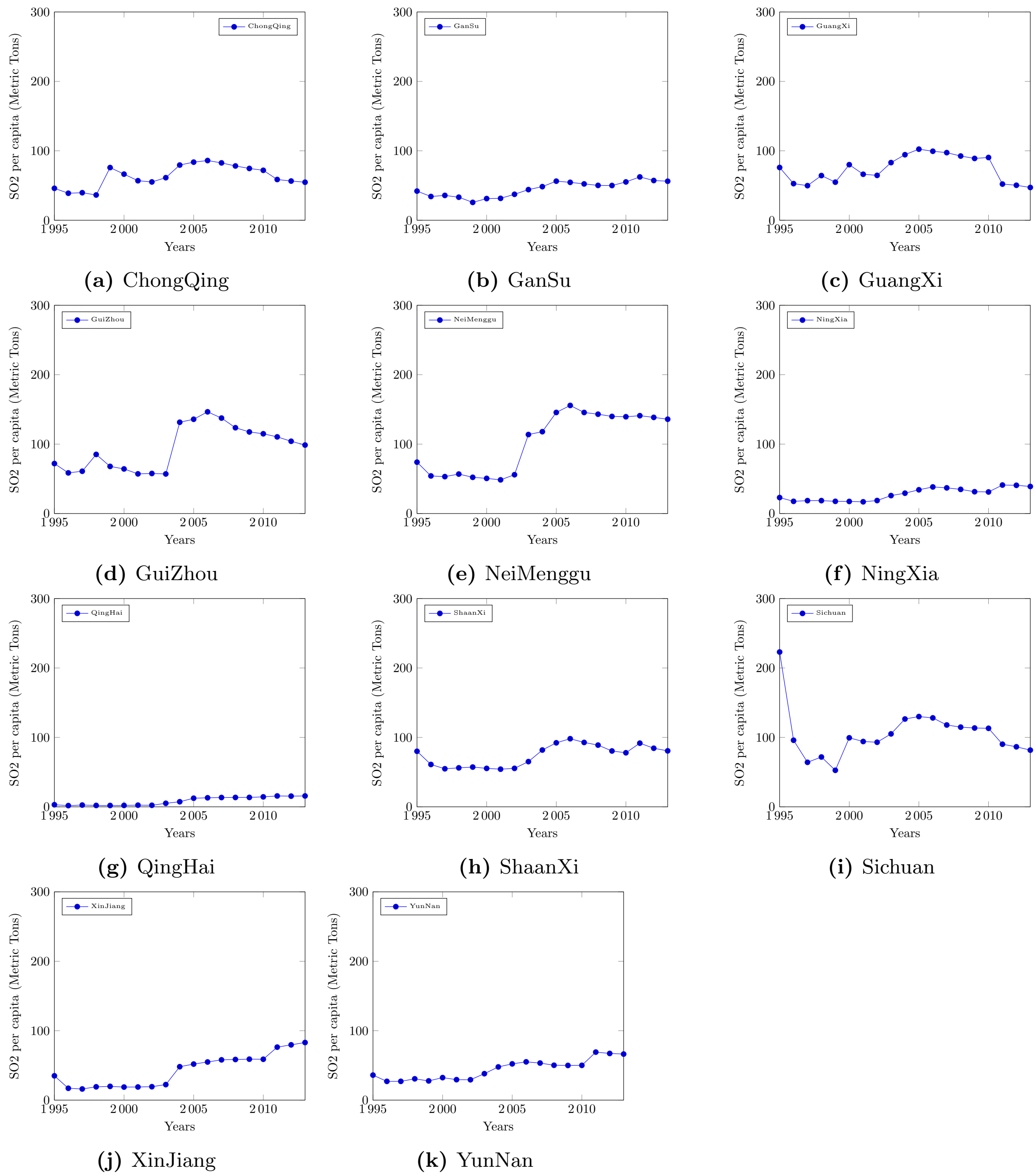
C.7 The SO2 Emissions for Northeast Areas in China:



(a) Heilongjiang **(b)** Jilin **(c)** Liaoning

Figure C.7: The SO2 Emission per capita for each province of Northeast Areas in China.

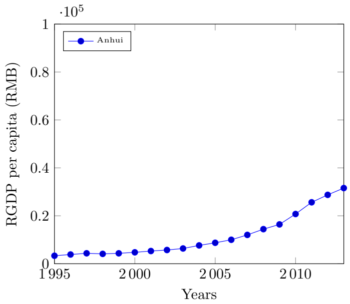
C.8 The SO2 Emissions for West Areas in China:



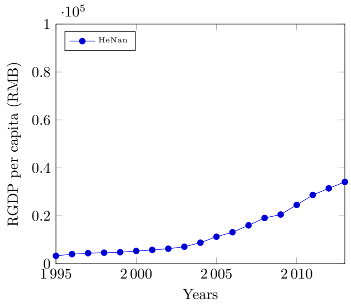
(a) ChongQing (b) GanSu (c) GuangXi (d) GuiZhou (e) NeiMenggu (f) NingXia (g) QingHai (h) ShaanXi (i) Sichuan (j) XinJiang (k) YunNan

Figure C.8: The SO2 Emission per capita for each province of West Areas in China.

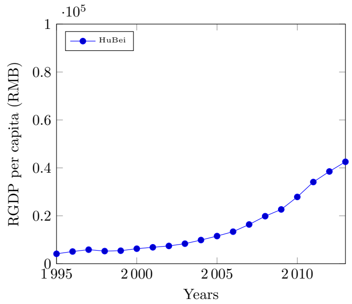
C.9 The Real GDP per capita for Central Areas in China:



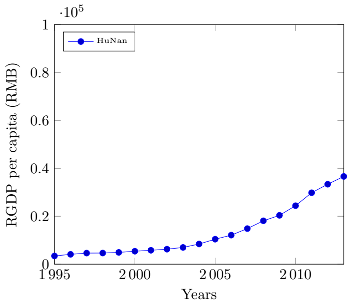
(a) Anhui



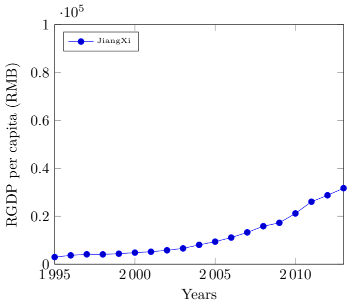
(b) HeNan



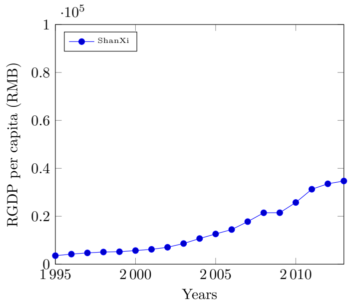
(c) HuBei



(d) HuNan



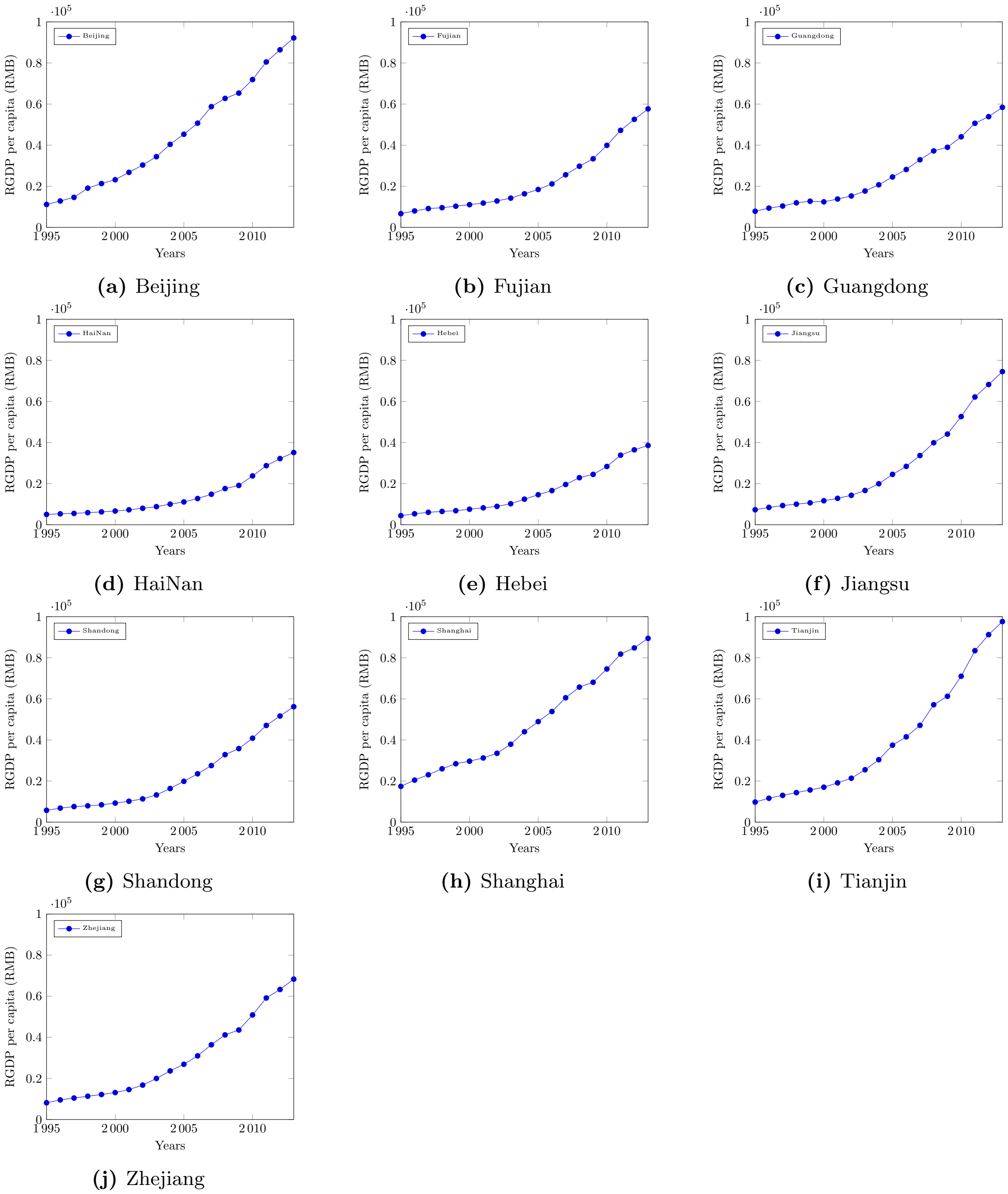
(e) JiangXi



(f) ShanXi

Figure C.9: The Real GDP per capita for each province of Central Areas in China.

C.10 Real GDP per capita for East Areas in China:



(a) Beijing **(b)** Fujian **(c)** Guangdong

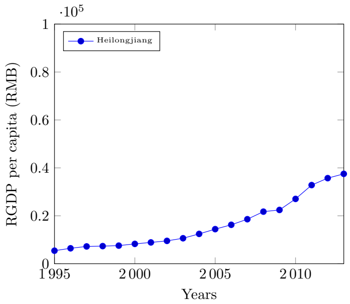
(d) HaiNan **(e)** Hebei **(f)** Jiangsu

(g) Shandong **(h)** Shanghai **(i)** Tianjin

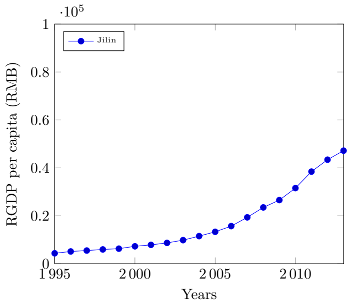
(j) Zhejiang

Figure C.10: The Real GDP per capita for each province of East Areas in China.

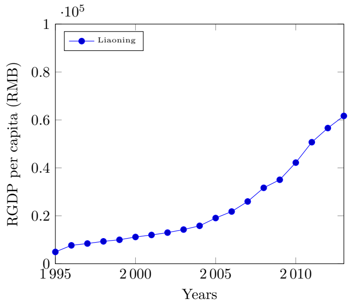
C.11 The Real GDP per capita for Northeast Areas in China:



(a) Heilongjiang



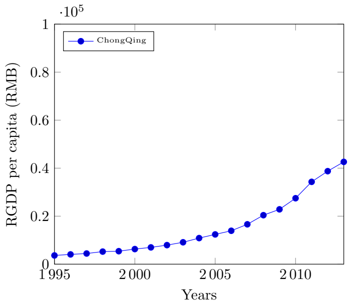
(b) Jilin



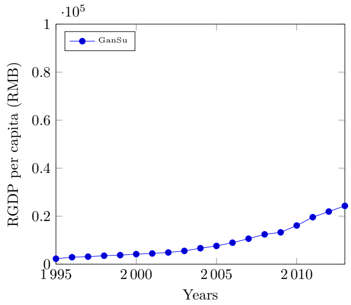
(c) Liaoning

Figure C.11: The Real GDP per capita for each province of Northeast Areas in China.

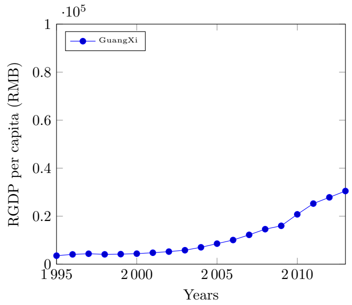
C.12 The Real GDP per capita for West Areas in China:



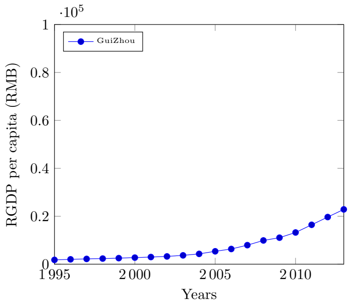
(a) ChongQing



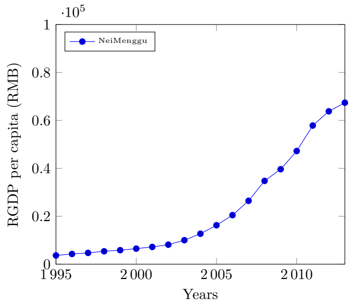
(b) GanSu



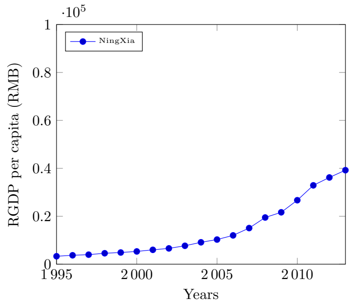
(c) GuangXi



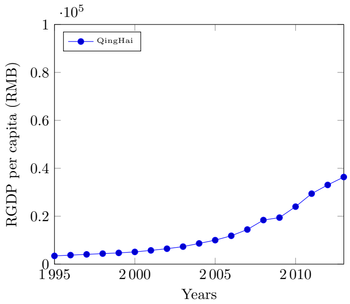
(d) GuiZhou



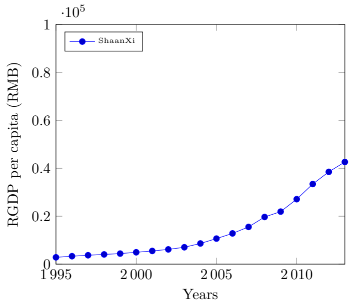
(e) NeiMenggu



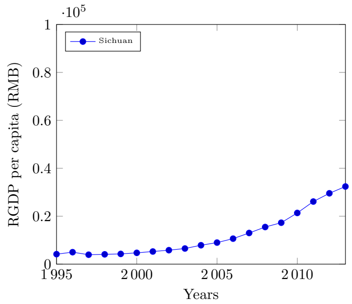
(f) NingXia



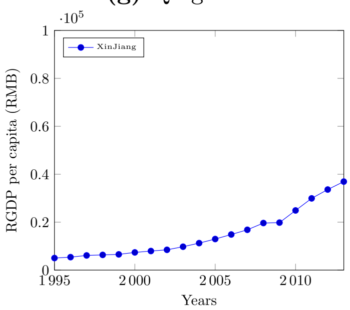
(g) QingHai



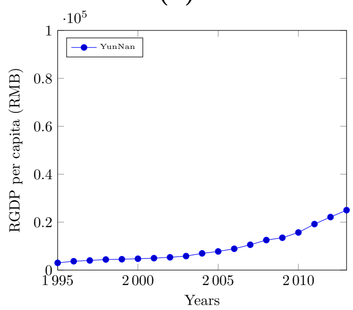
(h) ShaanXi



(i) Sichuan



(j) XinJiang



(k) YunNan

Figure C.12: The Real GDP per capita for each province of West Areas in China.