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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 30 regions, covering the period 1982–1997. The types of pollution included are wastewater, waste gas, and solid waste. We consider the development of the sources of pollution in a pooled cross-section analysis with pollution in absolute levels, in per capita terms, and relative to real Gross Regional Product (GRP). At intermediate levels of GRP per capita, the increase of solid and gas emissions tends to decelerate, but it accelerates again at high levels of GRP per capita. Water pollution decreases with per capita GRP. We also predict future waste gas emissions.

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. Building on recent empirical literature,[1] we address the question whether an Environmental Kuznets Curve (EKC) – that is, 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 reason is related to the size of the Chinese economy and its population.

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[1] Without aiming at providing an exhaustive list of references in the field, some of the relevant early studies are Grossman and Krueger (1995), Panayotou (1993), Selden and Song (1994), Shafik and Bandyopadhay (1992), and Stern *et al.* (1996).

The combined 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 future (see also Sachs, 1997). With regard to the enhanced greenhouse effect, China together with the USA is likely to have a considerable impact. Fairly soon, China is expected to take over the position of the USA as the biggest emitter of, for example, CO_2. It is therefore of paramount importance to gain as much insight as possible into the determinants of emissions and expected future developments. This is one of the main contributions of the present study. The second reason relates to the fact that, by studying the developments in one particular country, several difficulties that arise in determining income–emission relationships on the basis of cross-country studies are alleviated. The latter studies face the problem that the cross-sectional units can be relatively difficult to compare (or to be made comparable). Income data for high-income countries are more accurate than those for low-income countries (see Stern *et al.*, 1996). By focusing on Chinese data, the 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 – potentially inconsistent – databases when studying a 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' using market exchange rates or purchasing power parities. It is known that these different methods yield diverging results, in particular when very poor or former communist countries are involved with high import barriers (for example, Temple, 1999). By focusing on China, this problem is alleviated, although it has to be recognized that purchasing power differs over the regions. Finally, China has a relatively uniform political system, which reduces the problem of unobserved heterogeneity.

For these reasons, the present study can make a useful contribution to the research on the existence of Environmental Kuznets Curves for various pollutants. The availability of data for 30 regions over the period 1982–1997 allows for a pooled cross-section analysis in which the position of the income–emission relationship[2] can be studied, with fixed effects differing across regions. Controlling for different positions or shapes of the income–emission relationship is relevant even in a relatively homogeneous country such as China since patterns of specialization can dramatically differ among regions due to, for example, differences in participation in world trade or the effects of foreign direct investments. Such differences can importantly influence the location and shape of the income–emission relationship. In addition the present study can contribute to a better prediction of the future development of Chinese environmental problems under different development scenarios.

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[2] We prefer to talk about income–emission relationships (IERs) instead of an Environmental Kuznets Curve. An IER can take several shapes, of which the hump-shaped EKC is but one.

The main conclusion of the paper is that it is virtually impossible 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 considered and on how environmental impact is being measured (that is, in terms of levels of pollution, pollution per capita, or pollution per unit of real gross regional product (GRP)). For example, for solid waste measured in absolute levels we find an N-shaped relationship, while there is no statistically significant relationship if we consider emissions per capita, and it is downward sloping if pollution is modelled per unit of gross national product. Furthermore, statistically significant differences in region-specific fixed effects are found, implying that the location of the Kuznets curve is not stable across regions. This implies that there are substantial region-specific components in emissions that may be related to, for example, the specific industrial structure resulting from regional specialization patterns.

The outline of this paper is as follows: in section 2, we describe China's regional development. The environmental problems and the distribution of pollution among regions are discussed in section 3. In section 4, we discuss the main mechanisms that determine the shape of the income–emission relationship. We continue with an analysis of the empirically observed relationship between regional development and regional pollution in section 5. Section 6 summarizes the results, puts them into perspective with earlier findings, and 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 the 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 per cent.[3] The average standard of living has increased considerably as well. 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 GRP per capita was 367 yuan. In the same year Gansu's GRP per capita was 348 yuan. In 1997, Guangdong's GRP per capita amounted to 10,428 yuan, whereas Gansu's GRP per capita had risen to only 3,137 yuan. A more systematic overview is provided by making a distinction between coastal (in the sequel denoted by *) and landlocked regions and between northern (N) and southern (S) regions. Figures A1, A2, and A3 in appendix 1 provide details about the classification of the regions. Table A1 in the appendix provides regional growth rates for different time periods. For the period 1978–1993 the average (unweighted) growth rate of GRP in northern regions was 9.1 per cent and it was 10.5 per cent for southern regions (significantly different at a p-value of 0.04). For the coastal

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[3] Unless explicitly stated otherwise, the data used in this paper are from China Statistical Yearbooks.

Table 1. *Share (in per cent) 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).

and landlocked regions the annual growth rates were 10.7 per cent and 9.1 per cent, respectively (significantly different at $p = 0.02$). During the period 1994–1997 the northern and the southern regions experienced annual growth rates of 10.9 per cent and 12.9 per cent, respectively (significantly different at $p = 0.03$). For the coastal and landlocked regions these growth rates were 12.9 per cent and 11.2 per cent, respectively (significantly different at $p = 0.05$). Additional figures about the disparity between coastal and landlocked areas and its evolution over time are presented in table 1.

Further data are provided in table 2. They reveal that the North is, on average, relatively sparsely populated, relatively rich in terms of GRP per capita in 1978, but falling behind over time, specializing towards agriculture and away from industrial output.

2.2. Causes of the disparity of regional growth rates

Most Chinese economists agree on the factors that have contributed to the increase of the regional economic disparity since 1978 (see Hu *et al.*, 1995; Wei Houkai *et al.*, 1997; 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 contribute 64.1 per cent to the gross output value of industry, while in the southern part this was 76.4 per cent. In 1996, 72.6 per cent of total foreign investments were allocated to the southern part of China. Guangdong, Jiangsu, and Shanghai

Table 2. *Northern share in some 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.

attracted 48.9 per cent of total FDI. In the same year, 83.2 per cent of the contribution by Hong Kong, Macao, and Taiwan to the gross industrial output value 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 per cent of total industrial output value, in southern China it was 57.1 per cent. 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, household washing machines, radios, recorders, TV sets, and cameras produced in southern China amounted to 50.8 per cent, 95.5 per cent, 57.9 per cent, 98.0 per cent, 97.7 per cent, 79.6 per cent, and 84.0 per cent of China's total 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 favoured coastal areas, especially those in southern China. In 1978 China started to reform and opened its economy to the world. During the period 1979–1983, the central government provided more financial means 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 further develop an export-oriented economy in coastal areas.

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

3. China's environmental problems in a regional perspective

China's regional development is characterized by some socially 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, people in less developed regions are more heavily 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 per cent of the country's area. About 2.62 million square km is desertified. It is estimated that as a consequence 15–20 per cent of all species of plants and animals is endangered. Cultivated land reduces by 100 thousand ha annually. Many scientists argue that the over-exploitation of forests was an important cause of the flood appearing in the Chang River in 1998. Today China's forested area per capita is only one-ninth of the average world level. In Hainan, the natural forest was 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 preservation, forests are still in decline 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 insight into the discharge levels of industrial wastewater, industrial waste gas emissions (defined as an aggregate of emissions of CO_2, NO_2, and SO_2), and industrial solid waste disposal. This evidence clearly displays the regional variation in industrial pollution.

In view of the fact that the coastal areas comprise only 13.4 per cent of the country's surface, we see that the pollution problem is heavily concentrated there. It is also clear that industrial pollution is increasing rapidly, except for wastewater. Hence, China's environmental situation regarding pollution is

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 (million tons)	1982	11,674.3	50.0%
	1985	11,717.7	47.1%
	1990	12,150.4	47.0%
	1995	11,145.5	50.2%
	1997	9,390.4	48.7%
Waste gas (billion m^3)	1982	2,264.7	47.2%
	1985	2,745.8	45.5%
	1990	3,596.7	49.2%
	1995	5,242.1	49.7%
	1997	5,734.1	50.6%
Solid waste (million tons)	1982	173.7	43.4%
	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).

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 China's standards – very poor over more than 24 per cent of its length. For the Yellow River, Peril River, Huai River, Hai River, and Songhua and Liao River these figures are 60 per cent, 22 per cent, 51 per cent, 41 per cent, and 67 per cent, respectively. More than 70 per cent of the surface water (rivers) near cities is polluted. More than 50 per cent of the groundwater in the cities is polluted to different extents. Xinhuashe (1999) states that 'At present, there are 31 rivers and 51 sewage systems dumping sewage into the Bohai Sea. Every year, about 2.8 billion tons of sewage is discharged, accounting for 33 per cent of the country's total. The discharged solid waste reaches 700,000 tons, 50 per cent 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 per cent have acceptable air quality. Recently, the World Resources Institute listed the ten cities in the world with the highest air pollution; nine of them are in China. Acid rain problems occur in 30 per cent of all areas. It is estimated that the direct loss by air and water pollution amounts to 4–8 per cent of China's GDP annually (Xinhuashe, 1999). In the remainder of this section, we discuss the regional situation concerning wastewater, waste gas, and solid waste in more detail.

3.2.1. Industrial wastewater

In 1997, 18.8 billion tons of industrial wastewater were discharged. Industrial wastewater was mainly produced (63.8 per cent) by four sectors: petroleum processing and coke production, smelting and pressing of ferrous metals, raw chemical materials and chemical products, and the paper industry. From 1991 to 1997, the total volume of industrial wastewater emissions declined in most provinces, but there are several provinces or autonomous regions where emissions of industrial wastewater increased.

3.2.2. Industrial waste gas

Chinese statistical sources only report total emissions of industrial waste gas (defined as an aggregate of emissions of CO_2, NO_2, and SO_2) and of SO_2 separately. 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 non-metal mineral products. They account for 72 per cent 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 per cent. 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 responsible for 63 per cent of total industrial waste gas emissions. Waste gas from production and supply of electric power, gas and water accounted for 58 per cent of this. Of the latter part, waste gas from non-metal mineral production, especially cement production and smelting and pressing of non-ferrous metals, constituted almost 70 per cent of total waste gas in the production process.

Waste gas shows the same regional feature as industrial wastewater in that it is highly concentrated. Six provinces (Hebei, Liaoning, Jiangsu, Shandong, Henan, and Sichuan) are responsible for 41 per cent of total emissions. There is more particulate matter in the cities of northern China than in the South, 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 emissions.

Other emissions also reflect the regional disparity. 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 per cent of the total and Shandong for 11 per cent. 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 per cent. Of the total 5.48 million tons of industrial dust emissions, six provinces (Hebei, Liaoning, Shandong, Henan, Guangdong, and Sichuan) caused 41 per cent.

3.2.3. Industrial solid waste

Of all industrial solid waste, 86 per cent originates 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 per cent of solid waste is produced in the landlocked regions. Eight provinces (Hebei, Shanxi, Liaoning, Jiangxi, Shandong, Sichuan, Heilongjiang, and Henan) cause 55 per cent 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 is related to many factors, such as the coverage by plants, annual rainfall, the share of cultivated land, and the usage of technologies. 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 per cent) can explain the low absorption of waste gas. The limited seasonal rainfall, especially in northern 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 had 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 initially get more serious, but will eventually decline. 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 emphasize 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. An inverted U-curve need not suffice to describe 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 statement implicitly suggests that for high-income countries, the relationship between pollution and income is positive again. Or, even stronger, that the Environmental Kuznets Curve is U-shaped. A motivation for the latter can be as follows. 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, less intensive production modes, and the over-exploitation of natural resources. In advanced countries it is more related to excessive consumption. The export of many developing countries is mainly concentrated in raw materials, and imports are mainly industrial products, while advanced countries import and consume raw materials. 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. Given this wide range of reasonable possibilities, we will in our empirical application allow for a flexible specification of the income–emission relationship that allows for non-linearities between pollutants and per capita income.

To understand the development of environmental quality in China, it is relevant to keep in mind three factors that affect the relationship between per capita income and emissions. The *scale* effect entails that in a growing economy emissions tend to increase (at given emission intensities and a given industrial 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 (see, for example, Garbaccio *et al.*, 1999, for empirical information on the development of the Chinese energy–output ratio). For that reason it is sometimes also called technique effect (see Copeland and Taylor, 2003). As economies grow rich, they can afford more advanced 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 with the effects of per capita income on, for example, taxes on pollution or environmental standards.[4] Still another factor that may affect the pollution intensities of technologies are foreign direct investments. This may be particularly relevant for certain regions in China. Unfortunately, however, no accurate data are available to test for this. Third, one has to consider the *structural* (or *composition*) effect. A typical time path of the sectoral composition of an economy is one in which countries are initially characterized by a large agricultural sector, followed by a period of industrialization and subsequently followed by de-industrialization and a rising service sector (for example, Baumol, 1967; Maddison, 1991; and de Groot, 2000). It is 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 get richer, they initially tend to shift their consumption pattern towards manufacturing products and at later stages towards services. Under the assumption that services are less pollution intensive 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 specialization (between regions or countries). Due to this effect, countries or regions with a comparative advantage in pollution-intensive industries will, *ceteris paribus*, witness an increase in emissions not related to developments in per capita income.[5]

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[4] For China, one could question the relevance of this argument as several Chinese policies are centralized and therefore show limited variation across regions. However, as noted by, for example, Auffhammer *et al.* (2001) 'some provinces/cities adopted air pollution emission permit policies even before the implementation of any national legislation'.

[5] Somewhat related to this issue is the recent interest in income inequality as a determining factor. It has been forcefully put forward by, for example, Ravaillion *et al.* (2000) that distributive issues may play an important role, for example, because the income elasticity of energy demand is decreasing with income. Since we have no data available on income distribution in the regions considered in this study we are unable to explore this matter any further.

The hypothesis of the EKC and the ensuing empirical tests is – to say the least – subject to a fair amount of debate. The empirical tests are criticized for several reasons. First, there are criticisms on the way the hypothesis is being tested, using samples of different countries (for example, Dijkgraaf and Vollebergh, 2001; 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. At best, they include 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, for example, substitution away from energy in periods of rising energy prices. These problems can be overcome to some extent by decomposition techniques (for example, de Bruyn, 1997; Selden *et al.*, 1999; Sun, 1998). These techniques decompose changes in pollution of energy use into a scale effect, an intensity effect, and a structural effect. Thereby, they give some descriptive idea of the quantitative importance of the factors that may give rise to an EKC.

5. Empirical analysis

Despite the criticisms discussed in the previous section, the empirical assessment of the shape of the income–emission relationship (IER) for China is in our view useful as a descriptive device aimed at detecting some general patterns as well as region-specific effects. In order to allow for the detection of the wide range of potentially relevant functional relationships between income per capita and emissions, we use a flexible specification of the regression equation that allows for linear, quadratic, and cubic polynomial relationships between pollution and per capita income.

5.1. Data

The data set used in our analysis is obtained from official Chinese statistical material (mainly the Statistical Yearbooks). The data refer to a 16-year time period from 1982–1997, and to the 30 provinces and major cities, to be called regions henceforth. The regions are listed in table A1 in the appendix. For each region, we have land surface and population data. There are figures on total emissions of industrial wastewater, waste gas, and solid waste (for every year and region). Moreover, we have data on gross regional product, in current as well as in constant prices.[6]

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. For this aim, we distinguish between regions with low, medium, and high pollution levels. We consider wastewater, waste gas, and solid waste 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 is characterized by *low pollution*. Otherwise we call pollution *medium*. We also rank the regions according to income. If one

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[6] We are aware of the fact that there might be differences between regions with respect to purchasing power. Unfortunately data to correct for this are lacking.

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)

region's GRP per capita exceeds the national average level (6,079 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 (note that asterisks denote coastal areas, and *N* and *S* indicate North and South, respectively).

As the table shows, most of the advanced regions are regions with serious pollution, and most of backward regions are medium or light pollution regions. The seriously polluted advanced regions are coastal, and the lightly polluted under-developed regions are all landlocked. 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. This specification is relevant in case 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. For some pollutants, such as solid waste, per capita pollution might be relevant. 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.

For expositional purposes, we distinguish between two basic classes of models that can be estimated. These models all contain the gross regional product per capita (*GRP_CAP*) as the explanatory variable, which can be seen as the key variable of interest in an empirical investigation on the

Environmental Kuznets Curve. Extensions to more explanatory variables are straightforward and will be mentioned in the text when they are introduced. The index *i* will denote the region and *t* refers to time.

The first model reads

$$ES_{it} = \alpha_{oi} + \beta_1(GRP\_CAP_{it}) + \beta_2(GRP\_CAP_{it})^2 + \beta_3(GRP\_CAP_{it})^3 + \epsilon_{it} \quad (1)$$

where *ES* refers to the pollution indicator. In this model the intercepts are region specific but the income coefficients are uniform.[7] This model is thus based on the idea that regions follow a similar pattern of development of emissions as they develop, albeit at potentially different levels. These differences in levels can reflect all kinds of unobserved heterogeneity, among which differences in sectoral specialization are likely to feature prominently.

The second model is more restricted, as it requires a uniform intercept

$$ES_{it} = \alpha_0 + \beta_1(GRP\_CAP_{it}) + \beta_2(GRP\_CAP_{it})^2 + \beta_3(GRP\_CAP_{it})^3 + \epsilon_{it} \quad (2)$$

A general result from the analysis is that the null hypothesis of *equal intercepts* is rejected (using the F-test). This holds for all pollutants and for all specifications thereof (levels, per capita and per unit GRP). Therefore, the second model is not further explored in this paper. All regressions are estimated with a full set of fixed effects to control for unobserved region-specific heterogeneity.[8]

Special care is required in controlling for autocorrelation and heteroscedasticity. Autocorrelation has been addressed by estimating an AR(1) model. To account for heteroscedasticity, we estimate and report White's heteroscedasticity consistent estimators. We refer to Greene (1997) for econometric details.

[7] In principle, one could also allow for different income coefficients and subsequently test for equality (see Dijkgraaf and Vollebergh, 2001). In the present paper we do not pursue this road for two reasons. First, in most EKC studies equality of income coefficients is implicitly assumed. It is the very idea that a genuine relationship exists that forms the motivation to study the shape of the income–emission relationship in the first place. The second reason is more fundamental. First, 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 persistently low per capita income and one with persistently high per capita income. To make the picture complete, assume that there is no overlap in incomes over the observation period. Then tests on equality of income coefficients are likely to 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 coefficients declines if the difference in the range of income of different subgroups increases. Therefore, the tests usually employed to test for the homogeneity of coefficients do not enable the researcher to draw strong conclusions on homogeneity.

[8] We have also tested whether the distinction between North–South and landlocked–coastal is statistically sufficient to capture most of the variation in emissions between regions. Except for some special cases, this hypothesis is not supported by the data, so a full set of region-specific fixed effects has been included.

5.3. Wastewater

For wastewater there is a strong negative relationship between per capita income and emissions, measured in levels. The quadratic term as well as the third-order variable, although statistically significant, are dominated by the linear term, as is clear from table 5. There is strong evidence for autocorrelation. 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 patterns of both increasing and decreasing wastewater levels over time. For the top five richest regions the income range is much larger and the picture shows a clearly decreasing trend over time.

The result of a negative relationship between wastewater emissions and per capita GDP is opposite to the conclusion reached in Shafik (1994, p. 765). She finds that dissolved oxygen in rivers tends to increase and argues that this might be due to growing effluent pollution as a consequence of industrialization. However, she finds an increase in access to safe water, which seems a bit contradictory.

Figure 1 graphically depicts the results from the estimation procedure. In the sequel, we depict the estimated relationship for the 'median region' (that is, the region with the median fixed effect), as well as the relationship for the region with the highest and the lowest fixed effect. The result of a strong negative relationship between emissions and per capita income also obtains when emissions in per capita terms and per unit of GRP are the dependent variables: the linear part is significantly negative and dominates the other terms.

The existence of an Environmental Kuznets Curve for wastewater is therefore not supported by the data. Instead, a monotonically declining relationship between per capita income and wastewater (in all three

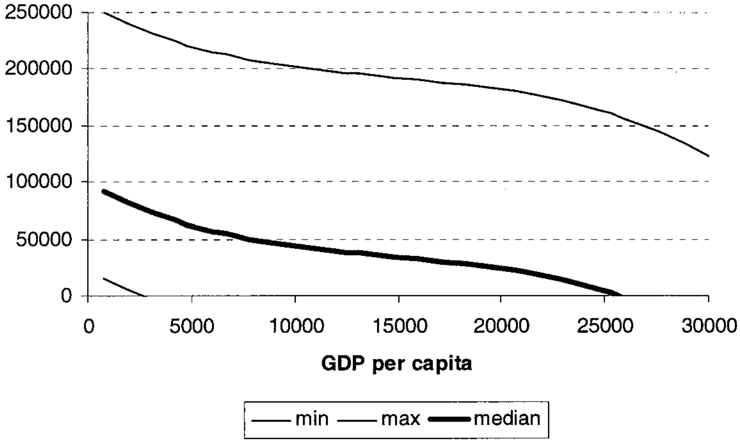

Figure 1. *Industrial wastewater as a function of per capita GRP*

Table 5. Parameter estimates for wastewater (sample period 1982–1997)

Dependent variable	*Wastewater in levels*		*Wastewater per capita*		*Wastewater per unit of GRP*	
Parameter	*Estimate*	*White t-statistic*	*Estimate*	*White t-statistic*	*Estimate*	*White t-statistic*
GRP_CAP	−9.99E+00***	−5.75	−2.00E−03***	−3.64	−2.33E−02***	−7.25
(GRP_CAP)^2	5.67E−04***	3.74	7.50E−08	1.22	1.40E−06***	5.15
(GRP_CAP)^3	−1.28E−08***	−3.31	−3.24E−12**	−1.97	−2.88E−11***	−4.40
AR(1)	0.65***	10.71	0.71***	16.79	0.85***	34.06
Beijing	96,237		53.7		150.2	
Tianjin	74,042		40.1		140.7	
Hebei	118,779		21.2		100.4	
Shanxi	73,751		22.1		105.4	
Neimenggu	53,037		18.1		100.4	
Liaoning	188,063		46.8		139.9	
Jilin	82,069		27.4		103.3	
Heilongjiang	122,816		32.9		135.6	
Shanghai	197,471		125.2		195.8	
Jiangsu	257,578		42.0		143.5	
Zhejiang	140,339		34.1		135.0	
Anhui	115,049		21.3		110.7	
Fujian	102,460		30.9		128.9	
Jiangxi	92,064		22.9		106.3	
Shandong	129,060		19.6		111.2	
Henan	128,640		17.5		92.5	
Hubei	174,739		33.1		124.2	
Hunan	193,350		32.9		135.4	
Guangdong	171,433		30.7		120.0	
Guangxi	114,396		25.7		107.7	
Hainan	40,873		18.6		101.6	
Sichuan	218,215		22.9		110.4	
Guizhou	49,041		13.2		66.6	
Yunnan	66,589		16.6		96.9	
Xizang	22,358		11.4		90.9	
Shaanxi	60,214		16.1		85.0	
Gansu	55,478		19.8		88.9	
Qinghai	31,774		18.5		89.1	
Ningxia	32,807		23.5		114.4	
Xinjiang	48,712		18.2		105.5	
R^2	0.98		0.99		0.97	
Observations	442		442		442	
F-statistic	7,891.2***		10,930.6***		3,959.0***	
F-statistic fixed effects	3.13***		2.03***		1.12	

Note: The t-statistics that are reported are White-heteroskedasticity consistent t-statistics. They are robust to heteroskedasticity within each cross-section, but do not account for the possibility of contemporaneous correlation across cross-sections. Significance levels are indicated with stars: ***, **, and * means significance at 1, 5, and 10 per cent respectively. The fixed effects are reported and have been tested for joint significance. The F-statistic fixed effects tests for the joint significance of the fixed effects (with the null-hypothesis that all fixed effects are equal to zero). All models estimated without fixed effects are significant at 1 per cent significance level.

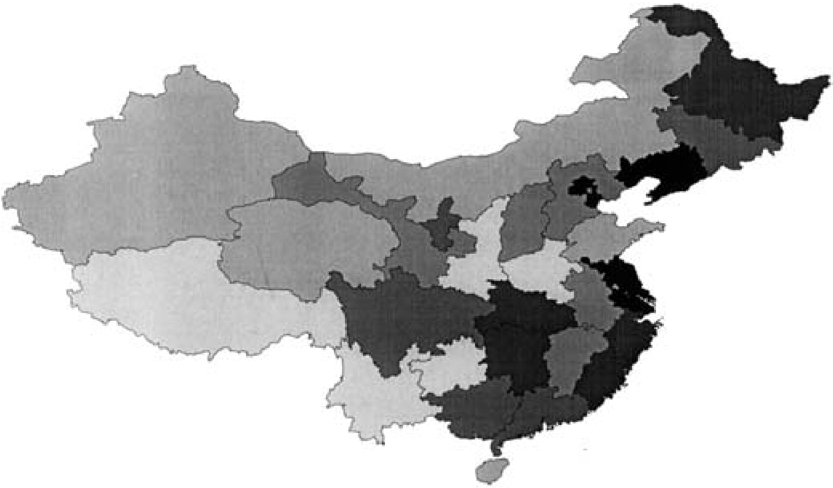

Figure 2. *Estimated fixed effects: industrial wastewater per capita*

Note: Regions were ranked in decreasing order of the estimated fixed effects. The five regions ranking highest are depicted in black, the next five regions in dark-grey, and so on.

dimensions) is found over the relevant range of income levels. Given that the dependent variable is industrial (rather than residential) wastewater, a plausible explanation for this result would be that, when incomes rise, there is increasing pressure on industries to emit less wastewater. Alternatively, given the strong autocorrelation in all three specifications, and given the very bad initial situation, harassing human health, there might be an autonomous trend in improving water quality over time. Finally, the negative relationship with income could be explained by the fact that the advanced high-income regions specialize relatively strongly in light industries, such as electronics, which are only moderately polluting and at the same time generate higher incomes.

Figure 2 contains information about the fixed effects obtained from the regression estimating per capita wastewater emissions. The dark-shaded regions have relatively high fixed effects, whereas the light-shaded regions have relatively low fixed effects. The fixed effects are clearly largest in the major cities and industrial areas, for example Beijing, Shanghai, Tianjin, and Jiangsu. This implies that in these regions wastewater emissions are huge, even after controlling for differences in GDP per capita.

5.4. Waste gas

In the regression with waste gas emissions in levels, all coefficients are statistically significant as shown in table 6. There is an overall positive relationship between pollution of this type and per capita income, although emissions increase at relatively low rates at intermediate levels of per capita income.

When we consider waste gas emissions per capita, the linear income term is statistically significant and dominates: waste gas emissions per

Table 6. Parameter estimates for industrial waste gas emissions (sample 1982–1997)

Dependent variable	*Gas in levels*		*Gas per capita*		*Gas per unit of GRP*	
Parameter	*Estimate*	*White t-statistic*	*Estimate*	*White t-statistic*	*Estimate*	*White t-statistic*
GRP_CAP	8.70E−01***	7.95	1.47E−04***	5.48	−4.62E−04***	−4.11
$(GRP\_CAP)^2$	−5.04E−05***	−4.72	−7.06E−09**	−2.28	2.48E−08**	2.28
$(GRP\_CAP)^3$	1.00E−09***	3.46	1.65E−13*	1.77	−5.09E−13*	−1.79
AR(1)	0.51***	2.97	0.13	0.83	0.11	0.68
Beijing	−2,005		1.34		5.40	
Tianjin	−2,709		0.79		4.61	
Hebei	3,211		0.47		4.07	
Shanxi	1,767		0.93		5.77	
Neimenggu	477		0.77		5.02	
Liaoning	4,138		1.28		5.68	
Jilin	56		0.57		4.37	
Heilongjiang	689		0.53		4.07	
Shanghai	−1,361		1.54		5.31	
Jiangsu	2,032		0.20		3.35	
Zhejiang	−628		0.02		2.94	
Anhui	851		0.15		3.05	
Fujian	−1,532		−0.06		2.61	
Jiangxi	−89		0.15		3.06	
Shandong	2,975		0.18		3.18	
Henan	3,024		0.25		3.61	
Hubei	828		0.16		3.07	
Hunan	735		0.11		2.88	
Guangdong	891		0.04		2.98	
Guangxi	19		0.09		2.56	
Hainan	−2,610		−0.24		2.02	
Sichuan	3,097		0.12		2.96	
Guizhou	409		0.28		3.94	
Yunnan	−566		0.03		2.51	
Xizang	−1,719		−0.25		1.04	
Shaanxi	−136		0.19		3.12	
Gansu	530		0.67		6.09	
Qinghai	−1,667		0.69		5.22	
Ningxia	−1,360		0.88		5.57	
Xinjiang	−1,445		0.28		3.25	
R^2	0.92		0.83		0.52	
Observations	441		441		441	
F-statistic	1639.1***		645.9***		144.5***	
F-statistic fixed effects	4.23***		7.84***		5.5***	

Note: The t-statistics that are reported are White-heteroskedasticity consistent t-statistics. They are robust to heteroskedasticity within each cross-section, but do not account for the possibility of contemporaneous correlation across cross-sections. Significance levels are indicated with stars: ***, **, and * means significance at 1, 5, and 10 per cent respectively. The fixed effects are reported and have been tested for joint significance. The F-statistic fixed effects tests for the joint significance of the fixed effects (with the null-hypothesis that all fixed effects are equal to zero). All models estimated without fixed effects are significant at 1 per cent significance level.

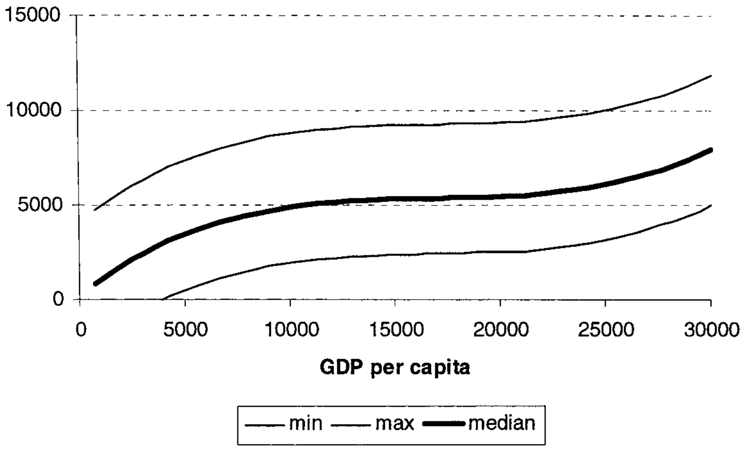

Figure 3. *Industrial waste gas emissions as a function of per capita GRP*

capita 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 strongly related to waste gas emissions. When considering waste gas emissions per unit of output, it turns out again that only the linear term is statistically significant and dominates the other terms. However, now the coefficient is negative, indicating that energy intensity of production is decreasing with rising per capita income. Although this change in the qualitative relationship is not very large, it is interesting. Looking at emission levels, it remains an open and important question whether the introduction of cleaner technologies will eventually lead to less total emissions. The fact that emissions of waste gas in levels and in per capita terms increase with per capita income might also indicate that higher per capita income leads to more energy demand, but that this demand is increasingly associated with less energy-intensive products. This is an illustration of the relevance of the composition effect that we discussed in section 4.

Our measure of waste gas includes several types of gases, which makes it difficult to compare these outcomes with earlier empirical findings, because the latter usually refer to specific gases. For SO_2 and NO_x, the typical empirical finding is an Environmental Kuznets Curve or an N-shaped income–emission relationship, whereas for CO_2 the relationship is generally monotonic (see de Bruyn and Heintz, 1999, for a survey). According to Auffhammer *et al.* (2001), however, for China, waste gas emissions are a good proxy of CO_2 emissions, so that our result in per capita terms seems to confirm earlier findings.

Figure 4 depicts the estimated fixed effects obtained from the regression using waste gas per capita as the dependent variable.

As can be expected, the fixed effects are largest in the North, with its concentration of heavy industries. In 1997, the high-ranking regions (in terms of fixed effects estimated in the equation with emissions in levels) of Guangdong, Shandong, Jiangsu, Hebei, and Liaoning jointly produce

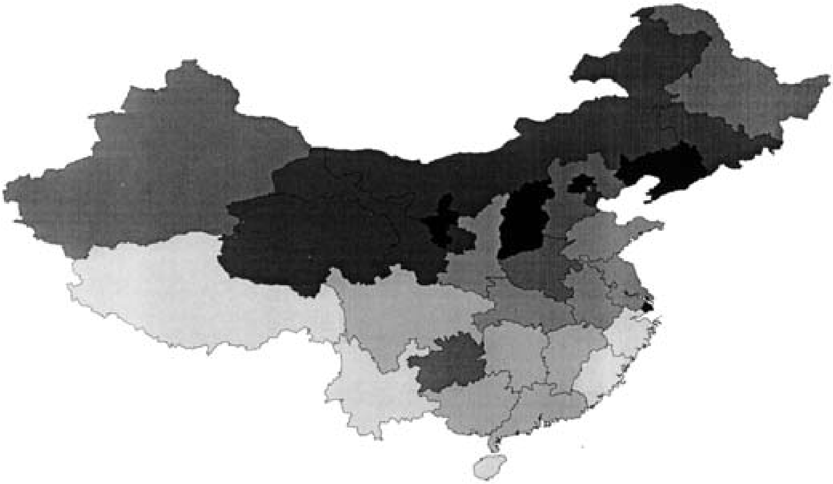

Figure 4. *Estimated fixed effects: Industrial waste gas per capita*

34.3 per cent of China's total electricity. Furthermore, they produce 40.3 per cent of China's total output in that year. Waste gas from electricity and cement constitutes 36.6 per cent and 13.5 per cent of China's total industrial waste gas emissions respectively.

5.5. Solid waste

The regression results for industrial solid waste are presented in table 7. From table 7 we infer that the coefficients for the equation in levels are statistically highly significant. Moreover, the variation in pollution is well explained. From figure 5 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

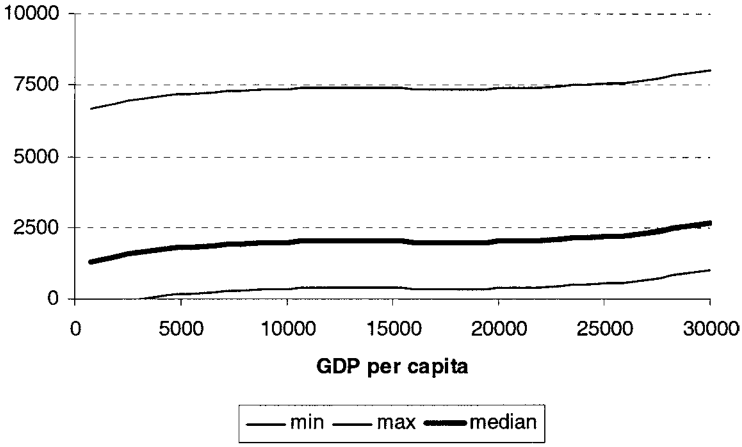

Figure 5. *Solid waste as a function of per capita GRP*

Table 7. Parameter estimates for industrial solid waste (sample 1982–1997)

Dependent variable	*Solid waste in levels*		*Solid waste per capita*		*Solid waste per unit of GRP*	
Parameter	*Estimate*	*White t-statistic*	*Estimate*	*White t-statistic*	*Estimate*	*White t-statistic*
GRP_CAP	1.65E−01***	3.36	1.08E−05	0.91	−6.07E−04***	−10.18
(GRP_CAP)^2	−1.10E−05***	−2.67	−3.46E−11	−0.03	4.08E−08***	7.43
(GRP_CAP)^3	2.38E−10***	2.40	−1.68E−15	−0.05	−8.56E−13***	−5.93
AR(1)	0.73***	12.74	0.64***	12.94	0.67***	14.40
Beijing	137		0.68		3.61	
Tianjin	−288		0.40		3.25	
Hebei	5,224		0.86		4.45	
Shanxi	3,367		1.21		5.59	
Neimenggu	1,729		0.91		4.55	
Liaoning	6,569		1.74		5.57	
Jilin	1,059		0.58		3.36	
Heilongjiang	2,941		0.92		4.20	
Shanghai	328		0.70		3.55	
Jiangsu	1,829		0.29		2.83	
Zhejiang	331		0.15		2.61	
Anhui	2,266		0.42		3.19	
Fujian	136		0.17		2.58	
Jiangxi	3,139		0.84		5.03	
Shandong	3,480		0.41		3.02	
Henan	2,030		0.24		2.40	
Hubei	1,476		0.31		2.77	
Hunan	1,510		0.28		2.63	
Guangdong	948		0.18		2.75	
Guangxi	1,003		0.28		2.59	
Hainan	−435		0.11		2.34	
Sichuan	3,637		0.34		2.82	
Guizhou	804		0.29		2.78	
Yunnan	1,593		0.49		3.40	
Xizang	−346		−0.02		1.28	
Shaanxi	1,347		0.46		3.22	
Gansu	941		0.50		3.57	
Qinghai	−170		0.50		3.35	
Ningxia	−23		0.74		4.15	
Xinjiang	−9		0.27		2.62	
R^2	0.98		0.97		0.96	
Observations	442		442		442	
F-statistic	7,648.4***		4,693.2***		2,913.6***	
F-statistic fixed effects	4.12***		4.74***		3.04***	

Note: The t-statistics that are reported are White-heteroskedasticity consistent t-statistics. They are robust to heteroskedasticity within each cross-section, but do not account for the possibility of contemporaneous correlation across cross-sections. Significance levels are indicated with stars: ***, **, and * means significance at 1, 5, and 10 per cent respectively. The fixed effects are reported and have been tested for joint significance. The F-statistic fixed effects tests for the joint significance of the fixed effects (with the null-hypothesis that all fixed effects are equal to zero). All models estimated without fixed effects are significant at 1 per cent significance level.

find support for an N-shaped IER as far as solid waste in levels is concerned. The results in terms of solid waste emissions per capita are completely different. The income coefficients are all statistically insignificant, and there is strong evidence of autocorrelation. To explain this result, one should bear in mind that the dependent variable is not residential solid waste but industrial solid waste, which is more related to income through the scale and intensity effect than through environmental awareness triggering less polluting behaviour. The lack of a clear statistical relationship therefore need not be surprising.

Finally, we have considered solid waste emissions per unit of GRP as a dependent variable. The coefficients are all statistically significant. However, no inverted U-shaped relation between solid waste per unit of GRP and per capita 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 whether there is a causal relationship or not. Possibly an autonomous mechanism is at work 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.

Another study dealing with solid waste is the one by Shafik (1994). But she deals with municipal solid waste and finds an increasing relationship with per capita solid waste as the dependent variable. Also in her case the relationship is hardly significant.

As depicted in figure 6, 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 by running auxiliary regressions on the fixed effects (see, for example, Heil and Selden, 2001, for an example, where fixed

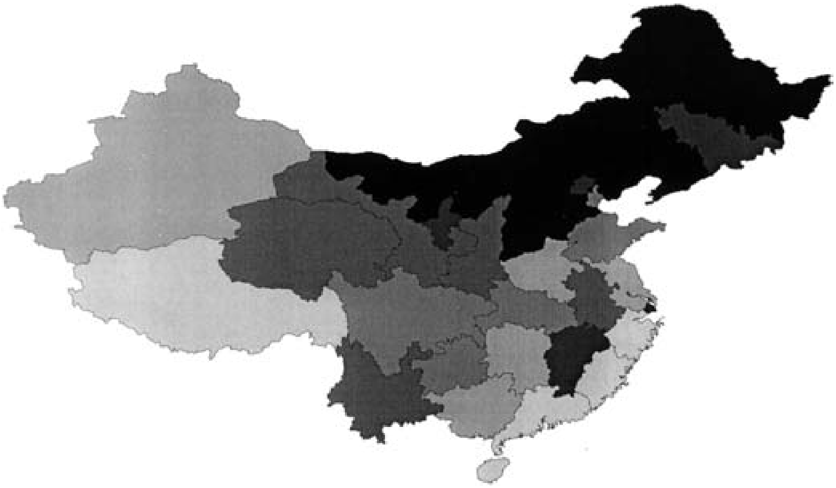

Figure 6. *Estimated fixed effects: solid waste per capita*

effects are regressed on oil prices to get an idea of the impact of these prices on carbon emissions projections). 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 per cent, 12.4 per cent and 11.3 per cent 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 characterized by severe environmental problems on aggregate, as shown in the remainder of this section). Shanxi produces a considerable amount of coal (nearly a quarter of China's output in 1997), so it produced more solid waste.

5.6. Prediction

It is tempting to predict future Chinese emissions of pollutants based on the previous econometric analysis. In particular, given the intensive discussion regarding the enhanced greenhouse effect and the relevance of participation of less developed countries, predicting the emissions of greenhouse gases would be of interest. Such exercises have been performed before, using various methods (for example, Martins *et al.*, 1992, Manne and Richels, 1992, and Auffhammer *et al.*, 2001). For the purpose of this section, we will not discuss these studies and their methods in detail, but instead we provide some of the estimates for emission growth obtained in these studies in order to facilitate a comparison of our predictions with those of other studies. Manne and Richels (1992) estimate China's annual growth rate of CO_2 emissions over 1990–2050 at about 2.3 per cent. Martins *et al.* (1992) estimate a growth rate of 3.7 per cent. The former suggest that China's share in CO_2 in the world will rise from 9.5 per cent in 1985 to 17 per cent in 2050; the latter estimate the share to be 29 per cent in 2050. Auffhammer *et al.* (2001) also report on CO_2 emissions, but now in total volume in 2050, and compare the results with other predictions, based on an IER approach.

Our tentative projections for waste gas emissions are based on our regional analysis of the IER. We have extrapolated our regression results for waste gas into the future, assuming different scenarios for the growth rate of GRP per capita. The scenarios and their implications for emissions are given in the upper half of table 8. In all scenarios we assume that the growth rate of GRP per capita linearly converges to 2 per cent per capita in 2050. Our scenarios account for different initial growth rates and for potentially heterogeneous development of the coastal and landlocked regions. In interpreting and using the results, care is evidently required since there is neither any guarantee that the estimated relationships are stable over time, nor that the estimation results are representative for income levels that far exceed those that are represented in the sample. For this reason, we provide projections for the period 1997–2025 which are reasonably reliable, as well as for the period 2025–2050 (and 1997–2050), which are less reliable since the average per capita income and emission levels far exceed those applicable to the years considered in our data sample. A further warning in comparing

Table 8. *Predicted growth of waste gas emissions for different development scenarios*

	Pessimistic	*Optimistic*	*Optimistic-Divergence*	*Optimistic-Convergence*
Growth rates in 1997 and 2050 (under assumption of linear convergence)				
• Coast	2%–2%	5%–2%	5%–2%	3%–2%
• Landlocked	2%–2%	5%–2%	3%–2%	5%–2%
Predicted annual emission growth rate 1997–2025				
	1.37%	5.64%	5.57%	2.47%
Predicted annual emission growth rate 2025–2050				
	3.49%	9.19%	9.21%	5.68%
Predicted annual emission growth rate 1997–2050				
	2.36%	7.30%	7.27%	3.97%

our results with earlier studies is that we have data on total industrial waste gas only, whereas the other studies make predictions for CO_2 emissions.

The projected average annual emission growth rates for the different scenarios and time periods are contained in the lower half of table 8. In the pessimistic development scenario, growth rates of GRP per capita equal 2 per cent per annum throughout the first half of the twenty-first century. They are uniform for the coastal and the landlocked regions. The predicted growth rate of emissions for the first quarter of this century is equal to 1.37 per cent and hence lower than the growth rate of per capita income. In the second quarter of this century, emissions are predicted to increase substantially. The predicted growth rate of emissions for this period is equal to 3.49 per cent. This result is evidently driven by the N-shaped form of the income–emission relationship for waste gas that results in strong increases of emissions as per capita income increases at relatively high per capita income levels. In the optimistic scenario, both the coastal and landlocked regions start at an annual growth rate of 5 per cent that converges to 2 per cent in 2050. Emissions are then predicted to grow at 5.64 per cent in the period 1997–2025 and to accelerate to 9.19 per cent in the period 2025–2050. Compared to the pessimistic scenario, regions start climbing the steep part of the income–emission relationship earlier in time, resulting in relatively high growth rates of emissions in all periods. Finally, we consider two scenarios of unequal development of the coastal and landlocked regions. In the divergence scenario, the coastal region develops as in the optimistic development scenario, while the landlocked regions only grow at 3 per cent in 1997. This results in a minor reduction in the growth of emissions to 7.27 per cent for the period 1997–2050. This reflects the fact that the landlocked regions start at relatively low levels of GRP per capita and by 2050 have not yet surpassed the critical level of GRP per capita above which emissions start to increase drastically in any of the two development scenarios. In contrast, the convergence scenario in which the landlocked regions develop according to the optimistic scenario, whereas the coastal regions start at 3 per cent GRP growth in 2000, results in a sharp decline of the growth rate of emissions to 3.97 per cent for the period 1997–2050, for opposite reasons to those discussed in the divergence scenario.

Two further remarks on these results are in place when we compare them to other predictions. First, given the sharp decline in population growth in China that has taken place recently and that is projected to continue for the next few decades, and given the fact that we did not include population size as a separate explanatory variable in the regression results that we have reported in this section, our predictions are likely to be on the high side of the relevant range.[9] Second, our regression results have revealed the relevance of N-shaped income–emission relationships. Such relationships result in accelerating emissions after regions have surpassed a certain per capita income level. By construction, such relationships are absent in Aufhammer *et al.* (2001) since they only include a squared per capita income term. Their predictions that are based on a similar method as ours therefore tend to underestimate the growth rate of emissions – almost by construction – if the N-shaped IER is indeed the empirically relevant one as our results suggest.

Clearly, given the importance of China's future CO_2 emissions in the context of the enhanced greenhouse effect, much more study is required before strong conclusions can be drawn that can be used in the debate on global CO_2-emissions. Still, we are convinced that the approach adopted in this paper that explicitly distinguishes Chinese regions and their potentially heterogeneous development is relevant for improving the quality of predictions (see also Auffhammer *et al.*, 2001). In any case, all results that have been obtained so far point at drastic increases in China's emissions as a fraction of total world emissions and therefore indicate the relevance of China and its future development for understanding, predicting, and ultimately curing the Chinese future contribution to the enhanced greenhouse gas effect.

6. Conclusions and policy recommendations

In this paper, we have analysed China's regional development and the associated change of China's regional environment. The main finding is that clear relationships between Gross Regional Product and pollution exist. The shape of the relationship heavily depends on the pollutant that is considered and on the specification of the dependent variable (in levels, in per capita terms or per unit of GRP).

For wastewater, we find a monotonic negative relationship indicating that water quality increases with income (and time). This holds for all specifications. For waste gas in levels there is a typical Kuznets pattern. When waste gas emissions are modelled in per capita terms, the relationship

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[9] We have tested for the effects of including population as an explanatory variable, but this did not substantially affect the results reported in this section on the IER. Insofar the development of GDP and population are correlated, the omission of population is also not a problem for the quality of the prediction. If, however, the relationship will change, the quality of the predictions will fall because of parameter instability over time.

is monotonically increasing in per capita income, although at a rate that depends on per capita income. When they are measured per unit of output, the relationship is decreasing. For solid waste we find support for an N-shaped income–emission relationship when estimated in levels. For solid waste per capita, no statistically significant relationship with per capita income is found.

The fixed effects describing differences between regions are statistically highly significant and imply that there are major differences between regions. These differences are likely to reflect differences in the underlying industrial structure. More in-depth 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.

We have also made some tentative predictions of waste gas emissions, based on the regional IER analysis. It turns out that even for exogenously determined moderate per capita growth rates the increase in emissions is considerable at 5.6 per cent annually on average for the period 1997–2025. The fact that this increase is higher than the per capita growth rate follows from catching up of the poorer regions and from the N-shaped income–emission relationship that suggests accelerating emissions after a certain per capita income level is surpassed. Fundamental transformation in production processes and exploitation of technological opportunities that are available in the west, reducing the energy intensity of production, are therefore of utmost importance.

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 intervention 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 beneficiaries from the sufferers of this environmental degradation. It is important to determine who is responsible for pollution damage, who is responsible for environmental improvement, and 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 recognizes 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' (January 1995). Therefore the outlook is not positive. But it should be noticed that there are factors constraining environmental deterioration. The commodity market turns its weight from seller-preference market to buyer-preference market; the reduction of growth rates reduces 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 (National Environment Protection Agency, 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, can it 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**

Region	*Annual growth rate of GRP 1978–1993*	*Annual growth of GRP 1994–1997*	*Annual growth rate of per capita GRP 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 GRP (1978–1993) from The Gross Domestic Product of China (1952–1995) and China Statistical Yearbook (1998).

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* Asterisks denote coastal regions.

Figure A1. *Coast versus non-coast*

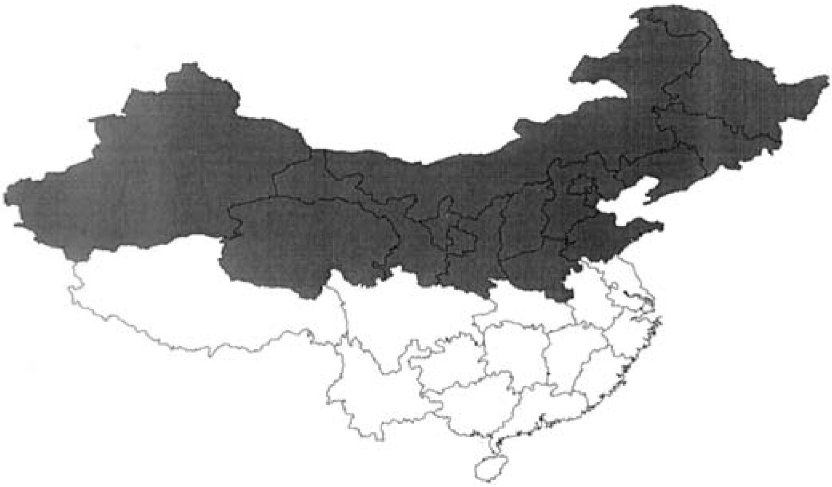

Figure A2. *North versus South*

Figure A3. *Names of provinces*

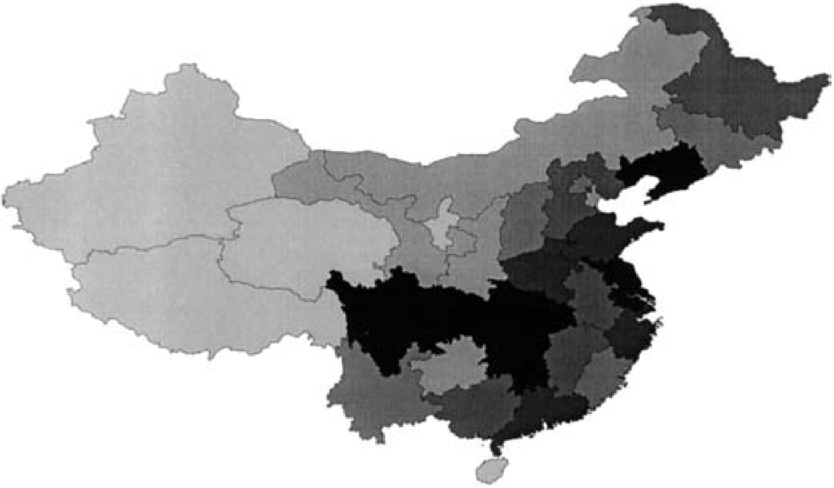

Figure A4. *Wastewater emissions in levels in 1997*

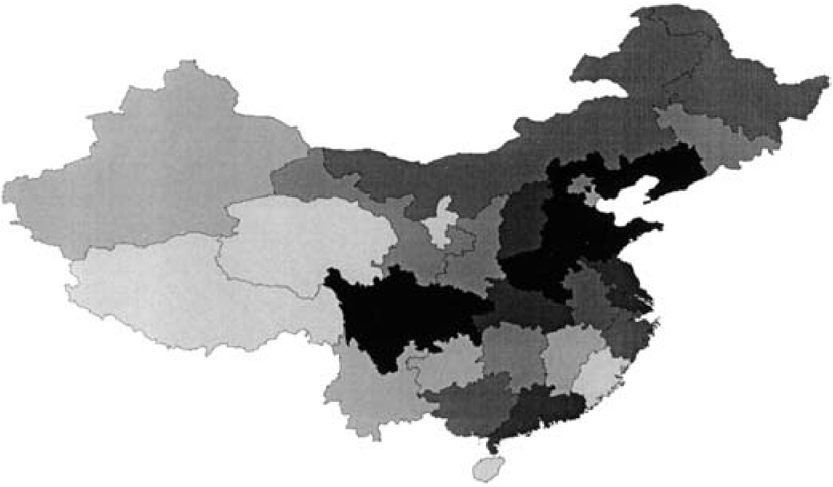

Figure A5. *Gas emissions in levels in 1997*

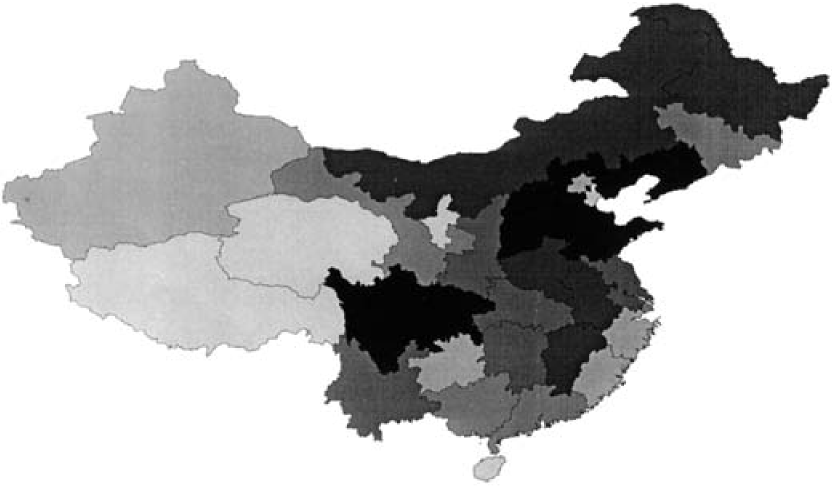

Figure A6. *Solid emissions in levels in 1997*