Environmental Kuznets Curves in the People's Republic of China: turning points and regional differences

Jiang, Yi and Lin, Tun and Zhuang, Juzhong

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Abstract

This paper examines the relationship between economic growth and environmental sustainability in the People's Republic of China by empirically estimating environmental Kuznets curve (EKC) models using provincial-level panel data from 1985 to 2005. The results show that there exists an inverted-U shaped relationship as hypothesized by the EKC model between per capita income and per capita emissions (or discharges) in the cases of waste gas from fuel burning and waste water, with a turning point at per capita gross domestic product of $12,903 and $3,226, respectively, in 2005 purchasing power parity terms. This relationship does not hold in the case of waste gas from production or solid waste. The estimation results from the model allowing region-specific slope coefficients show that the EKCs of the more developed coastal region have a flatter rising portion with turning points occurring at a higher income level than those of the less developed central and western regions. The paper argues that this may reflect technology diffusion and leapfrogging and institution imitation across regions at different stages of development. Policy implications of these findings are discussed.

I. Introduction

Recent official data show that during its 10th Five-Year Plan (FYP), the People's Republic of China's (PRC) reduction in emissions or discharges fell short of the targets for a number of pollutants. In 2005, sulfur dioxide (SO_2) emissions increased by 27% from its 2000 level, totaling 25.5 million tons and exceeding the target by 7.5 million tons. Chemical oxygen demand emissions reached 14.13 million tons, 8% higher than the target. In contrast, the country's economic development indicators surpassed the goals. Gross domestic product (GDP) registered a 9.48% annual average growth during the 10th FYP period.

The relationship between economic growth and environmental sustainability has been a subject of intensive discussions in recent years. Given the PRC's rapid pace of growth, its performance in mitigating environmental degradation inevitably attract attention. Would the country's environment continue to deteriorate or would it improve as its income level grows further? Given the PRC's significant regional differences in industrial structure, level of urbanization, and stage of development, does the relationship between economic growth and level of pollutant emissions (or discharges) differ across regions? This paper attempts to answer these questions by empirically estimating environmental Kuznets curves (EKC) models using provincial-panel data from the PRC.

The EKC model has been one of the controversial topics in environmental economics in recent years. It hypothesizes that the relationship between income and environmental quality—which is often measured by the level of pollution—is inverted-U shaped: at relatively low levels of income, pollution increases and the environment deteriorates with rising incomes; beyond some turning point, pollution declines and the environment improves with incomes. This relationship was first noted in a series of empirical studies in the early 1990s (Shafik and Bandyopadhay 1992, Panayotou 1993, Grossman and Krueger 1995, Selden and Song 1994). Subsequent empirical studies, however, showed that while the relationship holds in many cases, it cannot be generalized in many other cases. Further, researchers and policymakers are far from agreeing on the policy implications of the EKC model.

The EKC hypothesis has been tested in the case of the PRC by several authors. Groot et al. (2004) estimated EKCs for emissions or discharges of waste gas, waste water, and industrial solid wastes for the PRC using provincial panel data from 1982 to 1997. They found that the emission–income relation depends on the type of pollutants and on how the dependent variable is constructed. The waste gas emission in terms of levels is found to follow an inverted-U pattern, but waste gas emissions in per capita or per unit of output terms, as well as waste water discharge, do not. Liu et al. (2007) examined time series concentration data of various water pollutants in Shenzhen, a fast developing southern city of the PRC. Liu et al. found that production-induced pollutants, as opposed to consumption-induced pollutants, support the EKC hypothesis. Shen (2006) estimated a simultaneous three-equation model to address the endogeneity problem associated with per capita GDP and per capita pollution abatement expenses. Shen finds the EKC relationship for water pollutants but not air pollutants. Auffhammer and Carson (2008) find the EKC relationship between (log) per capita waste gas emissions and (log) total GDP in a two-way fixed effects model specification.

This paper differentiates from the existing EKC studies on the PRC in a number of aspects. First, the provincial-level panel data used in this paper span 21 years from 1985 to 2005, the longest and most up-to-date compared to the existing studies. Second, the paper puts a greater emphasis on identifying turning points of the EKC that do not seem to have been adequately examined.[1] Third, in light of the PRC's considerable and persistent regional disparity, this paper explores the regional heterogeneity in EKC and its policy implications by estimating a model allowing for region-specific coefficients of the explanatory variables, namely, per capita income and its square. Fourth, to estimate the EKC, the paper looks at four pollutants: waste gas from fuel burning, waste gas from production, waste water, and solid waste. The separation of waste gas emissions due to fuel burning from those due to production is justified on the basis that industries largely producing the former are not necessarily the industries largely producing the latter, and the industrial structure is likely to be related to the level of development, as vindicated by the estimation results.

The rest of this paper is organized as follows. Section II summarizes the literature on EKC. Section III discusses methodology and data, while Section IV reports the results. Finally, using the estimated EKC models, Section V projects the likely scenarios of emission levels of the pollutants examined in this paper at the provincial level in the PRC by 2010 and 2015 and discusses policy implications.

[1] Shen (2006) finds that turning points for water pollutants vary between 8,257–17,516 yuan (1993). Yuan is the unit name of the PRC's currency, the renminbi. All the *renminbi* numbers hereafter have been adjusted to its 1998 value unless otherwise indicated.

II. The Environmental Kuznets Curve: A Brief Literature Review[2]

The most common explanation for the EKC is that the income elasticity of demand for environmental quality is high such that consumers who have achieved a high standard of living will increase their demand for environmental amenities. Not only are richer consumers more willing to pay for green products, they also ask for better institutions to protect the environment (e.g., Selden and Song 1994). Grossman and Krueger (1995) argue that economic growth affects environmental quality both negatively (through scale effects) and positively (through composition effects and technological effects). When an economy is in the early stage of development, increasing output requires more natural resources and thus puts a heavier burden on the environment, the so-called scale effect. As the level of income grows, the economy shifts from being energy-intensive to knowledge- and technology-intensive in production, known as the composition effect. With economic growth also come cleaner production technology and more effective abatement procedures that improve the environment while maintaining high output, known as the technological effect. A turning point eventually occurs when the scale effect is outweighed by the composition and technological effects.

Several factors are considered to be important in determining the shape and turning point of the EKC. Among others, trade and investment across regions or nations are two of the most important forces (e.g., Bommer 1999, Harrison 1996, Wheeler 2000). Underdeveloped economies usually have a comparative advantage in producing labor-intensive goods that are often more pollution-intensive. They also tend to have relatively loose environmental legislation and regulation, which may attract dirty industries from developed economies through trade and direct investment. Moving pollution from developed to the underdeveloped economies, trade and investment could result in an EKC characterized by the underdeveloped countries (regions) on the rising segment of the curve and the developed ones on the declining segment.

There are, however, researchers who argue against this line of reasoning on the basis that investment and trade could potentially facilitate diffusion of environment-friendly technology (e.g., Reppelin-Hill 1999). By gaining access to the advanced technologies that allow more energy-efficient production and effective pollution abatement, developing countries could in fact reach the turning point of an inverted-U shaped EKC at a lower income level, or even bypass a certain portion of its rising part.

Enforcement of property rights and market rules, reduction in information asymmetry, formal regulation through the governments, and informal regulation pursued by civil society and/or nongovernmental organizations are effective in preventing environmental

[2] For a comprehensive survey of the empirical EKC literature, see Dinda (2004) and He (2007). Cavlovic et al. (2000) provides a meta-analysis of EKC.

degradation (e.g., Lopez 1994, Vukina et al. 1999, Dasgupta et al. 2000, Pargal and Wheeler 1996). As these institutional setups often start in a weak position and tend to be enhanced with progress in economic development, they are also seen as underlying factors of the inverted-U shaped EKC. If the underdeveloped countries (regions) fail to catch up with the developed ones in establishing the institutions to protect the environment, they may experience a prolonged period with the environment deteriorating as income grows.

Most empirical studies on EKC use cross-country data and, due to data limitation, focus largely on air and water pollutants. Both pollutant emissions (flows) and concentrations (stocks) have been used to measure environmental quality. In general, it has been found that the EKC relationship is more likely to hold for certain pollutants, including SO_2, particulate matter, nitrogen oxide (NO_x), etc., but less likely for carbon dioxide. Results are more mixed for water pollutants than for air pollutants. Evidence of EKC for some water quality indicators is weak or conflicting (e.g., Hettige et al. 2000, Shafik 1994). As far as the turning points are concerned, although wide variations are noted across studies even for the same pollutant, the majority falls within the per capita income range of $5,000–$8,000. Using a globally representative panel data set, Halkos (2003) found that the estimated turning point for SO_2 is PPP GDP per capita of $5,648 for the Organization for Economic Co-operation and Development (OECD) subsample and $3,401 for the non-OECD subsample.

A relatively small number of studies make use of single country data. Milimet et al. (2003) examined the relationship between air pollutants SO_2 and NO_x and per capita income using state-level panel data from the United States from 1900 to 1994. The turning point is found to be in the range of $7,000–$9,000 for SO_2 and $8,000–$12,000 for NO_x. List and Gallet (1999) used the same data set to estimate models allowing each state to have its own EKC. The results show considerable differences across states. The turning points vary from $1,770 for Arizona to $125,000 for Mississippi in the case of NO_x; and from $2,989 for Rhode Island to $69,047 for Texas in the case of SO_2. Vincent (1997), using a panel data set of Malaysian states, found that the EKC hypothesis does not hold in any of the six pollution-income relationships examined.

As mentioned in the previous section, several authors have tested the EKC hypothesis using the provincial-level panel data in the PRC, and found that it generally holds in the case of waste gas, but not in the case of waste water. Given the important policy implications that may be drawn from such studies, there is a need for a more in-depth analysis, including estimating turning points and exploring cross-region heterogeneity, which have not been adequately looked at, using more up-to-date data.

III. Methodology and Data

To test the existence of the EKC in the PRC, we estimate the following model using provincial-level panel data:

$$E_{ikt} = \beta_{1k}Q_{it} + \beta_{2k}Q_{it}^2 + \alpha_{ik} + \mu_{tk} + \varepsilon_{ikt} \quad (1)$$

i = 1,2,...,31,[3]

t = 1,2,...,21 or 1985,1986,...,2005,

where E_{ikt} is the per capita emission or discharge of waste *k* in province *i* at year *t* ; Q_{ikt} and Q_{ikt}^2 are, respectively, the per capita GDP and its square term of province *i* at year *t* ;[4] α_{ik} is a province-specific fixed effect that accounts for the time-invariant factors unique to each province (e.g., resource endowment); μ_{tk} is a time-specific fixed effect that captures common shocks to all the provinces in each year such as changes in environmental regulation, technological progress, or shift in preferences; and ε_{ikt} is the contemporaneous error term assumed to be stationary.

β_{1k} and β_{2k} are the slope coefficients that jointly define the relationship between per capita emission (or discharge) of pollutant *k* and per capita GDP. Equation (1) provides a depiction of the emission–income relationship rather than a causal explanation of why the relationship is as such as would be the case if variables that are potential determinants of income growth and environmental quality such as industrial structure, urbanization, investment in environmental protection, and regulatory intensity are included on the right-hand side of the equation. The two coefficients therefore capture all the direct and indirect marginal impacts of economic development on the environment as measured by the level of per capita emissions (or discharges) of a particular pollutant. An inverted-U relationship between pollution and income requires that $\beta_{1k} > 0$ and $\beta_{2k} < 0$. Note that in equation (1), β_{1k} and β_{2k} do not vary by province, implying an isomorphic EKC for all provinces.

The PRC's economic reform took an intended gradual approach. The focus of pro-development policies was first set in the coastal provinces and later shifted to the central and western regions. One advantage of this approach is that the trial regions could accumulate development experiences and lessons, which the latecomers could learn at a much lesser cost. Meanwhile, industrial relocation could occur between the relatively

3 Hainan province was separated from Guangdong province in 1988 and Chongqing municipality was separated from Sichuan province in 1997. Included in the data are 29 provinces and municipalities before 1988, 30 between 1988 and 1996, and 31 in 1997 and after. To account for the territorial changes, two dummies for post-1987 Guangdong and post-1996 Sichuan were added to the models.

4 The authors also tried cubic models. Similar as in the literature of List and Gallet (1999) and Cole Elliott (2003), the authors found N-shaped curves for waste gas from fuel burning, waste water, and solid waste; and inverted-N curve for waste gas from production. The peak turning points for the N curves are very close to those from quadratic models. The bottom turning points often fall far out of the sample.

developed regions and underdeveloped ones, during which the environment in the central and western regions could become vulnerable if more polluting industries move inland from the coastal region. From 1985 to 2005, the average per capita GDP for the coastal provinces increased from 3,733 yuan to 23,476 yuan; for the central provinces from 1,933 yuan to 10,513 yuan; and for the western provinces from 1,649 yuan to 7,613 yuan.[5] The large disparity in growth suggests that there is considerable room for technology transfer, institution imitation, as well as industrial relocation across regions. One possible consequence is that the three regions form distinct relationships between income and pollution. Therefore, it is worth exploring whether and how the EKCs vary by region.

Following List and Gallet (1999), we estimate a model assuming region-specific slopes for per capita GDP and its square:

$$E_{ikt} = \sum_{r} \left(\beta_{1rk} Q_{it} + \beta_{2rk} Q_{it}^2 \right) + \alpha_{ik} + \mu_{tk} + \varepsilon_{ikt} \quad (2)$$

where *r* denotes the costal, central, or western region to which province *i* belongs. In other words, each of the three regions is assumed to have distinct EKCs characterized by region-specific β_1 and β_2.

To implement the above methodology, we compiled provincial-level panel data from the *China Statistical Yearbooks* covering the period 1985–2005 (State Statistical Bureau, various years). To the best knowledge of the authors, this is the longest and most up-to-date panel among similar studies on EKC in the PRC. For the dependent variable, we look at per capita emissions or discharges of four pollutants, namely, waste gas from fuel burning, waste gas from production, industrial waste water, and industrial solid waste. The dependent variable measures the quantity of emitted or discharged waste gas, waste water, or solid wastes in which the pollutants (SO_2, particulate matter, chemical oxygen demand, etc.) are contained. It should be noted that as the concentration of the pollutants in these waste emissions or discharges varies by sources, the damage to the environment caused by the same amount of waste emissions or discharges could differ.[6] For the explanatory variables, we use the per capita real GDP of each province, adjusted to the 1998 price level by applying province-specific GDP deflators, and its square term.

We treat waste gas emissions due to production and those due to fuel burning separately because the provinces differ in their industrial structure and different industries have unequal contributions to each type of waste gas emission. The industrial structure is shaped by a variety of factors in the economy, including natural endowment, developmental strategy, industrial policies, and so on. As a result, provinces at similar development stages could have distinct industrial structures even after the endowment factor is accounted for. Some industries, such as power, steam, and hot water supply, produce waste gas emissions mainly from fuel burning, while others, such as cement

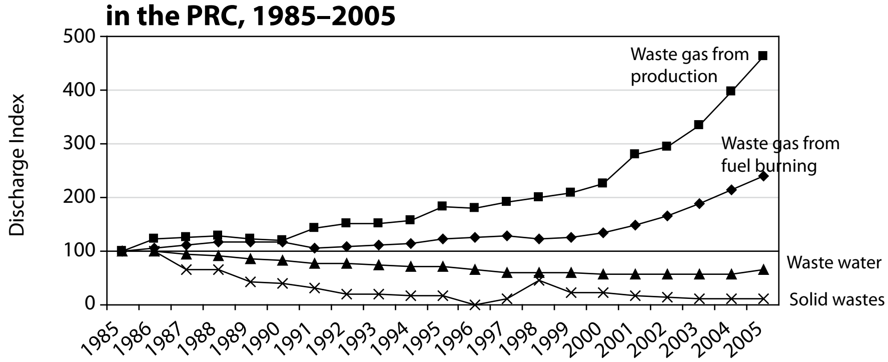
5 The Appendix lists provinces and municipalities that belong to each region.
6 A more desirable measure is emissions of the pollutants. Unfortunately, such information is not consistently available in the statistical yearbooks.

manufacturing, produce waste gas emissions largely from production. Therefore, waste gas from fuel burning and waste gas from production may exhibit different relationships depending on the level of economic development, due to the underlying differences in the industrial structure. Further, to the extent that different industries may be subject to different regulatory regimes in environmental protection, analysis that differentiates waste gas emissions according to their sources helps to design more targeted environmental protection regulations.

Table 1 reports summary statistics of the variables used in estimation. For the PRC as a whole, the mean per capita GDP of 31 provinces during 1985–2005 was 6,581 yuan measured in 1998 prices. The maximum per capita GDP was 58,014 yuan recorded in Shanghai in 2005 while the minimum was 1,049 yuan recorded in the western province of Guizhou in 1985. As far as per capita emission is concerned, large gaps also exist between the means, minimums, and maximums. Figure 1 presents a perspective on how the emission (or discharge) levels of the four pollutants change over time. Per capita waste gas emission, especially those from production, increased sharply from 1985 to 2005, by 3.6 times. On the other hand, per capita waste water discharge and solid waste decreased during the same period. In particular, the level of per capita solid wastes discharge fell by 90% from 1986 to 2005.

Table 1 also reports summary statistics of the concerned variables for the three regions: coastal, central, and western. The coastal region of the PRC is more developed than the central and western regions. Over the 21-year period, average per capita GDP of the coastal provinces is 2.2 times that of the central provinces, and 2.7 times of that of the western provinces. Moreover, the gap between the coastal provinces and the western provinces has further expanded to 3.1 times by 2005. Central provinces are slightly richer and have grown faster in recent years than have the western provinces. Mean per capita emissions of waste gas and waste water were higher in the coastal provinces than in other provinces, which is not the case with respect to solid wastes discharge.

Figure 1: Per Capita Waste Emissions (discharge) in the PRC, 1985–2005



Sources: Authors' calculation based on data from *China Statistical Yearbooks 1985–2005* (State Statistical Bureau, various years).

Table 1. Summary Statistics, 1985–2005

	Mean	Std. Dev.	Minimum	Maximum
Whole Country				
GDP per capita (yuan 1998)	6581.40	6498.12	1049.48	58013.79
Per capita waste gas from production (m^3)	4630.87	4540.62	0	38679.67
Per capita waste gas from fuel burning (m^3)	7659.66	5867.91	39.76	37440.61
Per capita industrial waste water discharge (ton)	20.38	15.39	0.316	123.22
Per capita industrial solid wastes discharge (ton)	0.046	0.069	0	0.544
Coastal Provinces				
GDP per capita (yuan 1998)	10274.79	8747.85	1413.41	58013.79
Per capita waste gas from production (m^3)	6296.54	5758.17	245.69	38679.67
Per capita waste gas from fuel burning (m^3)	9780.39	6615.23	876.66	37440.61
Per capita industrial waste water discharge (ton)	28.91	20.11	8.55	123.22
Per capita industrial solid wastes discharge (ton)	0.027	0.050	0	0.427
Central Provinces				
GDP per capita (yuan 1998)	4687.69	2691.72	1419.08	14101.29
Per capita waste gas from production (m^3)	3546.44	2968.10	928.83	20714.24
Per capita waste gas from fuel burning (m^3)	7262.15	5377.97	2364.47	36884.01
Per capita industrial waste water discharge (ton)	17.43	7.59	8.82	61.09
Per capita industrial solid wastes discharge (ton)	0.049	0.085	3.14e-07	0.544
Western Provinces				
GDP per capita (yuan 1998)	3744.32	2021.19	1049.48	10390.79
Per capita waste gas from production (m^3)	3535.52	3188.00	0	20462.93
Per capita waste gas from fuel burning (m^3)	5333.85	4101.00	39.76	27255.95
Per capita industrial waste water discharge (ton)	12.37	5.78	0.316	35.91
Per capita industrial solid wastes discharge (ton)	0.068	0.066	0	0.368

m3 = cubic meters.
Source: *China Statistical Yearbook 1985–2005* (State Statistical Bureau, various years).

IV. Results

Table 2 reports estimation results of equation (1) for each of the four pollutants. For both per capita waste gas emission from fuel burning and waste water discharge, β_1 is positive and β_2 is negative, both significant at the 5% or 1% level, suggesting an inverted-U shaped EKC. For these two models, the adjusted R^2 reaches 0.85 and 0.91, respectively. In the case of per capita solid waste discharge, however, although β_1 and β_2 have the expected signs, they are statistically insignificant. The adjusted R^2 is as low as 0.55. In the case of per capita waste gas emission from production, β_1 and β_2 have wrong signs. With β_1 being negative and β_2 positive, it suggests a U-shaped relationship between per capita waste gas emission from production and per capita GDP. To visually show the relationships, Figure 2 plots the estimated EKCs for waste gas emissions from fuel burning and waste water discharge conditional on the province and time-fixed effects, along with the actual observations.

Table 2. Estimates of the Coefficients and Turning Points of the Isomorphic EKC Model

	Fuel Waste Gas	Production Waste Gas	Waste Water	Solid Waste
GDP per capita	0.668***	-0.208**	7.33e-04**	1.27e-07
	(0.111)	(0.0931)	(3.13e-04)	(1.83e-06)
GDP per capita squared	−7.54e-06***	9.05e-06***	−3.28e-08***	−3.04e-12
	(1.47e-06)	(1.82e-06)	(5.63e-09)	(2.40e-11)
Turning point (yuan 1998)	44280***	na	11146***	20888
	(3142)		(3129)	(152596)
Time fixed effects	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes
Observations	630	627	634	543
Adjusted R^2	0.854	0.836	0.906	0.548

*** indicates 1% statistical significance, and ** for 5%.
Note: Robust standard errors in parentheses.

Table 2 also reports the level of per capita GDP at which the quadratic curve reaches a turning point, calculated as $-\beta_1/2\beta_2$. Conditional on province- and time-fixed effects, per capita waste gas emissions from fuel burning starts to decline when per capita GDP achieves 44,280 yuan. This level of income where the turning point occurs is relatively high compared to the mean per capita income of the sample. Only Shanghai reached per capita GDP of over 40,000 yuan since 2002 (41,510 in 2002; 46,354 in 2003; 52,521 in 2004; and 58,013 in 2005). In the case of per capita waste water discharge, the income level at which the turning point occurs is much lower, at 11,146 yuan. Most coastal provinces except Hainan and Guangxi were on the right side of the turning point by the end of 2005; while four central provinces (Heilongjiang, Hubei, Inner Mongolia, and Jilin) had just reached this level recently (Heilongjiang in 2004 and the other three in 2005). Plotting per capita waste water discharge against per capita income (see Figure 2) shows that the data points for Shanghai stand out far above the rest of the country. To evaluate the impact of Shanghai as an outlier in the case of waste water discharge, we re-estimated equation (1) without Shanghai. The turning point moves up to 17,916 yuan, and only eight coastal provinces had passed the threshold by 2005.[7] The turning point for solid wastes, at 20,888 yuan, is not statistically distinguishable from zero (t = 0.14).

[7] Estimates are $\hat{\beta}_1 = 1.06 \times 10^{-3}$ (3.35×10^{-4}), $\hat{\beta}_2 = -2.96 \times 10^{-8}$ (9.59×10^{-9}), and the adjusted R^2 is 0.786. The eight provinces (municipalities) are Beijing, Fujiang, Guangdong, Jiangsu, Liaoning, Shanghai, Tianjin, and Zhejiang.

Figure 2: Environmental Kuznets Curves for the PRC, 1985–2005

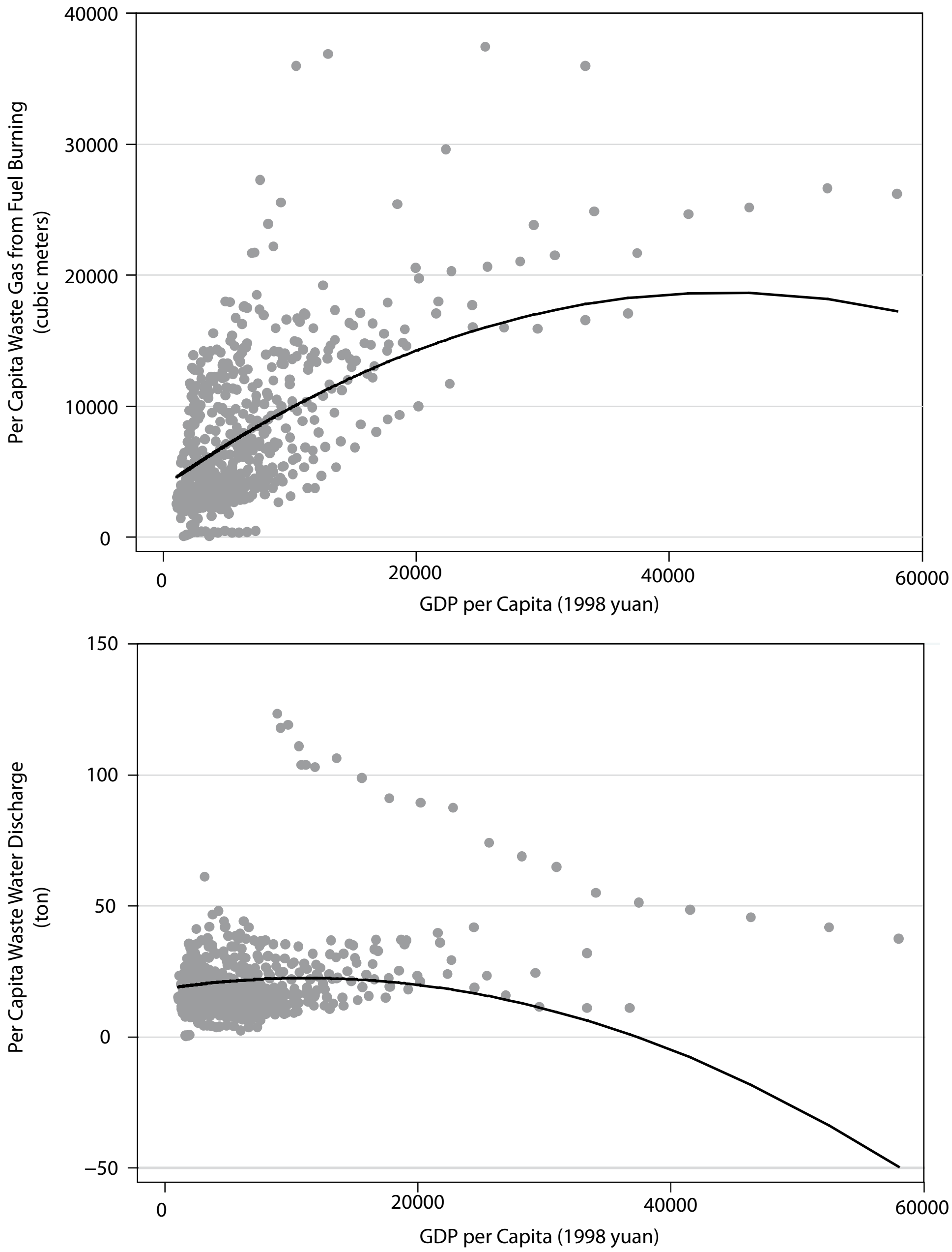


Table 3 presents estimation results for equation (2) as well as the calculated turning points by region. Consistent with the isomorphic EKC model, waste gas emissions from fuel burning and waste water emissions exhibit inverted-U shaped relationships with income, while waste gas from production displays a U-shaped relationship with income for all the three regions. The estimates for solid wastes are imprecise and thus not informative.

An examination of the estimates across regions reveals that, for both waste gas emission from fuel burning and waste water discharge, the segment of the EKC curve on the left-hand side of the turning point is steepest for the western region and flattest for the coastal region (i.e., the absolute value of β_1 being the largest for the western region, followed by the central region and the coastal region). This suggests that per capita waste gas emission from fuel burning and waste water discharge have increased faster in the western and central regions than in the coastal regions during the initial period of economic growth. Meanwhile, the central and western regions also have larger absolute values of β_2 than the coastal region has, which implies that the former have been more aggressive in correcting the "more development, more pollution" pattern than the latter.

As a result of differences in both β_1 and β_2, the per capita GDP at which the turning point occurs is higher for the coastal region than for the western and central regions. For waste gas emission from fuel burning, the coastal region's turning point is at 44,573 yuan, compared to 22,769 yuan for the central region and 14,229 yuan for the western region. Shanghai is the only coastal municipality that is on the right of the turning point of waste gas from fuel burning. Concerning waste water discharge, the coastal region's turning point is at 11,580 yuan, while those of the central and western regions are at 3,504 yuan and 5,606 yuan, respectively. All coastal provinces except Hainan and Guangxi, all central provinces, and all western provinces except Guizhou have entered the declining segment of the EKC curves. Due to the concern about Shanghai being an outlier, we re-estimate equation (2) excluding Shanghai.[8] The waste water turning points increase to 19,626; 7,322; and 8,054 yuan for the coastal, central, and western regions, respectively. Under this scenario, six coastal provinces (Beijing, Guangdong, Jiangsu, Shanghai, Tianjin, and Zhejiang); all central provinces; and four western provinces (Chongqing, Qinghai, Sichuan, and Xinjiang) had per capita waste water discharge decreasing with per capita GDP by 2005.

The bottom panel of Table 3 reports results of *F*-tests on the equality of income levels corresponding to the turning points among the three regions. The coastal region has significantly higher turning points for both waste gas from fuel burning and waste water than the western region. The central region differs from the other two regions in turning points of waste water discharge but not of waste gas from fuel burning, which is not surprising given the sizable standard errors of the estimates for the central region. These results imply that the isomorphic EKC model does not fully account for the heterogeneity in pollution-development patterns in the PRC.

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[8] Estimation results are available from the authors upon request.

Table 3. Estimates of the Coefficients and Turning Points of Heterogeneous EKC Models

	Fuel Waste Gas	Production Waste Gas	Waste Water	Solid Waste
Coastal Provinces				
GDP per capita	0.761***	−0.258**	8.35e-04**	−3.32e-06*
	(0.140)	(0.112)	(3.95e-04)	(1.95e-06)
GDP per capita squared	−8.54e-06***	9.64e-06***	−3.61e-08***	2.92e-11
	(1.64e-06)	(2.00e-06)	(6.79e-09)	(2.43e-11)
Turning point (yuan 1998)	44573***	na	11580***	na
	(2329)		(3570)	
Central Provinces				
GDP per capita	1.074*	−0.422	1.07e-03	−3.90e-06
	(0.568)	(0.363)	(8.13e-04)	(5.78e-06)
GDP per capita squared	−2.36e-05	1.57e-05	−1.53e-07***	−2.42e-10
	(5.17e-05)	(2.65e-05)	(4.46e-08)	(3.96e-10)
Turning point (yuan 1998)	22769	na	3504*	na
	(39441)		(1860)	
Western Provinces				
GDP per capita	1.334**	−0.937*	3.06e-03**	−1.26e-05
	(0.617)	(0.508)	(1.29e-03)	(9.58e-06)
GDP per capita squared	−4.69e-05	7.75e-05*	−2.73e-07***	−3.09e-10
	(4.79e-05)	(4.61e-05)	(9.10e-08)	(8.38e-10)
Turning point (yuan 1998)	14229	n.a	5606***	n.a
	(9041)		(1103)	
F-tests for Turning Points				
Coastal=central	0.31	n.a	**15.93**	n.a
Central=western	0.05	n.a	**3.60**	n.a
Coastal=western	**10.57**	n.a	**4.82**	n.a
Time fixed effects	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes
Observations	630	627	634	543
Adjusted R^2	0.854	0.836	0.916	0.559

na = not available.

*** indicates 1% statistical significance, ** for 5%, and * for 10%.

Note: Robust standard errors in the parentheses. The bold F-test value indicates that the test is significant at the 5% level.

V. Conclusions and Policy Implications

This paper estimated two environmental Kuznets curve models using provincial-level panel data from the PRC: one with an isomorphic EKC for all provinces and the other allowing three regions (coastal, central, and western) with substantially uneven economic development to have region-specific EKCs. The key findings of this paper are as follows.

First, an inverted-U shaped EKC holds for the PRC as a whole and for each of the three regions for per capita waste gas emissions from fuel burning and waste water discharges at an acceptable level of statistical significance. Such relationship also exists for discharges of solid waste, but is statistically insignificant. A U-shaped relationship between per capita emission and income is found for waste gas emissions from production.

Second, the turning point of the EKC for waste gas emissions from fuel burning occurs at a higher income level than that for waste water discharge. The turning point of the EKC occurs at per capita GDP of 44,000 yuan for waste gas emissions from fuel burning and at 11,000 yuan for waste water discharges for the entire country, which correspond to $12,903 and $3,226, respectively, in 2005 purchasing power parity terms.[9] The per capita incomes at which the turning points occur are comparable to the estimates yielded by many EKC studies using cross-country data (e.g., Halkos 2003).

Third, in the EKC model allowing for regional heterogeneity, the poorer central and western regions appear to have turning points occurring at lower income levels than the coastal region, suggesting that technology diffusion and leapfrogging and institution imitation through learning among regions at different developmental stages may have played a part in shaping the relationship between economic growth and environmental sustainability. These may have enabled provinces in less developed regions to use cleaner technologies and institute better regulatory frameworks for environmental protection at a lower income level as opposed to their counterparts in more developed regions, even though the relocation of more polluting industries from developed regions to less developed ones could partly offset such impacts.

Based on the estimated turning points, we carry out a back-of-envelop exercise as follows. First, we use the average annual growth rate of per capita real GDP over the sample period (1985–2005) to project per capita GDP for each province in future years. Second, using these projections and the estimated turning points of the EKCs for waste gas emission from fuel burning and waste water discharge, we identify the provinces that will see their per capita emission or discharge of these two types of waste declining by 2010 and 2015.[10] The results are presented in Table 4. By 2010, two more coastal provinces (Beijing and Tianjin) and one western province (Xinjiang) will join Shanghai on the right-hand side of the EKC for waste gas emissions from fuel burning, and four coastal provinces (Fujiang, Heibei, Liaoning, and Shandong); and five western provinces (Gansu, Ningxia, Shaanxi, Tibet, and Yunnan) will move to the right-hand side of the EKC for waste water discharges. By 2015, an additional four coastal provinces, five central provinces, and eight western provinces will pass their respective turning points of the EKCs for waste gas emissions from fuel burning. All provinces except Guangxi will pass the waste water turning points as well. According to these projections, the central and western provinces will catch up with the coastal provinces faster in pollution reduction than in economic development, as a consequence of technology diffusion and leapfrogging and institution imitation for environmental protection.

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[9] Applying World Bank International Comparison Program 2005 results, 1 dollar = 3.41 yuan.

[10] This approach is meant to be an illustration rather than rigorous forecasting. The latter is technically difficult. For instance, the time-fixed effects may not be stationary, which could lead to inaccurate prediction about timing. To be conservative, we use turning point estimates from the sample, excluding Shanghai for waste water discharge, in the projections.

Table 4. Projected Provinces to Pass the Turning Points of EKCs

	Coastal		Central		Western	
Projected annual average growth rate of per capita GDP during 1985-2005 (percent)						
Mean	10.2		9.0		8.1	
Maximum	12.2		10.0		10.5	
Minimum	8.1		7.8		9.6	
Provinces that pass the turning points						
	Fuel waste gas	Waste water	Fuel waste gas	Waste water	Fuel waste gas	Waste water
2005	Shanghai	Beijing Guangdong Jiangsu Shanghai Tianjin Zhejiang	None	All nine provinces	None	Chongqing Qinghai Sichuan Xinjiang
Projected in 2010	Beijing Shanghai Tianjin	All provinces except Guangxi and Hainan	None	All nine provinces	Xinjiang	All provinces except Guizhou
Projected in 2015	Beijing Fujian Guangdong Jiangsu Shanghai Tianjin Zhejiang	All provinces except Guangxi	Heilongjiang Hubei Inner Mongolia Jilin	All nine provinces	All provinces except Guizhou	All 10 provinces

Note: For waste gas from fuel burning, the turning points are 44,573 yuan (coastal); 22,769 yuan (central); and 14,229 yuan (western). For waste water discharge, the turning points are 19,626 yuan (coastal); 7,322 yuan (central); and 8,054 yuan (western).

Our results also indicate that it is important to distinguish waste gas due to production from waste gas due to fuel burning. Per capita emission of the former does not seem to show signs of slowing down. One of the possible causes of this could be that the PRC's current policy governing air pollution is stricter on emissions from fuel burning than from production. If this is the case, then a more balanced policy is called for.

The fact that the less developed regions have lower turning points implies that technology diffusion and leapfrogging and institutional imitation play an important role as mechanisms to reduce emissions and improve environmental quality. In this regard, public policies that facilitate technology diffusion and transfer, knowledge sharing on energy efficiency and emission abatement, and capacity building and institutional strengthening targeted at less developed regions are recommended for the PRC to move forward. Moreover, the concerned government agencies at various levels should be encouraged to share successful regulatory experiences. Nongovernmental organizations also have an important role to play in disseminating good practices in environmental protection. It is encouraging to note that the 11th FYP starting 2006 set the binding indicators in energy consumption, pollutant emissions, and ecosystem protection, indicating enhanced government actions in combating environmental degradation in the PRC.

Appendix A. Region Definitions

Region	Coastal	Central	Western
Provinces (municipalities)	Beijing	Anhui	Chongqing
	Fujian	Heilongjiang	Gansu
	Guangdong	Henan	Guizhou
	Guangxi	Hubei	Ningxia
	Hainan	Hunan	Qinghai
	Heibei	Inner Mongolia	Shaanxi
	Jiangsu	Jiangxi	Sichuan
	Liaoning	Jilin	Tibet
	Shandong	Shanxi	Xinjiang
	Shanghai		Yunnan
	Tianjin		
	Zhejiang		

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About the Paper

Yi Jiang, Tun Lin, and Juzhong Zhuang examine the relationships between different types of industrial waste emissions and economic growth in the People's Republic of China by estimating environmental Kuznets curve models using provincial-level panel data from 1985 to 2005. The authors find that waste gas emissions from fuel burning and waste water discharge do exhibit inverted-U shaped relationships with per capita gross domestic product. The turning points fall around $13,000 and $3,200 in 2005 purchasing power terms, for waste gas from fuel burning and waste water, respectively. The study also explores the regional variations in the relationships.

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