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Dynamics of China's Regional Development and Pollution

An investigation into the Environmental Kuznets Curve

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Abstract

This paper addresses the existence of an Environmental Kuznets Curve for China, using a sample of thirty regions and covering the period 1982-1997. The types of pollution included in the study are wastewater, waste gas and solid waste. We consider the development of the sources of pollution in a pooled cross-section analysis considering the pollution in absolute levels, in per capita terms and relative to real GDP. At intermediate levels of GDP per capita, the increase of solid and gas emissions tends to decelerate, but accelerates again at high levels of GDP per capita. Water pollution decreases with per capita GDP.

Key-words: Environmental Kuznets Curve, China, pollution, economic development

JEL-codes: O1, Q0.

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1. Introduction

China's economy has developed rapidly over the past 20 years. At the same time serious environmental problems have emerged. In this paper, we focus on the relationship between China's regional development and regional pollution. Following the seminal work by Grossman and Krueger (1995) we address the question whether an Environmental Kuznets Curve (EKC) – i.e. a hump shaped relationship between per capita income and pollution – can be found for China. Simultaneously studying the development of per capita income and pollution in China is interesting for at least two reasons. The first is related to the size of the Chinese economy and population. The fast economic development and the size of the economy will result in tremendous environmental impacts of the Chinese economy on both local and global environmental problems in the very future. Therefore, the analysis may result in policy conclusions relevant for the Chines economy. The second reason has to do with the difficulties that arise in many studies based on cross-country analysis. It is well known that difficulties are associated with methodological issues such as the appropriate estimation procedure (see, for example, de Bruyn and Heintz, 1999). A key point is that many EKC studies use cross-country data that may be difficult to compare. It could, for example, be that income data from high income countries are more accurate that those from low income countries (see Stern et al., 1996). By focusing on Chinese data, quality of the data can be expected to yield no bias in the estimation results (without arguing that data are reliable per se). Also, the problems arising from using different databases with a different sample of countries do not occur in the case of China (see, for example, Grossman and Krueger, 1995 as compared to Shafik and Bandyopadhyay, 1992). Furthermore, for cross-country studies per capita income data have to be denominated in a common currency. This is done by either 'deflating' by market exchange rates of purchasing power parities. It is known that these different methods yield diverging results, in particular when former communist countries are involved with high import barriers. By focusing on China, this problem does not arise. Finally, China has a relatively uniform political system, which reduces the problem of unobserved heterogeneity.

For these reasons, the present study can – in addition to systematically describing the development of the Chinese environmental problems as the economy grows mature – make a useful contribution to the research on the existence of an Environmental Kuznets Curve. The availability of data for 30 regions over the period 1982-1997 allows for a pooled cross-section analysis in which both the (in-)stability of the position of the Environmental Kuznets Curve over time and between regions can be studied. Such instability can be relevant even in a relatively homogeneous country such as China as patterns of specialisation among regions can be relevant and can also shift over time. The latter type of development may reflect, for example, the influence of increased participation in world trade or the effects of foreign direct investments.

The main conclusions of the paper are that it is difficult to talk about *the* Kuznets curve. It turns out that the relationship between pollution and income is highly dependent on the type of pollution that is being considered and on how environmental impact is being measured (i.e. in terms of levels of pollution, pollution per capita or pollution per unit of real GDP). For example, for solid waste measured in absolute levels we find an N-shaped relationship, while the relationship is upward sloping if we consider emissions per capita, and downward sloping if pollution is modelled per unit of gross national product. Furthermore, statistically significant period and regional fixed effects are found implying that the location of the Kuznets curve is neither stable over time nor over regions. Moreover, we reject the hypothesis that the position of the Kuznets curve (i.e. its intercept) is equal for all regions under consideration, implying substantial region-specific components in pollution that may be related to, for example, the specific industrial structure resulting from regional specialisation patterns.

The outline of this paper is as follows. First, we describe China's regional development (Section 2). Attention is paid to different views about China's regional development strategies and regional disparities. Next we describe in Section 3 the environmental problems and the distribution of pollution among regions. In Section 4, we discuss the main mechanisms that are potentially important in explaining the existence of an environmental Kuznets curve. We continue with an analysis of the empirically observed relationship between regional development and regional pollution in Section 5. Section 6 concludes.

2. China's regional development.

In this section we describe the uneven regional development in China during the past two decades in order to provide a background relevant for interpretation of the results from the econometric analysis. Unlike most developing countries, China's economy has grown rapidly. From 1986 to 1997, the average annual growth rate of gross domestic product (GDP) was 11.2%. The average standard of living has increased considerably. However, there exist major differences between regions.

2.1 Regional development disparity

To illustrate regional disparities in China we use two provinces as an example. In 1978, Guangdong's GDP per capita was 367 yuan. In the same year Gansu's GDP per capita was 348 yuan. In 1997, Guangdong's GDP per capita amounted to 10428 yuan, whereas Gansu's GDP per capita had risen to 3137 yuan. Hence, the disparity increased considerably. A more systematic overview is provided by making a distinction between coastal and interior regions and between northern and southern regions. Table A1 and Figures A1, A2 and A3 in Appendix 1 provide details about the classification of regions into the groups distinguished. Table 1 also gives regional growth rates for different time periods. It turns out that for the period 1978-1993 the average (unweighted) growth rate of GDP in northern regions was 9.1% and 10.1% for southern regions. For the coastal and interior regions the growth rates are 10.4% and 9.0% respectively. During the period 1994-1997 the northern and the southern regions experienced annual growth rates of 10.9% and 12.8% respectively. For the coastal and interior regions these growth rates were 12.9% and 11.2% respectively. Additional figures about the disparity between coastal and interior areas are presented in Table 1.

Table 1. Share (in %) of GDP and GDP per capita of coastal areas in total

Year	GDP	GDP per capita
1978	52.6	61.6
1980	52.3	61.4
1986	53.1	61.7
1991	55.1	63.5
1995	58.3	66.6
1997	58.0	66.3

Source: Processed from China's Regional Historic Statistical Material Collection (1949-1989) and China Statistical Yearbooks (1992), (1996) and (1998).

Further data are summarised in Table 2. The data reveal that the North is – on average – relatively sparsely populated, relatively rich in terms of GDP per capita in 1978, but falling behind over time, specialising towards agriculture and away from industrial output.

Table 2. Northern share in economic indicators

	1978	1985	1990	1996
Population	42.1	42.2	42.3	42.2
Area	59.3	59.3	59.3	59.3
GDP	46.5	44.6	43.9	41.1
Grain output	40.9	40.7	44.6	48.2
Gross output value of industry	49.4	45.1	44.5	39.5
Total investment in fixed assets	51.5	50.0	46.6	38.4

Source: Data processed from China's Regional Historic Statistical Material Collection (1949-1989) and China Statistical Yearbooks.

2.2 Causes of the disparity of regional growth rates

Most Chinese economists agree on the factors that have contributed to the enlargement of the regional economic disparity since 1978 (see Hu et al., 1995, Wei Houkai, 1992, and Zhou Minliang, 1998). First, the regional disparity is mainly attributable to different paces of development of non state-owned enterprises (Zhou Minliang, 2000). In the northern part of China non state-owned enterprises contributed 64.1% to the gross output value of industry, but in the southern part this was 76.4%. In 1996, 72.6% of total foreign investments went to the southern part of China. Guangdong, Jiangsu and Shanghai received 48.9%. In the same year, 83.2% of the contribution by Hong Kong, Macao and Taiwan to the gross output value of industry originated in the south.

Second, the changes in industrial structure differ by region. At the outset of the policy of economic reform, heavy industry was mainly located in northern China, whereas southern China mainly had light industry. In 1981, the gross output value of light industry in northern China was 45.0% of total industrial output value, in southern China it was 57.1%. In the beginning of the 1980s, when a shortage of light industry products became manifest, the central government initiated preferential policy to encourage the light industry. The enterprises in southern China followed the market and benefited. In 1996, refrigerators, electric fans, TV sets, and cameras produced in southern China amounted to 60.3%, 71.0%, 96.1%, 84.9%, and 90.0% of total China's output, respectively. The price reform of heavy industry products came relatively late, thereby hindering the development of northern China.

Third, the central government's policy has encouraged coastal areas, especially those in southern China. In 1978 China stepped on the road of reforming and opening to the world.

During 1979-1983, the central government provided more financial power to two southern coastal provinces, Guangdong and Fujian, in order to support the market-oriented reform. These provinces were also entitled to absorb investments from abroad. Subsequently four special economic zones were established, 14 coastal cities were opened to trade, three delta regions were declared open economic regions, and Hainan became a special economic province. In 1988, the strategy of coastal area development was proposed. The main idea was to develop an export-oriented economy in coastal areas.

In addition to these specific regional policies, the central government dismantled the organisationally inefficient collective farming and spread the family system over the whole country. It encouraged foreign investments and allowed for the development of non state-owned enterprises, adjusted the price system and descended some economic decision powers to local governments. These policies produced strong incentives to the development of all provinces, but especially to those in southern coastal areas.

3. China's environmental problems in a regional perspective

China's regional development is characterised by some undesirable features. First, there are large income inequalities among regions, which have widened over time. Second, serious unemployment prevails in areas where state-owned heavy industries are located. Third, regions suffer from social problems: especially in periods of price increases, most of the people in less developed regions are more affected in their living standards than those living in advanced regions. Finally, the combination of these (negative) tendencies has resulted in accumulated environmental problems, often concentrated in specific areas. In the remainder of this section, we elaborate on these environmental problems. Other reviews on China's pollution problems can be found in Vermeer (1998) and Edmonds (1999).

3.1 Soil erosion and water problems

Soil erosion occurs in 38% of the country's area. About 2.62 million square km are desertified. It is estimated that as a consequence 15-20% of all species of plants and animals is endangered. Cultivated land reduces by 100 thousand ha annually. Many scientists believe that the overexploitation of forests was an important cause of the flood appearing in the Chang River in 1998. Today China's forest area per capita is only 1/9 of the average world level. In Hainan, the natural forest reduced from 12 million ha in the 1960s to 5.3 million ha at present.

Water shortage is becoming serious, especially in northern China, due to little rainfall. About 300 cities in China face water shortage, which is deemed urgent in 50 cities. In Gansu, though the government has built up a forested region for water resources reservation, forests are still declining and the snow line is rising because of inefficient protection and drought **(**Li Xihui**,** 1999**)**.

3.2. Pollution

Table 3 and Figures A4-A6 provide some insight in the industrial waste gas emissions (defined as emissions of CO_2, NO_2 and SO_2), industrial solid waste disposal and the discharge of industrial wastewater. Both the Table and the Figures clearly display the regional variation in industrial pollution.

Table 3. Industrial pollution in coastal areas (absolute and relative to total industrial pollution)

Pollution type	Year	Coastal areas absolute	Coastal areas % of total
Waste water	1982	11674.3	50.0%
(million tons)	1985	11717.7	47.1%
	1990	12150.4	47.0%
	1995	11145.5	50.2%
	1997	9390.4	49.7%
Waste gas	1982	2264.7	47.2%
(billion m^3)	1985	2745.8	45.5%
	1990	3596.7	49.2%
	1995	5242.1	49.7%
	1997	5734.1	50.6%
Solid waste	1982	173.7	43.4%.
(million tons)	1985	208.6	42.9%
	1990	253.2	43.8%
	1995	282.7	43.7%
	1997	279.0	42.5%

Source: China's Environmental Statistical Materials (1981-90) and China Statistical Yearbook (1991, 1996, 1998).

In view of the fact that the coastal areas occupy only 13.4% of the country, we see that the pollution problem is more serious there. It is also clear that industrial pollution is increasing rapidly, except for wastewater. Hence, China's environmental situation regarding pollution is evidently deteriorating (see, for example, also the National Environment Protection Agency, 1996). The following casual observations underline this judgement. In 1995, water quality in the Yangtze River was – to Chinese standards – very poor over more than 24% of its length. For the Yellow River, Peril River, Huai River, Hai River, Songhua and Liao River these figures are 60%, 22%, 51%, 41% and 67%, respectively. Over 70% of the surface water (rivers) near cities is polluted. Over 50% of the groundwater in the cities is polluted at different degrees. Xinhuashe (1999) states that "At present, there are 31 rivers and 51 sewing systems dumping sewage into the Bohai Sea. Every year, about 2.8 billion tons of sewage is discharged, accounting for 33% of the country's total. The discharged solid waste reaches 700,000 tons, 50% of the coastal areas' total in this category, while the area of the Bohai Sea is only one sixtieth of the State's total sea area". Of all 600 cities, less than 1% have acceptable air quality. Recently the World Resources Institute listed the 10 cities in the world with the highest air pollution; nine of them are in China. Acid rain problems occur in 30% of all areas. It is estimated that the direct loss by air and water pollution amounts to 4-8% of China's GDP annually (Xinhuashe, 1999).Let us now turn to a more detailed analysis of the regional situation concerning wastewater, waste gas and solid waste.

a. Industrial wastewater

In 1997, 18.8 billion tons of industrial wastewater was discharged. Industrial wastewater was mainly produced (63.8%) by 4 sectors: petroleum processing and cokes production, smelting and pressing of ferrous metals, raw chemical materials and chemical products, and, finally, paper making and paper products. From 1991 to 1997, the total volume of industrial wastewater emissions has been declining in most provinces, but there were still several provinces or autonomous regions where emissions of industrial wastewater have increased.

b. Industrial waste gas

Chinese statistical sources report only on total emissions of industrial waste gas and on SO_2. Separate data on CO_2 and NO_2 are not available. Industrial waste gas mainly originates from three sectors: production and supply of electric power, gas and water, smelting and pressing of non-ferrous metals, and, finally, non-metal mineral products. They account for 72% of China's total volume of industrial waste gas emission in 1997. From 1991 to 1997, the country's industrial waste gas emissions increased by 34%. Industrial waste gas emissions consist of two parts: waste gas originating from the process of fuel burning and waste gas from other production processes. In 1997, the former part was 63% of total industrial waste gas emissions. Of the former part, waste gas from production and supply of electric power, gas and water amounted to 58%. In the latter part, waste gas from non-metal mineral production, especially cement production and smelting and pressing of non-ferrous metals, constituted almost 70% of total waste gas in the process of production.

Waste gas shows the same regional trend as industrial wastewater. Industrial waste gas is highly concentrated. Six provinces (Hebei, Liaoning, Jiangsu, Shandong, Henan and Sichuan) are responsible for 41% of total emissions. There is more particulate matter in the cities of northern China which – combined with waste gas, and given an arid or semi-arid environment – increases air pollution. In southern areas, there is a gradual extension of areas suffering from acid rain due to the presence of more low hills, abundant rainfall and wet climate, mixed with increasing waste gas emission.

Other emissions also reflect the regional disparity as can be illustrated by the following numbers. In 1997, China emitted 13.63 million tons of SO_2. Eight provinces (Hebei, Shanxi, Liaoning, Jiangsu, Shandong, Henan, Sichuan and Guizhou) were responsible for 54% of the total. Shandong held 11% of the total. Of the country's 6.85 million tons of industrial soot emissions in 1997, Hebei, Liaoning, Heilongjiang, Shandong, Henan and Sichuan were responsible for 41% of the total. Of the 5.48 million tons of industrial dust emissions, six provinces (Hebei, Liaoning, Shandong, Henan, Guangdong, and Sichuan) caused 41% of the total.

c. Industrial solid waste

Solid waste is an important source of pollution. Of all industrial solid waste, 86% originated from three industrial sectors: mining and quarrying, production and supply of electric power, water and gas and, finally, smelting and pressing of non-ferrous metals. The regional disparity in industrial solid waste is different from the pattern for industrial wastewater and industrial waste gas. Table 3 shows that about 57% of solid waste is produced by the interior regions. Eight provinces (Hebei, Shanxi, Liaoning, Jiangxi, Shandong, Sichuan, Heilongjiang and Henan) caused 55% of the country's industrial solid waste emissions. The growth rates are highest in Beijing, Neimenggu, Shaanxi and Xinjiang.

3.3 Pollution damage

Pollution damage in a country is related to many factors, such as the coverage by plants, annual rainfall, the share of cultivated land, and the level of technology. Plants can absorb waste gas, rainfall can dilute wastewater, and advanced technology can improve pollution abatement. In China, there are relatively many areas consisting of plateaux, mountains and deserts. Only a small percentage of land is cultivated and population is concentrated in a few regions. The little coverage of forest (less than 15%) can explain the low absorption of waste gas. The limited seasonal rainfall, especially in North China, enhances stock pollution. The relatively poor technology makes it difficult to reduce pollution effectively. In addition, pollution is concentrated in densely populated areas.

4. The relationship between regional development and regional pollution

In recent years, the Environmental Kuznets Curve (EKC) hypothesis has received much attention in the environmental economics literature. The literature builds on the seminal article by Kuznets (1955) in which he derived a hump-shaped relationship between per capita income and income inequality. In 1965, after Kuznets published his article to depict the relationship between income distribution and economic development, Williamson (1965) published a paper focusing on regional inequality and economic development. He analysed data from 24 countries, and found that whereas the regional gap in low income countries is lower, the regional gap in middle income countries is higher, and that in high income countries it is lower again. Thus he obtained the (hump shaped) Kuznets curve and concluded that as the economy develops, the regional gap will experience an increase first and a decline afterwards.

The hypothesis of the Environmental Kuznets Curve claims that as an economy develops, environmental problems will get more serious initially, but will decline eventually. The hypothesis postulates a relationship between welfare and environmental quality and might lead to a better understanding of the opportunities for sustainable development. For the analysis that is to follow, it is important to emphasise that the inverted U-shaped relationship between per capita income and pollution is but one of the many forms that a more general Income-Emission Relationship can take. Perhaps an inverted U curve does not suffice to express the relationship between environmental and economic development. The executive director of the UN Population Fund once said: “Much of the environmental degradation witnessed today is due primarily to two groups of people-the top billion richest and the bottom billion poorest” (Todaro, 1997). This suggests that for high incomes the relationship between pollution and income is positive again, or maybe even that the environmental Kuznets curve is U-shaped. One underlying idea is the following. Environmental deterioration can be split into two parts: pollution and the reduction of natural resources (land, forest, grass and mineral resources). The U-curve reflects the fact that environmental degradation in underdeveloped countries is related to population pressure, extensive production modes, the overexploitation and overusing of natural resources. In advanced countries it is more related to excessive consumption. Many developing countries’ export is mainly concentrated in raw materials and imports are mainly industrial products. Advanced countries on the other hand import and consume raw material. Though the top richest and bottom poorest people are both the main origins of environmental degradation, the developing countries often bear the worst environmental consequences. In our empirical application, we will choose a flexible specification of the income-emission relationship that allows for non-linearities between pollutants and per capita income.

In order to understand the development of environmental quality in China, it is relevant to keep in mind three broad factors that affect the relationship between per capita income and emissions. The *scale* effect simply implies that in a growing economy emissions tend to increase (at given emission intensities and a given production structure). Given the high growth rates that China experienced in the past decades, this has an important positive effect on emissions. The *intensity* effect is affected by several factors, all of which are related to technology. As economies grow rich, they are likely to be able to afford better and more efficient technologies resulting in lower intensities. This may be one mechanism that gives rise to a 'real' negative relationship between income and emissions. However, intensities are also affected by changing prices of (or taxes on) polluting inputs into the production process. These changes in price are unlikely to be directly related to per capita income, but they may have important impacts on emissions. Arguments have been put forward that, as people become wealthier, they tend to push for stricter environmental policies (for example, de Bruyn and Heintz, 1999). This may give rise to a relationship between per capita income and emissions along the effects of per capita income on, for example, taxes on pollution or environmental standards. Still another factor that may affect the pollution intensities of technologies being used are foreign direct investments. This factor may be particularly relevant for certain regions in China. Unfortunately, however, no data are available about this aspect. Third, one has to consider the *structural* effect. A typical time path of the sectoral composition of an economy is one in which countries are initially characterised by a large agricultural sector, followed by a period of industrialisation and subsequently followed by de-industrialisation and a rising service sector (for example, Baumol, 1967, and de Groot 2000). It goes beyond the scope of this paper to discuss the underlying mechanisms in detail. However, one can conclude from the literature on sectoral developments that as consumers become richer, they initially tend to shift their consumption pattern towards manufacturing products and at later stages towards services. Under the assumption that services are pollution-extensive and manufacturing goods pollution-intensive, such a demand-driven change in the sectoral composition of economies associated with developments in per capita income can give rise to a hump-shaped relationship between per capita income and emissions (see de Groot, 1999). However, and this seems especially relevant for the case of China as discussed previously, the sectoral composition of economies is also affected by patterns of specialisation (between regions or countries). Countries or regions with comparative advantages in pollution-intensive industries will due to this effect -ceteris paribus- witness an increase in emissions which is not related to developments in per capita income. Somewhat related to this issue is the recent interest in income inequality as a determining factor. It has been forcefully put forward by e.g., Ravaillion et al. (2000) that distributional issues may play an important role, e.g., because the income elasticity of energy demand is decreasing in income. Since we have no data available on income distribution in the distinguished regions we are unable to explore this matter any further.

The hypothesis of the EKC and the ensuing empirical tests have – to say the least – been subject to a fair amount of debate. The empirical tests have been criticised for several reasons. First, there have been criticisms on the way the hypothesis is being tested, using studies of different countries (for example, Dijkgraaf and Vollebergh, 2000, and List and Gallet, 1999). Second, most empirical studies that perform straightforward regression analysis yield relatively little insight into the driving forces that give rise to an EKC. They have at best included time trends to test for developments unrelated to per capita income. These trends may reflect technological progress resulting in lower energy intensities, but they may as well be the resultant of substitution away from energy in periods of rising energy prices. These problems have been overcome to some extent by decomposition techniques (for example, de Bruyn, 1997, Selden et al., 1996, and Sun 1998). These techniques decompose changes in pollution of energy use into a scale effect, an intensity effect and a structural effect. They thereby give some descriptive idea of the quantitative importance of the factors that may give rise to an EKC.

Despite the criticisms, we will empirically try to determine the shape of the Income-Emission Relationship (IER) for China in the next section. We allow for a flexible specification of the regression equation that allows for linear, quadratic and cubic polynomial relationships between per pollution and per capita income. The latter is important in view of the potentially relevant N-shaped IER's.

5. Empirical analysis.

5.1 Data

The data set used in our analysis is obtained from official Chinese statistical material, mainly from the statistical yearbooks. The data refer to a 16-year time period, running from 1982 up to 1997, and to the 30 provinces and major cities, to be called regions henceforth, listed in Table A1 in Appendix 1. For each region we have land surface and population data. There are figures on total emissions of waste gas, solid waste and wastewater (per year and per region). Moreover, we have data on gross domestic product, in current as well in constant prices. The data are available from the authors upon request.

As a first exploratory analysis of the data, we try to categorize the regions in our data set according to their state of economic development and environmental quality for the year 1997. This is done by distinguishing between regions with low, medium and high pollution levels. We consider wastewater, solid waste and waste gas per square km for each region and express them relative to the averages of the country (larger is 1, smaller is 0). If the sum of the indices exceeds 2 the region is called *highly polluted*, if it is below unity the region suffers from *low pollution*. Otherwise we call *pollution medium*. We also rank the regions according to income. If one region's GDP per capita exceeds the national average level (6079 yuan), we define the region as an *advanced* region. Otherwise, the region is defined as *underdeveloped.* This results in the classification of regions presented in Table 4 (asterisks denote coastal areas, *N* and *S* indicate North and South, respectively).

Table 4. Regional ordering based on pollution and economic development

	Serious pollution	*Medium pollution*	*Light pollution*
Advanced regions	Beijing*(N) Liaoning*(N) Tianjin*(N) Shandong*(N) Guangdong*(S) Jiangsu*(S) Shanghai*(S) Zhejiang*(S)	Fujian*(S) Heilongjiang(N)	
Backward regions	Hebei*(N) Henan(N) Shanxi(N) Anhui(S)	Guangxi*(S), Hainan*(S) Jilin(N) Ningxia(N) Shaanxi(N) Guizhou(S) Hubei(S) Hunan(S) Jiangxi(S) Sichuan(S)	Gansu(N) Neimenggu(N) Qinghai(N) Xinjiang(N) Yunnan(S) Xizang(S)

As the table shows, most of the advanced regions are the regions with serious pollution, and most of backward regions are medium or light pollution regions. The seriously polluted advanced regions are situated in coastal areas, and the lightly polluted underdeveloped regions are all situated in interior regions. At first sight there are no major systematic differences according to the distinction between North and South.

5.2 The econometric modelling

Since there exists no consensus about the theoretical background of the environmental Kuznets curve, we have considered several specifications of the econometric equation to be estimated. In one type of specification we have total emissions as the dependent variable, assuming that the Kuznets curve is driven by consumer preferences, that are affected by total pollution rather than by pollution per capita or per unit of production. Alternatively, if the engine behind the Kuznets curve is deemed to be production driven, it is more likely that the dependent variable should be related to emissions per unit of production. Finally, emission per capita has been employed in some studies to measure the degree of pollution. For expositional purposes we sketch several models to be analysed in the sequel. These contain only per capita income (Y) as explanatory variables. Extensions to more explanatory variables are straightforward. The index i will denote the region and t refers to time.

In Model I we consider a region specific EKC. The model reads

$$ES_{it} = \alpha_{0i} + \beta_{1i} Y_{it} + \beta_{2i} Y_{it}^2 + \beta_{3i} Y_{it}^3 + \varepsilon_{it}$$

where ES refers to the pollution indicator. In this model the intercepts as well as the slopes are region-specific.

Model II allows for region-specific intercepts but requires identical slopes:

$$ES_{it} = \alpha_{0i} + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \varepsilon_{it}$$

Model III is the most restricted model, requiring uniform intercepts as well as slopes:

$$ES_{it} = \alpha_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + \varepsilon_{it}$$

A general result from the analysis is that the null hypothesis of *equal intercepts* does not find any support in the data (using the F-test). This holds for all pollutants and for all specifications thereof (levels, per capita and per unit GDP). Therefore, model III is not used in the regressions, because model II with regional fixed effects is clearly preferred. One could argue that the distinction between North-South and Interior-Coastal could capture already a lot of the variation between regions. This has been tested for, but except for some special cases, this hypothesis is not supported by the data.

Tests for *equality of slopes* have been performed as well. In a number of cases the null hypothesis of equality of slopes had to be rejected, although not as convincingly as in the case of equality of intercepts. Note that there is a difficulty in interpreting the outcome of this test, which can be illustrated as follows. Suppose that a "genuine" inverted U shaped EKC exists, uniform with respect to the coefficients corresponding to per capita income, but possibly allowing for heterogeneity in intercepts. Suppose also that a distinction can be made in two groups of regions, one with persistent low per capita income and one with persistent high per capita income. To make the picture complete assume that there is no overlap in income over the period of observations. Then tests on equality of slopes are likely to be reject the null hypothesis (depending on the difference in income between the two sub-groups, the number of observations, the variance of the dependent and the independent variable, etc.). More specifically, the validity of tests on the equality of slopes declines if the difference in the range of income of different subgroups increases. Consideration of scatter diagrams for groups of regions in our sample give reasons to be cautious with applying tests for homogeneity.

All specifications have been estimated with (i) only per capita income measures, (ii) per capita income measures plus a time trend plus population and (iii) per capita income measures, a time trend and population density. Per source of pollution, nine regression equations result. These have all been estimated with fixed effects (i.e., region-specific intercepts). Details about the results are available upon request from the authors. In the remainder, we present the results for the various sources of pollution in levels, per capita terms and per unit of (real) GDP. The results reported in the tables below are based on regressions excluding time trends, population or population density. Mentioning is made of serious effects of inclusion of these types of variables.

5.4 Solid waste

The regression results for solid waste are presented in Table 5. The regression results for the level-equation are graphically represented in Figure 1. In order to give an impression of the relevance of the fixed effects (i.e. of the region-specific effects), the equation is drawn for the region with the lowest (Tianjin) and the highest (Liaoning) fixed effect and for the median fixed effect. More detailed information on the fixed effects is provided in Figure 2. It depicts the fixed effects obtained from the regression with solid waste per capita as the dependent variable. These fixed effects reflect the region-specific pollution after differences in income have been controlled for. High fixed effects can be an indication for inefficient technologies, specialisation in pollution-intensive sectors, etc.

Table 5. Solid waste

	levels		per capita		per GDP	
	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value
Y	0.42239	12.02538	5.29E-05	5.92E+00	-0.00076	-18.4111
Y^2	-3.4E-05	-8.23674	-3.62E-09	-3.43E+00	5.76E-08	11.89684
Y^3	8.37E-10	6.753953	9.37E-14	2.97E+00	-1.3E-12	-9.23611
R^2	0.950581		0.936994		0.897435	
$F-$statistic	4222.14		3264.294		1920.604	

< Insert Figures 1 and 2 around here >

We can see from Table 5 that the coefficients for the equation in levels have the expected sign, and are statistically highly significant. Moreover, the variation in pollution is well explained. From Figure 1, it is clear that the Income-Emission Relationship is increasing at low per capita income levels as well as at relatively high incomes. It is slightly decreasing for intermediate incomes. Therefore we find some support for an N-shaped IER as far as solid waste is concerned. The addition of a time trend and population density as explanatory variables does not add relevant new insights. The results in terms of pollution *per capita* are also highly significant, but over the relevant range of per capita income levels, the IER is now continuously upward sloping (though relatively flat at medium income levels). Finally, we have considered solid waste emissions *per unit of GDP* as dependent variable. The coefficients are all statistically significant. However no inverted U-shaped relation between solid waste per unit of GDP and income can be observed. It appears that the relationship over the relevant domain is negative, suggesting that solid waste emissions per unit of production decrease as incomes increase. Regarding the latter conclusion, it is unclear if there is a causal relationship. When the same regression is run with time as an explanatory variable, then the trend is highly significant. This observation might lead one to conjecture that there is an autonomous mechanism reducing solid waste per unit of production. It is difficult to distinguish between the two possibilities suggested above because income shows a clear time trend.

As depicted in Figure 2, the fixed effects obtained from the per capita regression equation differ greatly between regions. They are clearly largest in the northern part of China. It would be constructive to make an effort in explaining the differences. However, given the lack of data no formal econometric analysis can be performed to do so. We confine ourselves to a few observations. For the case of solid waste the province of Liaoning is ranking highest (for all regression specifications we performed). This can be explained by pointing at the fact that this is a province specializing in the production of raw materials and mining. Iron, steel production and manufacturing of steel products amount to about 11.8%, 12.4% and 11.3% of total production in China. On the other hand, Tianjin has a relatively large secondary industry and has little mining and therefore produces relatively little solid waste (although it is characterised by severe environmental problems on aggregate, as shown in the remainder of this section). Shanxi produces a considerable amount of coal (nearly 1/4 of China's output in 1997), so it produced more solid waste. [2]

5.5. Wastewater

For water it turns out that there is a strong negative relationship between per capita income and wastewater emission, measured in levels. The quadratic term as well as the third order variable are dominated by the linear term, as is clear from Table 6 and Figure 3.

[2] In the introduction to the present section is has been put forward that the test on the equality of slopes tends to reject the null hypothesis of equality. But we also noticed that there is a caveat, because it might be the case that income data per region do not show enough variation. In order to investigate this further we have taken the five regions with the highest per capita income in 1997 and the five regions with the lowest per capita income in 1997. It turns out indeed that the incomes of the former regions are more or less uniformly lower than those of the latter, over the entire time span of our observations.

Table 6 Water

	Levels		Per capita		per GDP	
	coefficient	*t-value*	*Coefficient*	*t-value*	*Coefficient*	*t-value*
Y	-6.278026	-5.943383	-0.001730	-6.180802	-0.049948	-24.68266
Y^2	0.000380	3.048898	3.49E-08	1.056686	3.55E-06	14.87085
Y^3	-9.68E-09	-2.595742	-2.31E-12	-2.336995	-8.45E-11	-11.82734
R^2	0.965849		0.972844		0.810178	
$F-$statistic	6676.252		8452.608		1021.139	

< Insert Figures 3 and 4 around here >

Hence, seen from the perspective of the individual economic agents higher incomes go hand in hand with less polluted water. The interpretation that higher incomes are used for cleaning purposes is not warranted however, because the dependent variable is industrial wastewater. Therefore, a more plausible explanation would be that when incomes rise, there is some pressure from the agents to emit less wastewater. We have also included population in the regression equation. Then it turns out that the statistical significance of per capita income vanishes and that the population variable is highly significant, suggesting that population size has an important impact on emissions: if more people are present, less water is polluted. When we consider wastewater emissions per capita as the dependent variable, then the same picture emerges: the linear part is significantly negative and dominates the other terms. So, with this specification the existence of an environmental Kuznets curve is not supported by the data. Finally, we consider wastewater per unit of production as the dependent variable. We find statistically significant parameters for the explanatory variables. The linear part is dominant again.

When the regression is run with time and population as additional explanatory variables, these are statistically significant and the income parameters become insignificant. A conclusion that can be drawn from these exercises is that no support is found for an environmental Kuznets curve for wastewater. Rather a negative time trend or a negative relationship between income and wastewater emissions seems prevalent.

For wastewater the relationship with income might be an indirect one. The advanced higher income regions specialize in relatively light industries, such as electronics. These industries are only moderately polluting and at the same time generate higher income. For the two provinces

Liaoning and Tianjin mentioned already in the discussion on fixed effects of solid waste approximately the same picture emerges (see Figure 4). The hypothesis of equal slopes over regions is rejected. A closer inspection of regions with high and low per capita incomes provides some useful information. It turns out that the picture for the five low income regions is rather fuzzy. The income range for the 18 years under consideration for these regions (being the poorest in 1997) is rather small. Within this small range we observe various patterns, increasing and decreasing wastewater levels over time. For the top 5 richest regions the income range is much larger and the picture shows a clearly decreasing trend over time.

5.6 Gas emissions

For gas emissions all coefficients are statistically significant and of the "right" sign. However, there is an overall positive relationship between pollution of this type and per capita income. See Table 7 below.

Table 7 Waste gas

	Levels		per capita		per GDP	
	coefficient	t-value	coefficient	t-value	Coefficient	t-value
Y	0.978867	15.98049	0.000160	5.814326	-0.000478	-3.926159
Y^2	-6.19E-05	-8.570296	-8.04E-09	-2.484632	2.61E-08	1.816203
Y^3	1.34E-09	6.216633	1.94E-13	2.005789	-5.40E-13	-1.257966
R^2	0.890549		0.810621		0.483537	
$F-$statistic	1928.076		1021.901		236.0184	

< Insert Figures 5 and 6 around here >

It is also found that inserting a time trend does not render the coefficients insignificant. Also, when population density is included this turns out to be significant, but the environmental Kuznets curve properties are maintained. When we consider waste gas emissions per capita then only the linear income term is statistically significant, and gas emissions increase as a function of per capita income. A possible explanation would be that increases in income per capita are strongly related to energy demand, which is in turn still strongly related with waste gas emissions. The latter observation is to some extent confirmed by the regression with emissions per unit of production. It turns out that only the linear section is statistically significant and dominates the other terms.

In 1997, the high ranking regions Guangdong, Shandong, Jiangsu, Hebei and Liaoning produce 34.3% of total China's electricity. And as the economy progresses, advanced regions need more cement for constructing house. The five provinces listed above produce 40.3% of China's total output that year. Waste gas from electricity and cement arrive to 36.6 and 13.5% of China's total industrial waste gas emission. More detailed information on the regional fixed effects after controlling for per capita income is depicted in Figure 6, illustrating the geographical concentration of gas emissions in the North-Western part of China.

Regarding the question of equality of slopes, the F-test is far less outspoken than in the previous cases. At the 1% level of confidence the null hypothesis of equal slopes would not be rejected. This confirms the widespread view of a tenuous relationship between income, energy use and waste gas pollution.

5.7 An overall assessment of China's regional environmental problems

We conclude this empirical section with a simple attempt to provide some insight into the seriousness of 'aggregate' environmental problems in the Chinese provinces. This is done by ranking the provinces according to their fixed effects obtained in the previously discussed regression analyses. In other words, we rank the provinces after having controlled for differences in per capita income. The fixed effects that remain potentially capture a variety of effects, among which size, sectoral composition, strictness of environmental regulation and environmental awareness of firms feature prominently.[3] The ranking presented in Appendix 2 is based on the average rank for the three sources of pollution.[4] The results reveal that Lianong is – after controlling for difference in development – the most seriously polluted province, irrespective of whether pollution is measured in absolute terms, in per capita terms or per unit of real GDP. Also Beijing, Shanghai and Shanxi suffer from relatively severe problems in terms of pollution per capita or per unit of real GDP. Their problems are less severe in absolute terms, caused by their relatively small size. Environmental problems are relatively limited in Xizang, Hainan, Xinjiang, Fujian and Yunnan. A useful extension of this analysis would obviously be a further in depth analysis of these differences. This is left for future research.

[3] The results are based on the regression analyses excluding population and density. We have also ranked the provinces according to the fixed effects that remain after having controlled for those factors. The results of those analyses are available upon request from the authors.

[4] Ranks for the individual sources of pollution are available upon request.

6. Conclusions and policy recommendations

In this paper, we have analysed the situation of China's regional development and change of China's environment in the context of regional pollution. The main finding is that the environmental Kuznets curve applies to several specifications of the relationship between income and pollution. However, this is not uniformly the case. The shape of the relationship heavily depends on the specification of the dependent variable in the case of solid waste (levels, per capita or per unit of gross domestic product). For wastewater we find a negative relationship indicating that water quality increases with welfare. For waste gas in levels there is a typical Kuznets curve. When waste gas emissions are modelled per capita or per unit of gross domestic product the relationship is essentially increasing in per capita income. The fixed effects describing differences between regions, are statistically very significant and imply that there are major differences between regions. These differences are likely to reflect differences in the underlying industrial structure. More indepth statistical analysis would be required to further substantiate this conclusion. Lack of suitable data does not allow us to perform such an analysis at this stage.

In designing environmental policies China will have to take account of its own special position. But it might also benefit from experiences with environmental policies elsewhere in the world. There might be some room for economic instruments such as levies and permits, which seem to be suitable in an economy where market forces are already in place and will play a more dominant role in the future. The shortcomings of government invention and market failure contribute to China's pollution problem. This occurred inevitably in China's economic transformation with loosening economic planning and intervention. The important question to care about now is not to distinguish the benefactors from the sufferers of this environment degradation. It is important to determine who is responsible for pollution damage, who is responsible for environmental improvement, how to join forces to curb pollution by institutional management so as to get high benefits at low cost. In these aspects, China could learn lessons from advanced countries, and also from its own experiences. We end by briefly describing some threats and opportunities for Chinese environmental policy.

In general, China's pollution situation is critical, especially in advanced regions. Some types of pollution are still increasing. Although the central government recognises the imperative of environmental protection, Jiang Zemin has put forward that in the process of economic development "we can't eat the food the ancestors inherited, and cut the road of descendants for living". But with an enormous population, relative scarcity of natural resources, and an ambitious development plan, it is “more difficult to have effective environmental protection” (Jan, 1995). Manne et al. (1993) estimate China's annual growth rate of CO_2 emissions over 1990-2050 at about 2.3%. Martins et al. (1992) estimate a growth rate of 3.7%. The former suggests that China’s share in CO_2 in the world will rise from 9.5% in 1985 to 17% in 2050; the latter estimates the share to be 29% in 2050. Therefore the outlook is not positive. But it should be noticed that there are factors constraining environment deterioration. The commodity market turns its weight from seller-preference market to buyer-preference market; the reduction of growth rates diminishes demand for energy consumption; at present there is excess supply of electricity and coal. Moreover, China has drawn up dozens of laws and acts linked with environmental protection, issued over 300 environmental standards. Local governments even promulgated over 600 rules to protect the environment. There are over 100 thousand people involved in environmental management and environmental studies (NEPA, 1996). The central government controls the pollution spread of Huai River and Tai Lake successfully. More and more people are concerned about their production and living environment. Only if China pays additional attention to environmental protection, it can offset the pressure from population, scarce resources and development.

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Appendix 1

Table A1. Comparison of average regional growth rates (%) between 1981-92 and 1994-97[5]

Region	Annual growth rate of GDP 1978-1993	Annual growth of GDP 1994-1997	Annual growth rate of per capita GDP 1978-97
Beijing* (N)	9.4	11.2	9.4
Tianjin* (N)	8.1	13.9	9.0
Hebei* (N)	9.7	13.7	10.2
Liaoning* (N)	8.7	8.9	8.6
Shanghai* (S)	8.4	13.5	9.5
Jiangsu* (S)	12.3	14.0	12.9
Zhejiang* (S)	13.3	15.5	14.2
Fujian* (S)	13.3	16.7	13.7
Shandong* (N)	11.5	13.5	12.0
Guangdong* (S)	13.9	13.8	13.3
Guangxi* (S)	9.2	12.6	9.0
Hainan* (S)	-	7.9	-
Shanxi (N)	8.5	10.5	6.7
Neimenggu (N)	9.8	10.4	9.5
Jilin (N)	9.2	11.2	9.6
Heilongjiang (N)	6.9	9.7	7.2
Anhui (S)	9.8	15.5	10.6
Jiangxi (S)	9.8	14.1	10.1
Henan (N)	10.4	13.2	10.6
Hubei (S)	9.9	14.0	10.4
Hunan (S)	8.4	11.2	8.5
Sichuan (S)	9.2	10.4	9.9
Guizhou (S)	9.2	8.6	8.3
Yunnan (S)	9.7	10.6	9.2
Xizang (S)	-	14.5	-
Shaanxi (N)	9.6	9.3	8.9
Gansu (N)	8.4	10.1	8.8
Qinghai (N)	6.6	8.5	5.9
Ningxia (N)	8.9	10.6	7.9
Xinjiang (N)	11.2	9.3	9.8

Source: Data on GDP (1978-1993) from The Gross Domestic Product of China (1952-1995) and China Statistical Yearbook (1998).

5 Asterisks denote coastal regions.

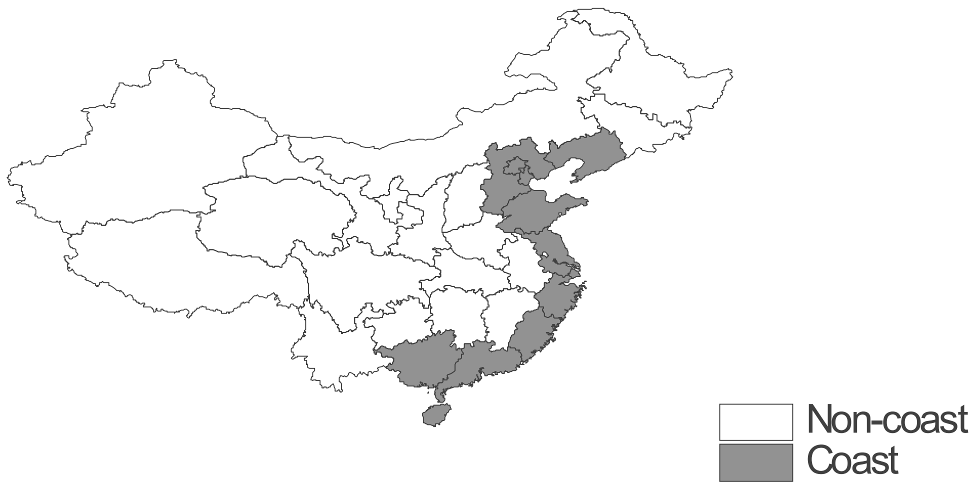

Figure A1. Coast versus non-coast

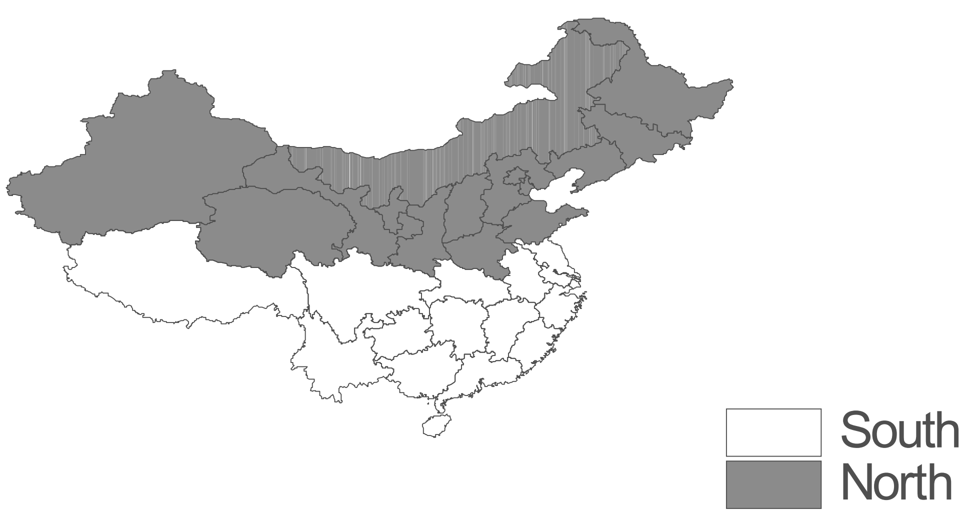

Figure A2. North versus South

Figure A3. Names of provinces

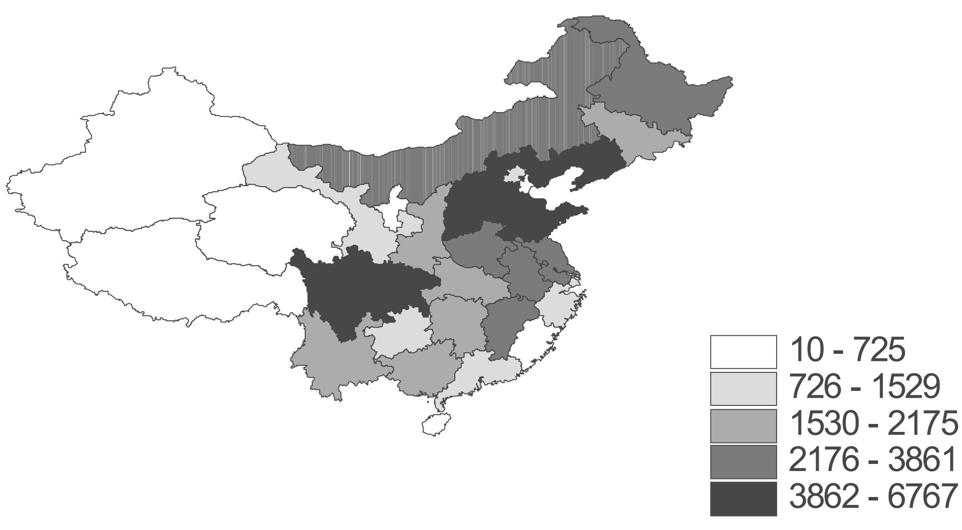

Figure A4. Solid emissions in levels in 1997

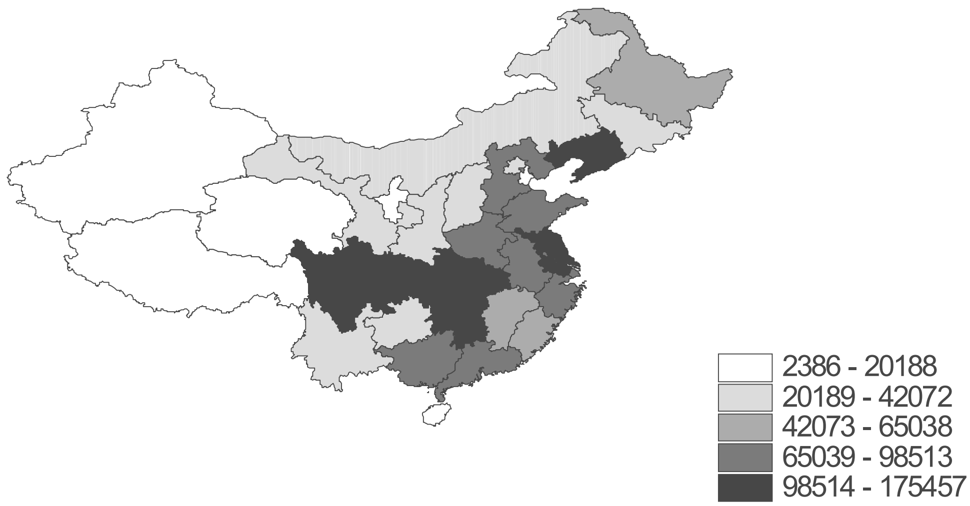

Figure A5. Waste water emissions in levels in 1997

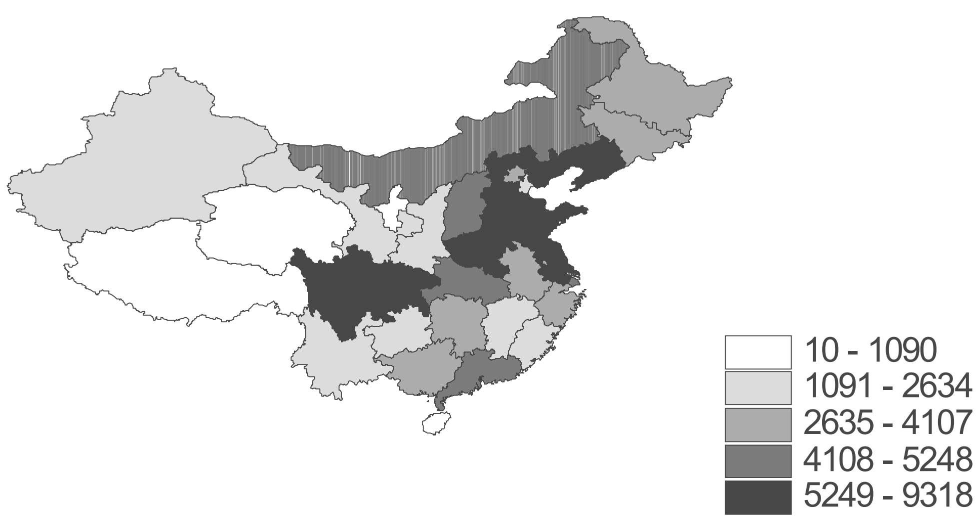

Figure A6. Gas emissions in levels in 1997

Appendix 2

	Pollution in levels	Pollution per capita	Pollution per unit of GDP
1	Liaoning	Liaoning	Liaoning
2	Sichuan	Beijing	Beijing
3	Hebei	Shanghai	Shanghai
4	Shandong	Shanxi	Shanxi
5	Jiangsu	Heilongjiang	Gansu
6	Henan	Tianjin	Tianjin
7	Hunan	Ningxia	Ningxia
8	Anhui	Jilin	Heilongjiang
9	Shanxi	Hebei	Jilin
10	Hubei	Neimenggu	Hebei
11	Heilongjiang	Gansu	Jiangxi
12	Guangdong	Jiangxi	Neimenggu
13	Jiangxi	Qinghai	Jiangsu
14	Guangxi	Jiangsu	Qinghai
15	Jilin	Hubei	Hunan
16	Zhejiang	Hunan	Hubei
17	Yunnan	Sichuan	Anhui
18	Neimenggu	Anhui	Sichuan
19	Gansu	Shandong	Guangdong
20	Shanghai	Shaanxi	Guizhou
21	Shaanxi	Guangxi	Shandong
22	Guizhou	Guizhou	Zhejiang
23	Fujian	Henan	Shaanxi
24	Beijing	Guangdong	Guangxi
25	Ningxia	Zhejiang	Henan
26	Xinjiang	Yunnan	Fujian
27	Tianjin	Fujian	Yunnan
28	Qinghai	Xinjiang	Xinjiang
29	Xizang	Hainan	Hainan
30	Hainan	Xizang	Xizang

Note: The ranks are based on an unweighted average of the ranks based on the fixed effects obtained from the regression equations for the three sources of pollution, excluding population size or density (that is, only controlling for per capita income).

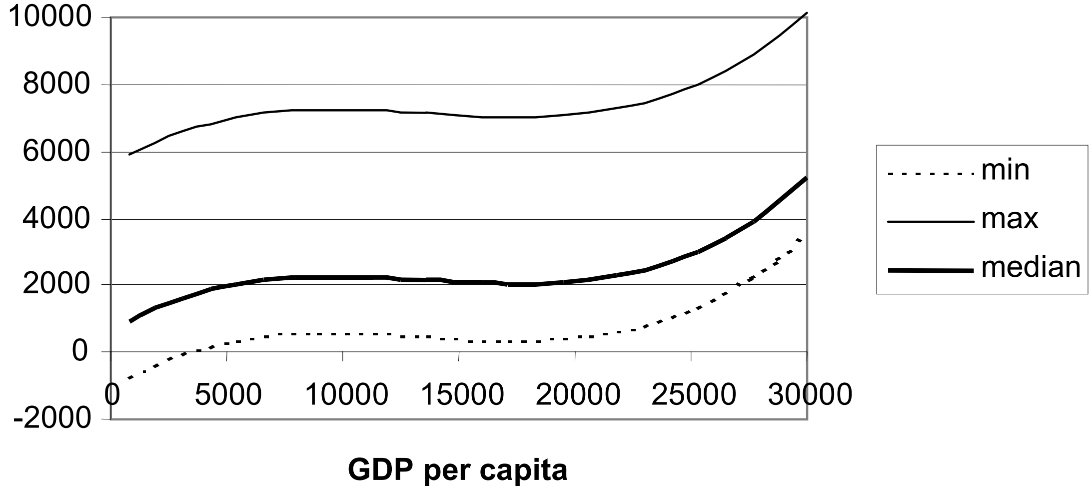

Figure 1. Solid Waste as function of per capita GDP (level equation)

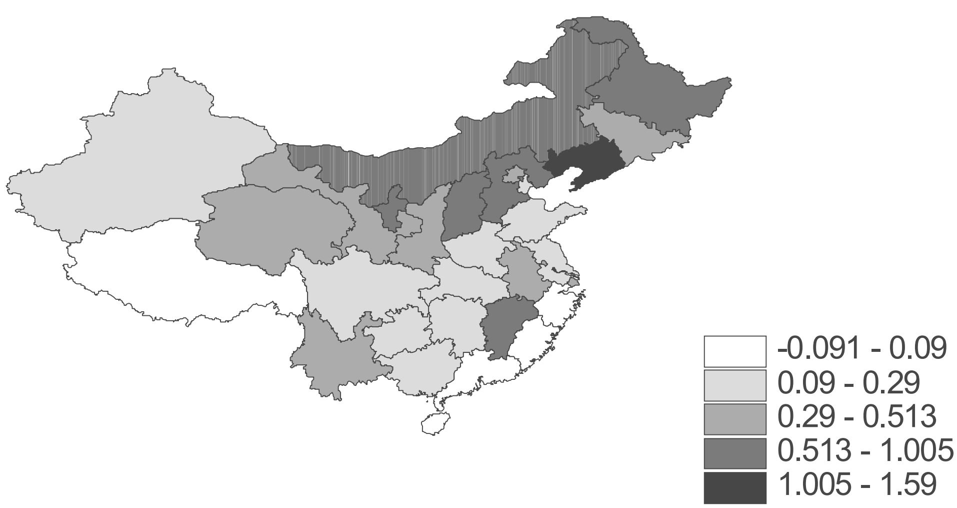

Figure 2. Fixed effects of solid waste obtained from per capita regression

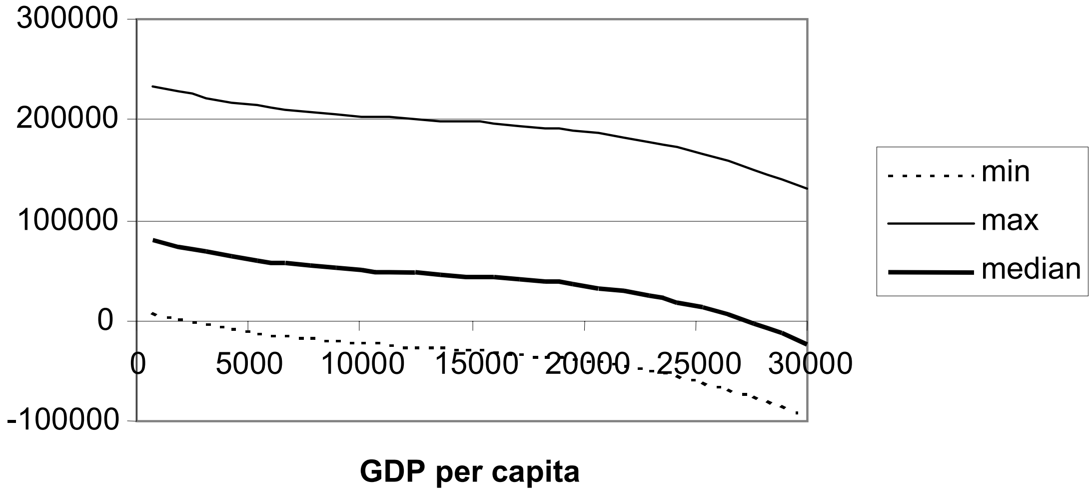

Figure 3. Waste Water as function of per capita GDP (level equation)

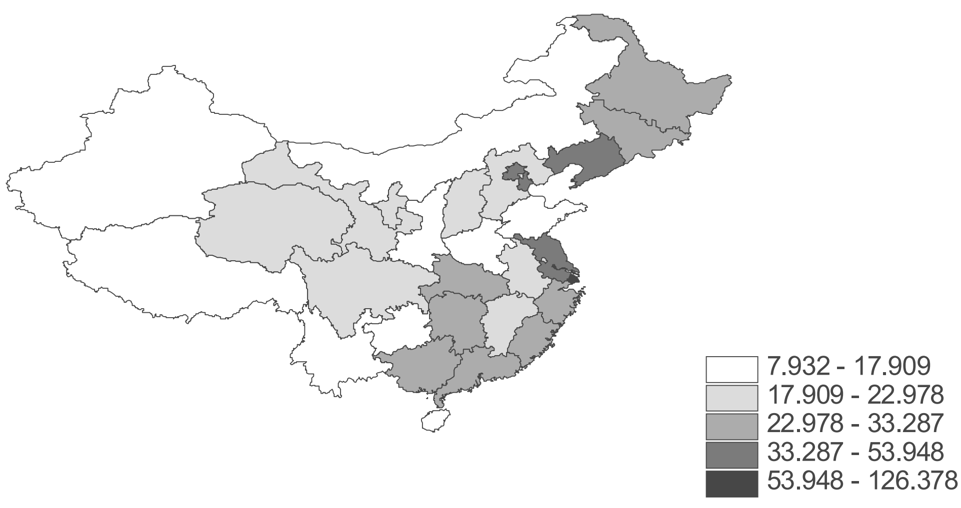

Figure 4. Fixed effects of waste water obtained from per capita regression

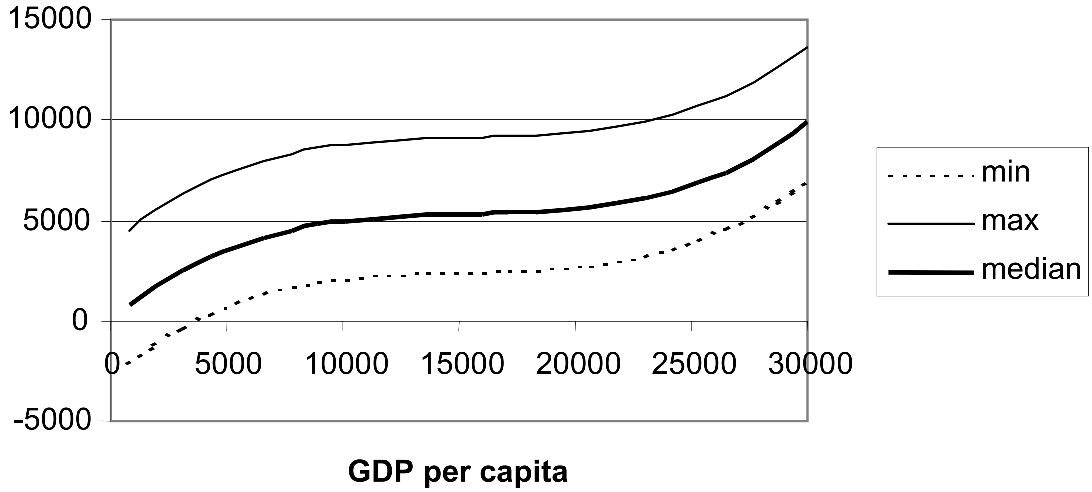

Figure 5. Gas emissions as function of per capita GDP (level equation)

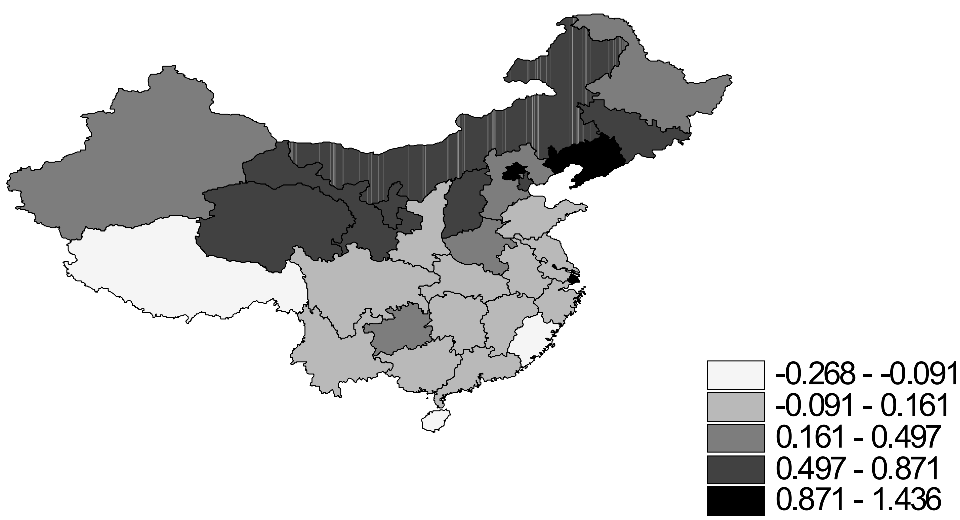

Figure 6. Fixed effects of gas emissions obtained from per capita regression