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Abstract

This paper discusses the validity of the Environmental Kuznets Curve hypothesis for the case of China's industrial SO_2 emission through both reduced and structural model. The estimated China-specific EKC curve for per capital industrial SO_2 emission predicts the turning point of 9000 yuan (2750 USD, PPP). However, given China's fast population expansion speed, the decreasing trend in the per capita emission will not bring an immediate reduction in total industrial SO_2 emission. Our structural EKC model succeeds in decomposing industrial SO_2 emission density into the contribution from its three famous structural determinants and a marginal impact from international trade. The latter is actually composed of a significantly negative direct impact and indirect ones going through the composition effect, which further depends on the current capital/labour abundance ratio and the actual income level of a province.

Summary

In this paper, based on provincial level panel data of China from 1992 to 2003, we test, firstly, the existence of Environmental Kuznets Curve for industrial SO_2 emission. Following, we decompose the economic determinants of this SO_2 emission density into: income effect (GDPPC), scale effect (Industrial GDP per km^2) and composition effect (K/L, capital abundance ratio). Finally, we study the direct and indirect role of international trade intensity ((X+M)/GDP). The estimated China-specific EKC curve for per capital industrial SO_2 emission predicts the turning point of 9000 yuan (2750 USD, PPP). However, given China's fast population expansion speed, the decreasing trends in the per capita emission will not bring an immediate reduction in total industrial SO_2 emission. We equally succeed in decomposing industrial SO_2 emission density into its three famous economic "effects". However, different from our expectation, the composition effect, measured by industrial capitalistic ratio K/L in this paper, instead of being a pollution-increasing role as generally accepted idea, turns out to lead industrial SO_2 density to reduce as a technology-reinforcing factor. We find that for the role of trade, besides a significantly negative direct impact, its indirect impacts on emission also go through the composition effect. This indirect impact actually depends on the current capital/labour abundance ratio and the actual income level of a province. Although we traced some supportive evidence for the "pollution haven" hypothesis, given China's extremely rich endowment in labor force, trade liberalisation only plays marginal role in reality (via composition effect). For most provinces, the currently existing negative environmental impact of trade is actually due to their relatively low capital/labour abundance ratio with respect to their actual income level. To change this situation, their economic growth should be accompanied by faster capital accumulation, which can help to update production and abatement technology and therefore reduces pollution.

Key Words: China, EKC, international trade, industrial SO_2 emission, decomposition, "pollution haven" hypothesis.

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1. Introduction

China, one of the countries with highest economic growth rate, risks equally to be nominated as the most polluted country in the world. With the increasing importance attached to environment in development process and the common understanding achieved on the definition of sustainable development, how to realize economy growth and avoid environment deterioration at the same time becomes an important topic for Chinese economy.

The Environmental Kuznets Curve (EKC), which assumes the relationship between various environmental degradation indicators and per capita income to be depicted by an inverted U curve, seems to be an attractive hypothesis. It implies the environment degradation, firstly reinforced with economic growth, will be decoupled from economic growth trends and bended downwards after income level attains certain critically high level.

Since Grossman and Krueger (1991) firstly investigated the econometrical evidence for this attractive inverted-U curve, over 100 papers have addressed this topic from different angles and many of them did confirm the existence of EKC from cross-country international experience during the last 30 years. However, the general critics confronted by most of the EKC studies are the incoherence and incomparability in the forms and turning points found in different studies using various dataset and econometrical strategies. This largely reduces their credibility. Although theoretical explanations implicating the automatic decoupling between economic growth and environmental deterioration as a rational dynamic trajectory for individual economy is widely accepted, in a strict econometrical perspective, the reduced-form estimation for a simple correlation between income and pollution by using international panel data, risks to be "spurious" and even further from being "optimal" trajectory for each of the individual countries included in the database.

The necessity for a developing country as China to understand the structural mechanism of pollution evolution during economic growth is two-folds. Firstly, empirical findings on EKC hypothesis generally predict environmental situation improvement to happen after per capita income attains the range of 4000-8000 USD (1985 price, PPP). Though holding rapid economic growth dynamism, till 2003, China's per capita GDP is only 2387 USD (1985 price, PPP), which is much lower with respect to this range. Does this mean a continuous environment deterioration tendency to be unavoidable during China's further economic growth? If that is the case, will the threshold of irreversibility of China's environment be attained and the sustainability of China's economic development endangered? Secondly, some economists suspected that the EKC found by cross-section data are possibly showing only a static "pollution haven" effect caused by trade liberalization, which works as a channel for developed countries to discharge their environmental burdens to developing ones. If this is true, trade liberalization process can orientate China's specialization towards polluting industries. The probability for China to realize the same inverted-U curve for pollution evolution as its developed trade partners will be more difficult as fewer countries will still stay at the side of pollution burden receivers when China becomes enough rich to act as a pollution exporter.

In this paper, after explaining the choice of pollution indicator, we firstly test the existence of a reduced-form EKC for industrial SO_2 emission in China by using the provincial level panel data from 1992 to 2003. Secondly, for a better understanding of the structural determinants of China's environmental quality, we decompose the structural determinants of industrial SO_2 emission. Thirdly, to analyze the direct and indirect role of international trade in emission determination, we include into our estimation model the trade intensity (defined as the ratio of international trade to GDP of the same period) individually and interactively with the other structural determinants. Finally, we conclude.

2. Pollution indicator choice—industrial SO_2 emission

We choose industrial SO_2 emission as environmental indicator in this paper. The first reason to choose this emission is its importance in China's environment. Among various air pollution cases, SO_2 emission is the most important air pollution problem in China. Nowadays, over one third of Chinese big cities have SO_2 concentration levels at least twice higher than the standard of $60\mu g/m^3$ fixed by the WHO (World Health Organization) for the developing countries.[1] Researches start to reveal the potential negative impact of this emission on public health status, especially as a significant cause of

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[1] China Environment Statistic (1998).

respiratory diseases.[2] Due to SO_2 emission, the ever-expanding acid rain problem in both south and north China has also resulted in rapid reduction in equipment and soil productivity.[3]

Secondly, SO_2 emission in China is directly related to its rapid industrialization process. Still inefficient in energy utilization, China's economic growth depends heavily on the fast increase of energy consumption. Although the tendency of energy efficiency improvement was continuously observed during the last twenty years, China's energy consumption per unit of GDP is still 7.28 times of Japan, 5.62 times of Germany, 3.52 times of US, 1.18 times of India and 3.28 times of world average level.[4] Richly endowed low cost coal, China's over 70% of economic activities is actually fueled by domestic coal supply, whose combustion forms the principal source of SO_2 emission. Therefore, studying this emission case can offer us a better entry point for the understanding of the real causality between economic growth and emission.

Thirdly, the choice of SO_2 emission in our study is also due to the fact that SO_2 emission is generally believed to be the local pollution case having the highest probability to show inverted U curve evolution with income growth. Therefore, by concentrating on SO_2 pollution, we expect to get more reference and comparison for our results.

Another point to notify is that in this study, we choose to only concentrate on industrial SO_2 emission. This is due to the following three considerations. First, among the total SO_2 emission, industrial production activities is always the largest source. Figure 1 shows SO_2 emission emitted by industrial sectors always occupied about ¾ of the total SO_2 emission. Second, SO_2 emission variation was also principally caused by the variation in the emission coming from industrial sectors, the part of emission from other sources stayed relatively stable. Finally, the reporting of the total SO_2 emission on provincial level shows general omission during 1996-1997, we are therefore obliged to use industrial SO_2 emission data whose time series for each province are complete.

<Please insert Figure 1 about here>

Like most of the papers discussing the EKC hypothesis, we firstly investigate the existence of inverted U curve for per capita industrial SO_2 emission. Following, we also study the relationship of

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[2] Xu et al,1994, Wells, Xu et Johnson, 1994 and World Bank, 1996a.

[3] World Bank, 1996b.

[4] Zhu (2003).

per capita GDP with respect to industrial SO_2 emission density. Emission density is calculated by dividing annual industrial SO_2 emission with the surface of the corresponding province. There are double interests in analysing this environmental indicator. Firstly, as geographical surface of each province is constant number, this indicator preserves the principal characteristic of total industrial SO_2 emission for each province, which is the central interest of this paper since ultimate environmental quality and assimilation capacity of the ecosystem are both determined by total volume of emission. Secondly, emission density in a province can also be rewrite as the product of per capita emission and population density (see equation 1). As the same quantity of emission cause more health damage in a province with higher population density, the evolution of emission density can actually extrapolate some characteristics of pollution concentration indicator.

$$\frac{Emission}{Area}=\frac{Emission}{Population}\times\frac{Population}{Area}=\frac{Emission}{Population}\times Population\ \ density \tag{1}$$

3. Is there an EKC for the case of industrial SO_2 emission in China?

Table 1 summarizes the statistics for all the data used in the emission determination analysis through section 3-5. Given this panel database covers 29 provinces during the most important economic reform period 1992-2003, we distinguish wide value spectrum for both pollution and economic indicators, which is a necessary condition for robust EKC estimates.

<Please insert Table 1 about here>

We first look at the existence of an “inverted U” relationship between per capita SO_2 emission and income per capita. In this step, we employ a simple reduced-form estimation function as equation (2), which directly connects per capita SO_2 emission ($so2pc_{it}$) to GDP per capita ($GDPPC_{it}$).

$$so2pc_{it}=X_i+\beta_t+\alpha_1 GDPPC_{it}+\alpha_2(GDPPC_{it})^2+\alpha_3 t+\varepsilon_{it} \tag{2}$$

The index $_i$ and $_t$ represent province and year respectively. X_i signifies the immeasurable constant province-specific effect. β_t are the time-specific intercepts, which is used to account for the common stochastic shocks to all the provinces in the same period. Time trend t is further included to capture the common technical tendency in the dynamic evolution of SO_2 emission.

<Please insert Table 2 about here>

The main EKC estimation results for per capita industrial SO_2 emission are reported in Table 2. We employ both random and fixed effect estimators for panel data. The Simple Model columns report the estimates based directly on equation (2) and the AD(1,0) columns list the results in which the first order serial-correlation problem is corrected by including the instrumented lagged dependant variable so_{pcit-1} in regression function.[5] To test the possible re-increasing trends of EKC after the dichotomy between economic growth and pollution, we also regress the cubic EKC model. Different from the estimation based on international experience, our estimation results show relatively good stability for model and estimation method changes. Though the cubic model predicts a re-increasing trend for per capita industrial SO_2 emission after the per capita GDP attains 20000-25000 Yuan, the location of its peak turning point corresponds well to that found by the squared model. Both models predict the dichotomy between per capita economic growth and per capita industrial SO_2 emission to happen when per capita GDP attains 9000-9500 Yuan (1990 constant price), which is equal to 2750 USD according to purchasing power parity or 1100 USD according to official exchange rate (1985 constant price of USD).[6]

<Please insert Figure 2 about here>

The estimated EKC are then depicted in figure 2. The actual locations of the 29 provinces in year 2003 are also indicated in the figure. Except for the several provinces whose per capita income level has surpassed the estimated turning point, most of these provinces still stay on the increasing track of the EKC by year 2003. Following the assumption of EKC hypothesis, we should anticipate more pollution problem in most of the Chinese provinces.

Following we estimate EKC hypothesis for the case of industrial SO_2 emission density. At this step, we estimate an EKC model as equation (3). As emission density can be regarded as the product of per capita industrial emission with population density (cf. eq. (2)), we also add population density as a supplementary explanation in estimation function.

$$so2den_{it} = X_i + \beta_t + \alpha_1 GDPPC_{it} + \alpha_2 (GDPPC_{it})^2 + \gamma denpop_{it} + \alpha_3 t + \varepsilon_{it} \qquad (3)$$

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[5] The instrumentation method employed here is developed by Balestra-Nerlove (1966) for the “fixed effect of the dynamic linear penal model”. More details are in P. Sevestre and A. Trognon (1996, chapter 7).

[6] Both the two turning points in USD are 1985 constant price. The conversion between 1990 CNY and 1985 USD is computed by author according to related price index in World Development Indicator (2003).

<Please insert table 3 about here>

The estimation results based on this function are reported in Table 3. Different from the case of per capita emission, the estimation on the industrial SO_2 emission density seems to be unable to support the EKC hypothesis. In the three estimation based on the whole sample of the 29 provinces, neither the squared nor cubic model obtains significant coefficients for income terms. We only find a significantly positive coefficient (0.391) for income term in the linear model. Does this means economic growth will unavoidably lead emission density to increase in China?

As the emission density is an indicator consisting of two factors: the province's total annual emission quantity as the numerator and the province surface as denominator, the reason for which emission density does not support EKC hypothesis may reside in these two factors. Let's first look into the province surface. In table 4, following decreasing order of per capita GDP, we list the income level, geographical surface and industrial SO_2 emission density data in year 2003 for each of the 29 provinces. Interestingly, all the three indicators for the three municipalities directly under central government, Shanghai, Beijing and Tianjin, are very different from those of the other 26 provinces. Possessing relatively higher per capita income level, these three cities also happen to have the smallest geographical areas. Therefore, their SO_2 density levels are naturally much higher than other provinces. The same conclusion can also be obtained from the panel a. of figure 3, where almost all the observations for the 26 provinces are concentrated in the lower-left part of the diagram and the several exceptional points in the higher-right part belong to the three municipalities. Is the linear positive relationship between SO_2 density and income simply caused by the participation of the exceptional observations of the three cities?

<Please insert table 4 about here>

<Please insert figure 3 about here>

To test this possibility, we divide the database into two sub-samples: 26 provinces and 3 cities and redo the estimation. The results are also reported in Table 3 and their graphical illustrations are given in the panel b and c of Figure 3. In this step, we use both the method of Balestra-Nerlove (1966) and first-difference General Methods of Moments (GMM) for linear, dynamic panel data proposed by Arellano and Bond (1991) to deal with the serial correlation problems. Out of our expectation, the estimates for both the sub-samples of 26 provinces and that of the 3 cities still predict increasing tendency for China's industrial SO_2 emission density during economic growth process.[7]

The last two columns of Table 3 report the estimates of a combined model, in which a spline structure is used to allow the estimation to be applied to the whole database but permit at the same time distinguishing the potential income coefficient differences between the 26 provinces and the 3 cities.[8] Once more, the combined model confirms the common increasing tendency for the industrial SO_2 density. Furthermore, the emission density's increasing trends for the 26 provinces seems to follow very similar tendency as those for the 3 cities, except the absolute emission density level is much higher for the 3 big cities (c.f. panel c of figure 3).

One possible explanation for the co-existence of the inverted U curve for per capita industrial SO_2 emission and the monotonically increasing tendency for industrial SO_2 emission density is population expansion. Table 5 reports the simple correlation coefficients of industrial SO_2 emission density with respect to per capita industrial SO_2 emission and population density. The very large correlation coefficient (0.94) between SO_2 density and population density reveals the closer causality between them. As the geographical dimension of each province is time-invariable, the correlation between SO_2 density and population density actually reflects the correlation between the total industrial SO_2 emission and provincial population growth. Following this reasoning, the divergence in the evolution trajectory of industrial SO_2 density and that of the per capita SO_2 emission is actually similar to that mentioned in Stern et al. (1996): although the per capita emission peaks relatively early, the total volume of emission will continue increasing under the pressure of population expansion. This finding is further confirmed by the EKC estimation results for the total industrial SO_2 emission reported in table 6, which generally predict increasing trends for total industrial SO_2 emission evolution in both the 26 provinces and the 3 cities.

<Please insert table 5 about here>

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[7] The division of the database is not necessary to be explicitly between provinces and big cities. We also estimate emission density's EKC model for the sub-samples of 26 provinces+Beijing, 26 provinces+Beijing+Tianjin. The estimation results are very similar to those obtained from sub-sample of the 26 provinces.

[8] Although the estimation results of the 3-city sample predict an inverted-U curve for industrial SO_2 emission density, as its turning point corresponds to a very high income level (27033 yuan), which is much higher than the maximum income level appearing in the actual database, so for the three cities, the estimated SO_2 density actually shows an ever-increasing trend in the available income range.

<Please insert table 6 about here>

4. Structural determinants of industrial SO_2 emission

Although the EKC analyses in last section can not dispel our worries about the continuously deteriorating industrial SO_2 pollution situation in China, the relatively earlier turning point found in the per capita SO_2 emission experience with respect to that obtained from international experience is still a positive signal. In this section, we investigate the potential structural determinants of pollution in the aims to de-masque the EKC "black-box" and turn it to a policy implication tools.

4.1. The structural model

(1) Grossman decomposition adaptation to our provincial level panel data

If we agree that emission is a by-product of production, according to Grossman (1995), the industrial SO_2 emission in each province i during period t can be written as a product of its three determinants as in equation (4).

$$SO_{2,it}=Y_{it}\sum_j\left(\frac{Y_{j,it}}{Y_{it}}\times\frac{SO_{2j,it}}{Y_{j,it}}\right) \tag{4}$$

The index j=$1, \ldots, n$ signifies different industrial sectors. Y_{it} presents the total industrial GDP in province i during period t and $SO_{2,it}$ signifies the total industrial SO_2 emission of the same province. $Y_{j,it}$ means the GDP created in industrial sector j of province i during period t and $SO_{2j,it}$ is the corresponding sector-level SO_2 emission.

Following section 3, our structural form estimation will concentrate on the determination of industrial SO_2 density in each province. Therefore, we divide the time-invariable provincial surface ($area_i$) on both sides of the equation (4) and obtain

$$\frac{SO_{2,it}}{area_i}=\frac{Y_{it}}{area_i}\sum_j\left(\frac{Y_{j,it}}{Y_{it}}\times\frac{SO_{2j,it}}{Y_{j,it}}\right). \tag{5}$$

The term $(SO_{2,it}/area_i)$ is therefore the industrial SO_2 density in province i during period t, and the first term on the right-hand side of equation $(Y_{it}/area_i)$ becomes the industrial activity density. $(Y_{j,it}/Y_{it})$ gives the proportion of product of sector j in total industrial product of province i. Finally, the term $(SO_{2j,it}/Y_{j,it})$ calculates the sector-specific pollution intensity. If we suppose sector specific emission intensity ($SO_{2j,it}/Y_{i,jt}$) can be represented by provincial-level average emission intensity $(SO_{2,it}/Y_{it})$

adjusted by a sector-specific emission efficiency indicator $e_{i,jt}$, we have $\frac{SO_{2i,jt}}{Y_{i,jt}}=\frac{SO_{2,jt}}{Y_{jt}}\times e_{i,jt}$, equation (5) can then be transformed into

$$\frac{SO_{2,it}}{area_i}=\underbrace{\frac{Y_{it}}{area_i}}_{scale}\times \underbrace{\sum_j(\frac{Y_{j,it}}{Y_{it}}\times e_{j,it})}_{Composition}\times \underbrace{\frac{SO_{2,it}}{Y_{it}}}_{Technique} . \tag{6}$$

The three structural determinants of emission are easier to distinguish in equation (6). The term $(Y_{it}/area_i)$ corresponds to scale effect. A higher industrial activity density normally means higher emission density given other factors staying constant. The inclusion of the sector-specific efficiency indicators $e_{j,it}$ permit us to distinguish other two effects. Firstly, with the aid of this efficiency indicator, we are able to include the provincial-level average SO_2 emission intensity directly in the formation of SO_2 emission density, which is actually an ideal measurement for technical effect. We expect a negative correlation between this terms and the industrial SO_2 emission density. Secondly, the sector-specific emission efficiency indicators can also directly involve with the proportion of different sectors in total industry to form the composition effect term $\sum_j(\frac{Y_{j,it}}{Y_{it}}\times e_{j,it})$. If at period t, the emission intensity of different sectors stay at their original level $e_{j,it-1}$, but the proportion of the polluting sectors, whose emission intensity is higher than provincial average level ($e_{j,it-1}>1$), increases in total industrial economy, we will obtain a new composition effect term at period t as $\sum_j(\frac{Y_{j,it}}{Y_{it}}\times e_{j,it-1})$, which will be larger than $\sum_j(\frac{Y_{j,it-1}}{Y_{it-1}}\times e_{j,it-1})$. This actually gives us a way to present composition-related emission increase.[9]

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[9] One point need to be indicate is that equation (3.8) is actually an identity equation, therefore the term of composition effect $\sum_j(\frac{Y_{j,it}}{Y_{it}}\times e_{j,it})=1$ in each period. To derive its contribution in total emission or emission density, here we actually use comparative static analysis—all the reasoning is actually based on the hypothesis that "all else equal"—all else equal, especially $e_{j,it}=e_{j,it-1}$, if the ratio of the relatively more polluting industrial sectors in total industrial economy increases, we have $\sum_j(\frac{Y_{j,it}}{Y_{it}}\times e_{j,it})=\sum_j(\frac{Y_{j,it}}{Y_{it}}\times e_{j,it-1})>\sum_j(\frac{Y_{j,it-1}}{Y_{it-1}}\times e_{j,it-1})$, therefore $\sum_j(\frac{Y_{j,it}}{Y_{it}}\times e_{j,it-1})>1$. This actually reflects the increase of total emission purely caused by structural changes.

(2) Relationship between Industrial SO_2 emission intensity and income: can we use per capita GDP to extrapolate technical effect?

To transform the decomposition function (6) into an estimable model, however, we face one difficulty. Although both scale and composition effects can be directly measured by economic statistic indicators in estimation function, for technical effect, we can not directly use provincial-level average industrial SO_2 emission intensity as measurement due to the potential endogeneity.[10] We therefore need to find an economic indicator closely related to technical effect but not involving industrial SO_2 emission in its measurement.

Among the previous empirical structural analysis on pollution determination, Selden and Song (1994) and Panayotou (1997) used per capita GDP as extrapolation for technical effect. Whether per capita GDP can also be served as a good approximate for technical effect in China's case? We firstly check the direct relationship between per capita GDP and provincial level average industrial SO_2 emission intensity. The estimation results are in reported table 7. To distinguish potential coefficient difference between the 3 big cities and the 26 provinces, as in section 3, the estimates is also composed of four parts.

<Please insert Table 7 about here>

<Please insert Figure 4 about here>

Figure 4 gives the corresponding graphical demonstrations for the estimated relationships. In all the four estimations, a common decreasing tendency in industrial SO_2 intensity with respect to income growth can be easily found. Although this relationship shows slight fluctuations at the border income level of some samples, in a general sense, we believe per capita income growth leads negative correlation with respect to industrial SO_2 emission intensity, therefore can be served as a suitable extrapolation for pollution-abatement technology progress tendency. This finding reminds us the similar conclusion of Hettige et al (2000, p460) and confirms that of Selden and Song (1995), Panayotou (1997) and Cole and Elliott (2003).

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[10] Since the industrial SO_2 emission, under this circumstance, will appear in both sides of estimation equation.

(3) The structural estimation function

The estimation in last sub-section built up the relationship between emission intensity $\frac{SO_{2,it}}{Y_{it}}$ and GDPPC. Therefore we can directly replace average emission intensity by a function of GDPPC$_{i,}$. So we have

$$\frac{SO_{2,it}}{area_i}=\underbrace{\frac{Y_{it}}{area_i}}_{scale}\times\underbrace{\sum_j\left(\frac{Y_{j,it}}{Y_{it}}\times e_{j,it}\right)}_{Composition}\times\underbrace{f(GDPPC_i)}_{Technique} \qquad (7)$$

Different from EKC hypothesis, in equation (7) per capita GDP is only one pollution-reduction factor for SO_2 emission density, which acts collectively with scale enlargement and composition transformation to finally determine the emission results, but not the solo factor that leads pollution evolution to form the inverted U form curve.

Based on the equation (7), we can obtain the final estimation function used in this chapter to investigate the structural determination of emission.

$$SO_{2it}=\alpha_i+\eta_t+\beta GDPPC_{it}+\gamma Scale_{it}+\theta Composition_{it}+\eta popden_{it}+Z_{jt}'\varphi+\rho t+\varepsilon_{jt} \qquad (8)$$

Besides using *GDPPC* and its polynomials to measure the technical effect, we use provincial total industrial GDP divided by the surface of the same province to measure the scale effect ($Scale_{it}$). We expect a positive coefficient for it. Cole and Elliott (2003) have used emission per capita as the dependant variable in their investigation for the structural determinants of EKC. However, this obliged them to use per capita GDP to capture both the technical and scale effect. Compared to their paper, the advantages for us to use ***industrial*** SO_2 emission ***density*** as dependant variable are actually two folds. On one hand, by only concentrating on SO_2 emission from industrial production, the scale effect can be clearly distinguished from technical effect since the former is measured by total ***industrial*** GDP and the latter is measured per capita GDP. On the other hand, using the ***density*** of industrial SO_2 emission as dependant variable also helps us to reduce the potential correlation between total industrial GDP and per capita GDP, since the former is now deflated by the geographical surface of the province and the latter by population size.

The original construction of composition effect in equation (8) requires possessing the detailed sector-specific emission intensity and value added data. However, only sector-level value added data are available in Chinese industrial statistics. We therefore need another approximate for composition effect for our estimation. Considering this structural model is very similar to that proposed by Antweiler et al (ACT, 2001), we decide to follow their example and use capital abundance ratio $(K/L)_{it}$ to describe composition effect for each province. An implicit assumption of this composition effect extrapolation is a sector whose production procedure uses more intensively capital should has more pollution problem.[11] Therefore, a positive efficient is expected for this variable. As we will employ panel data estimator for this equation, we also permit both provincial-specific and time-specific effect in the function. For the correspondence to section 3, the estimations for emission density all include the population density terms.

4.2. Estimation results of the structural model

The estimation results based on equation (8) are reported in Table 8. For the technical effect measured by per capita income GDPPC, we keep using the spline combined function form and only gradually delete the insignificant polynomial income terms during estimation process.

<Please insert Table 8 about here>

The inclusion of the structural and scale characteristics into the determination of industrial SO_2 emission density obviously increases the whole model's explanation power; the adjusted R^2 value increases from 0.50 (see table 3) to 0.62. The more satisfactory statistic values for the auto-correlation test reveal the potential serial correlation problem in the previous EKC analyses may be caused by variable omission. The positive coefficient before scale effect confirms our expectation, a higher industrial activity density does predict a higher industrial SO_2 emission density. The significant but ***negative*** coefficient obtained for the capital abundance ratio $(K/L)_{jt}$ however is contrary to our original anticipation and the general conclusion obtained from international experience.

<Please insert figure 5 about here>

One possible explanation for this contrary-to-intuition result about the role of capital-labor ratio is that the industrial sectors employing intensively capital are not necessarily the sectors that pollute more. Figure 5 illustrates such a possibility by plotting China's 39 industrial sectors in a diagram

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[11] The same hypothesis has already been widely used in the similar analyses as Copeland and Taylor (1994,

according to their capita-abundance ratio and SO_2 emission intensity data in 2004. Clearly, the correlation between capital abundance ratio and sector SO_2 emission intensity is not the expected simple positive one, although for the sectors most intensive in labor, higher capital/labor ratio means higher emission intensity, once the capital abundance ratio attains certain level (showed by the squared and cubic model estimated according to the 39 points of observation), high capital/labor ratio might also lead emission intensity to decrease. This finding is actually echoing to Dinda et al (2000), which indicate the potential ambiguity in using capital abundance as measurement for industrial composition, since the "capital intensive sector could also be more likely to be clean technology owner".

Concerning the technical effect, the spline estimation function still reveals different results between the 26 provinces and the 3 cities. While expected negative correlation between GDPPC and SO_2 emission density is confirmed for the 26 provinces, that is not the case for the 3 cities. For them, the inclusion of scale and composition effect into the structural estimation function only partially decomposes the combined correlation between emission density and per capita income growth proposed by EKC hypothesis. The coefficients obtained for the income terms still predict an inverted U curve for this EKC-style relationship, but with the turning point decreasing to the range of 7900-8400 yuan according to the estimation methods. This divergence between provinces and big cities can be partially explained by their structural difference, where the industrial production in the 3 cities might be more consumption-led than that in the other 26 provinces.

For the reason of comparison, we also apply the structural determination model to the case of total industrial SO_2 emission. The estimation results are reported in table 9. Although the decomposition effect is less efficient than that for the industrial emission density case, the estimate results are relatively stable. We confirm the positive scale effect and the unexpected negative composition effect as those in emission density case. The low efficiency of decomposition can also be traced from the coefficients of technical effect—the involvement of scale and composition effect in estimation can not reveal the expected negative relationship between emission and technical effect, the new relationship between per capita GDP and total emission still shows inverted U form.

<Please insert Table 9 about here>

1997), ACT (2001) and Cole and Elliott (2003).

5. Is international trade good for China's environment?

The persistence of the inverted U form emission/income relationship in the structural model in both emission density and total emission cases warns us about the constrained decomposition efficiency of our structural model proposed in section 4. We suspect potential efficiency to come from the fact that we still omit some structural determinants in the model.

If the "Pollution Haven" hypothesis holds, international trade should also be another important emission determinant for the case of China, whose last twenty years' economic growth results largely benefited from its openness toward the external world. Compared to developed countries, China is, at the same time, rich in labor forces and less rigorous in pollution control. Following the reasoning of Copeland and Taylor (1995), we can expect, on one hand, China's natural comparative advantages orientate its specialization towards labor-intensive sectors which is often supposed to be less pollution-intensive; on the other hand, its less stringent environmental regulation also facilitates its specialization in some pollution-intensive sectors. The total effect of trade on environment should, therefore, depends on the forces contrast between the natural comparative advantage measured by the endowment situation of production factor and the comparative advantage related to its relatively less strict environmental regulation.

In this section, we employ the empirical model of ACT (1998, 2001) to check trade's impacts on China's industrial SO_2 emission. The estimation function can be illustrated by equation (9).

$$\begin{aligned} SO2_{jt} &= \alpha_j + \eta_t + \beta GDPPC_{jt} + \gamma Scale_{jt} + \theta (K/L)_{jt} + Z_{jt}'\varphi + \rho t + \varepsilon_{jt} \\ &\quad + \gamma_0 open_{jt} + \gamma_1 open_{jt} \times (K/L)_{jt} + \gamma_2 open_{jt} \times (K/L)^2_{jt} + \gamma_3 open_{jt} \times GDPPC_{jt} + \gamma_4 open_{jt} \times GDPPC^2_{jt} \end{aligned} \tag{9}$$

Indeed, this equation is an extended version of the estimation function (8) used for the investigation of the structural determinants of the industrial SO_2 emission. The five supplementary terms included to investigate the environmental impact of trade are regrouped in the second line of (9).

Besides the simple trade intensity variable ($open_{jt}$), measured by the ratio of the sum of export and import over total GDP ((X+M)/GDP), which is included to trace the potential direct impact of trade on industrial SO_2 emission,[12] we also include the multiplicative terms of trade intensity ($open_{jt}$)

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[12] The same measurement for the trade intensity has also been used in Agras and Chapman (1999) and Suri and Chapman (1998), ACT (2001) and Cole and Elliott (2003).

with the capital-labor abundance ratio $(K/L)_{jt}$ and per capital income $GDPPC_{jt}$ to capture the interaction between the factor-abundance and pollution haven motive in determination of the composition transformation in China during its trade liberalization process.[13] Following ACT (2001), we also interact the quadratic per capita income $GDPPC_{jt}^2$ and quadratic capital-labor ratio $(K/L)_{jt}^2$ into with trade intensity ratio in eq. (9). As explained in ACT (2001), this is because under the force-contrast between the comparative advantages in two different dimensions, the theory does not tell at which point further increases in the capital-abundance ratio raise pollution (via composition effect) or when increases in per capita income finally lower pollution (via composition effect). Using this flexible interactive structure, we expect the interacted quadratic capital-labor abundance ratio with trade intensity to imply an emission-increasing impact of trade for high capital/labor ratio but an opposite effect for lower ratios. This corresponds to the situation that, regardless of the other characteristics of China provinces, if its capital-labor abundance ratio is sufficiently lower with respect to that of its trade-partners, it must export less polluting good. Alternatively, if its capital/labor ratio is not enough lower, it might have more chance to export polluting good given its more relaxing environmental regulations. Similarly, we expect the interacted quadratic per capita income to imply pollution-reduction impact of trade when provincial level income is relatively high but pollution-increasing impact when income is relatively low. This actually corresponds to the fact that, for a province, if its income per capita is sufficiently low, it may import polluting goods even its factor endowment comparative advantages are in labor-intensive sectors. Inversely, if its income is not so low, it may keep producing in labor-intensive sectors which are generally less polluting.

The reasons that we simply use provincial-level *absolute* capital-labor abundance ratio and provincial-level *absolute* per capita income in the trade-related multiplicative terms instead of the relative K/L and *relative* per capita income with respect to the sample average K/L and per capita income as ACT (2001) and Cole and Elliott (2003) is due to the consideration that we are interested in international trade of each Chinese province with all the other *foreign countries*. Therefore, for each province, it is the differences between its K/L and per capita income and those of the *world average*

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[13] To use GDPPC to indicate "pollution haven" comparative advantage is based on the generally assumed negative relationship between income and environmental regulation stringency. Therefore we believe a lower per capita income generally means higher probability to be a "pollution haven".

(China excluded) that decided their comparative advantages. However, since this world average is actually the same for all the provinces each year, including them will only change the scale of the coefficients of the multiplicative terms. Therefore in the estimation results reported in tables 10 and 11, we do not make this arrangement. The only interest to make this arrangement is when we consider the fact of China's relatively faster economic growth and capital accumulation rate, which may reduce the gaps between world average (China excluded) and Chinese provinces in both capital-abundance ratio and per capita income in time. But considering our estimation covers only 12 years, we do not believe this arrangement can make very difference in the estimation results.[14]

We run the estimation for both the industrial SO_2 emission density (c.f. Table 10) and total industrial SO_2 emission (c.f. Table 11), with the former includes population density term in estimation.

<Please insert Table 10 about here>

<Please insert Table 11 about here>

Let's first look at the results for the emission density. In all the columns, the inclusion of trade intensity variables in estimation does not affect the good coherence of the estimated coefficients of the three basic structural determinants of emission. Scale effect keeps its around-1 positive coefficient. While the capital-labour abundance ratio, as an approximating measure of composition effect, continues to have the counter-assumption significantly negative coefficients.

Model (1) only includes the direct determinant role of openness. The estimation results of full model illustrated by equation (9) are reported in the following columns. Keeping using spline model to distinguish the difference between provinces and big cities in model (2), we fail to obtain significant coefficients for all the openness-related terms. However, the significance of the coefficients in the spline structure shows obvious decrease when the trade-related terms are included (c.f. table 8 and 9). At the same time, the five trade-related terms show a collective significant F-test with a value of 4.7 for fixed effect (FE) estimation and 10.91 for Arellano-Bond (AB) dynamic GMM estimation. We suspect the existence of the multi-colinearity between the trade-related terms and the spline structure for technique effect. Therefore in model (3), we remove spline structure for the technique effect in estimation. The result shows that, with total explicative power of the model keeps unchanged, all the

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[14] The estimation results with this arrangement are reported in the appendix. As we expected, the inclusion of the

trade-relative terms become significant after the spline structure of the technique effect is removed. We regard this as an implication that trade characteristic of the provincial economy helps to accomplish the structural decomposition of EKC that we discussed in last section. After the inclusion of the five trade-related terms, we finally succeed in obtaining a general negative coefficient for per capita GDP, which measures the pure technique effect.

Trade openness, once collectively included with the other trade-related multiplicative terms, seems to have a significant pollution reduction impact. This actually corresponds to the findings of ACT (2001) and Cole and Elliott (2003) based on international experience. The estimation results for the interactive terms between trade and comparative advantage characteristics also confirms the theoretical expectation of ACT (2001), with the exception of the non-significant trade-$(K/L)^2$ multiplicative term.[15] For a province, if its K/L ratio stays lower than 890 000 Yuan/person according to FE estimation or 416 667 Yuan/person in Arellano-Bond estimator, its SO_2 emission will fall with trade liberalization. While for a province whose per capita GDP is lower than 8000 Yuan according to fixed effect estimation or 11 000 Yuan according to GMM estimation, increase in trade openness will be accompanied by industrial SO_2 emission density growth, since their comparative advantage in dirty production deepens.

Although the coefficients are relatively less significant, the estimation results for the total industrial SO_2 emission reported in Table 11 are coherent to those for emission density. As in the emission density case, the inclusion of trade intensity does not affect the stability of the coefficients for scale, composition and technique effect. The simple trade intensity term is also proven to be an emission-reducing factor. Moreover, we also observe similar force-contrast patterns between the factor-endowment-ased comparative advantage and pollution haven hypothesis. The high coherence between the results obtained for different pollution measurements actually reveals the good stability of the structural model proposed by ACT (2001).

Figure 6 reports the combination situation of the K/L ratio and per capita GDP for the 29 Chinese provinces in year 2003. The horizontal and vertical lines denoted as FE and AB delimitate the

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relative terms of K/L and income does not change the principal estimation results.

[15] This exception might be able to explained by the fact that the capital/labor ratio of the most Chinese provinces are generally low.

K/L-per capita GDP diagram into four zones, which represents the four possible combination situations between the factor-endowment comparative advantage and pollution haven motive. Clearly, all the 29 Chinese provinces actually possess obvious comparative advantages in less polluting labor-intensive industries.[16] For most of them, their relatively low income level also endows them some advantages in polluting industries. Only the three cities according to the Arellano-Bond estimation or the eight richest provinces and cities (Shanghai, Beijing, Tianjin, Guangdong, Zhejiang, Jiangsu, Fujian, Shandong and Liaoning) according to FE estimation have surpassed the phases of the force-contrast between the factor-based and pollution-haven-based comparative advantage.

<Please insert Figure 6 about here>

The illustration of the combination between the endowment-based and the “pollution haven”-based comparative advantage in Figure 6, however, can not give us precise idea about the role actually played by trade in each province. In fact, the final result of force-contrast between these two comparative advantages should depend on the exact level of per capita income and factor endowment situation in each province. (ACT, 2001 and Cole and Elliott, 2003) To resolve this problem, we need to calculate the elasticity of emission with respect to trade intensity. We also calculate the elasticity of emission with respect to its three structural determinants.[17] Given the limited space, we only report the elasticity on national-level for both industrial SO_2 emission density and total emission in Table 12. The magnitude of the elasticity seems to be reasonable and shows good coherence with the decomposition results. For the same emission determinant, the difference in estimation method does not affect the direction of the elasticity, although fixed effect estimator supplies obviously more significant elasticity results. For both emission indicators, we find positive and significant elasticity for scale effect and negative and significant one for composition effect. Concerning the elasticity of technique effect, its magnitude in both emission cases seems to be particularly big, which implies the high efficiency of China’s pollution abatement activities. The only divergence in the elasticity results between emission density and total emission cases is in the aspect of trade intensity. Although trade intensity seems to be a negative factor for emission density variation, we find positive trade elasticity

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[16] This is also the reason why we fail to obtain a significant coefficient for the interacted trade-$(K/L)^2$ term.

[17] The elasticity calculation is based on the Delta method and the estimation result of Model (4) in Table 10 and Model (5) in Table 11.

for total industrial SO_2 emission. However, the value of these trade elasticity, similar to the findings in ACT (2001), "no matter positive or negative", are all very close to zero. This actually indicates the marginal influence of trade on emission variations.

<Please insert Table 12 about here>

To deepen our understanding on the role of trade on SO_2 emission, we plot in Figure 7.a and 7.b the potential correlation of the provincial specific trade elasticity with capital/labor ratio and per capita GDP. According to the analysis of ACT (2001), under free trade regime, the hypothesis of "pollution haven" suggests the poorer province have higher propensity to specialize in polluting industrial. However, Figure 7.a does not reveal the expected negative correlation between trade elasticity and per capita income. Similar, although the traditional comparative advantage theory suggests the provinces having higher capital stock to specialize in sectors intensive in capital and therefore to have more emission, in Figure 7.b, we only observe a decreasing distribution of trade elasticity with respect to capital/labor ratio.[18]

<Please insert Figure 7.a and 7.b about here>

Another surprise that we can observe from Figure 7.a and 7.b is that, for most of the provinces, their trade elasticity stays positive, even for the riches provinces (cities) as Shanghai and Tianjin which are located in the Zone B of Figure 6, where their endowment-based comparative advantages in cleaner industries is reinforced by their disadvantage as "pollution haven". Only the provinces as Xinjiang, Hainan, Qinghai, Yunnan and Neimenggu, which actually appear in the Zone A of figure 6, show negative trade elasticity.

The seemingly-contradictory results between Figure 6 and 7 reveals to certain sense the incapacity of our elasticity analysis in illustrating how the capital/labor ratio and per capita GDP can jointly determinate the role of international trade in emission. In fact, when we calculate the trade elasticity for emission, we are always based on the "all else equal" hypothesis. Therefore, describing the simple correlation between trade elasticity and one structural emission determinant always ignores the potential impact of the others.

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[18] These ambiguous relationships between trade elasticity for emission with respect to income level and capital abundance ratio, however, is very similar to that found in ACT (2001).

To better clarify the relationship between industrial SO_2 emission and international trade; we calculate the derivative of emission with respect to international trade from the estimation result of Model (4) of Table 10 and Model (5) of Table 11. Thus, we obtain a trade derivative whose magnitude at each period depending directly on the actual values of GDPPC and K/L ratio. Based on this derivative, we trace in Figure 8 the curve that illustrates all the possible combinations of GDPPC and K/L ratio assuring the derivative of emission with respect to trade to have a value of zero. The upper-panel of Figure 8 describes the curve for industrial SO_2 emission density, the lower-panel give the same curve for total industrial SO_2 emission. For these two emission indicators, the combinations between per capita GDP and capital/labor ratio that assure the trade derivative equal to zero are both in an inverted U form, except the inverted U curve for emission density are relative smaller than that for total emission. These curves divide the diagram into two parts. For the provinces situated above the delimitating curve, increase of trade intensity leads the emission indicator to decrease, for those situated below the curve, reinforcement of trade intensity will cause emission indicator to rise.

<Please insert Figure 8 about here>

Given the actual situation of the GDPPC-K/L combination, Figure 8 illustrates that most of Chinese provinces still face positive emission derivative with respect to trade intensity (especially for the density case). To realize an environment-friendly openness process—this means to move towards the outside of inverted U curve, economic growth process in these provinces needs to be accompanied with faster capital accumulation. This is particularly true for most of the provinces locating along the increasing part of the curve. This conclusion reminds us the specific finding for China's case that the capital/labor ratio is probably a measurement of technical capacity. Although heavy industries generally use more intensively capital in their production process than the light industries, for the enterprises belonging to the same industry, the augmentation of capital/labor ratio probably signifies more reinforcement of production efficiency and therefore pollution reductions.

6. Conclusion

In this paper, based on panel data on Chinese provincial level from 1992-2003, we first test the existence of an EKC in the case of industrial SO_2 emission density. Following, we decompose the economical determinants of SO_2 emission into: scale, composition and technical effects. In the third step, we study the direct and indirect role of international trade intensity ((X+M)/GDP).

The estimated China-specific EKC curve predicts the turning point for the dichotomy between economic growth and per capita industrial SO_2 emission to appear when China's per capita GDP attains 9000 yuan, about 2750 USD, which is actually much lower than that found from the international experiences (4400-7100 USD). However, given China's fast population expansion speed, the decreasing trends in the per capita emission will not bring an immediate reduction in total industrial SO_2 emission. At present, our EKC estimates for both industrial SO_2 density and total industrial SO_2 emission predict a quite gloomy future for the sustainability of China's economic growth.

In structural model, per capita GDP, an extrapolation measure for the technique effect, becomes one of the emission determinants besides the scale and composition effects. Although the reduced-form estimation function obtained from original EKC hypothesis suggests an ever-increasing correlation between economic growth and industrial SO_2 emission density, the estimation results based on structural model of emission determination shows that income growth should be considered as a pollution-reducing factor given its significantly negative correlation with industrial SO_2 emission intensity. The estimation results from the structural model confirm this finding, especially for the 26 Chinese provinces.

However, estimation results of this step also reveal the potential efficiency defection of our original structural model, since we can only partially decompose the negative technique effect for the emission density case of the 3 big cities and for the total industrial SO_2 emission case. We therefore deepen our structural model estimation by including another important emission determination factor—trade openness. This part of analyses is based on the same estimation function of ACT (2001), which is actually an extended model further including trade-related terms. Our principal results confirm the theoretical analysis of ACT (2001). We find that for the role of trade, besides a significantly negative direct impact, its indirect impacts on emission also go through the composition effect. This indirect impact actually depends on the current capital/labour abundance ratio and the actual income level of a province. Although we traced some supportive evidence for the "pollution haven" hypothesis, given China's extremely rich endowment in labor force, trade liberalisation only plays a marginal role (via composition effect). However, when the attention is paid to the role of trade in each province, we realize its sign and magnitude at a given time also depends on the value of the other emission determinants. For most provinces, the currently existing negative environmental impact of trade is actually due to their relatively low capital/labour abundance ratio with respect to their actual income level. To change this situation, their economic growth should be accompanied by faster capital accumulation, which further helps to update production and abatement technology and therefore reduces pollution. This conclusion, together with the estimation results of the second step, indicates the ambiguity of the capital abundance ratio as the measurement for composition effect, which, at least for the case of China, may also measure to some degree the technical efficiency of production/emission.

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Table 1. Statistic description on the data used in EKC analysis

Variable	Variable definition	Unit	Obs.	Mean	Std. Dev.	Min	Max
so2pc	Annual industrial emission per capita	kg/person	348	13.225	8.173	2.331	58.914
so2den	Annual industrial SO_2 emission density	g/m^2	348	5.608	10.629	0.021	69.836
so2int	Annual industrial SO_2 emission intensity	g/yuan	348	13.061	13.911	1.598	137.816
GDPPC	Per capita real GDP	Yuan/person	348	4145.761	2932.655	913.6758	19053.71
K/L	Capital Abundance per labour	Yuan/person	348	62477.85	58781.88	4883.607	302040.8
Scale	Industrial GDP density	Yuan/m^2	348	1.300	3.661	0.003	32.254
Open	Trade intensity ((X+M)/GDP)	Percent	348	28.132	33.657	4.006	192.843
Popden	Population density	Persons/km^2	348	360.742	431.866	5.917	2759.878

(1) All the variables measured in value are converted into the yuan of 1990 constant price.

(2) The total industrial capital stock is calculated by permanent inventory method by using real value of fixed investment data (on the constant price of 1990) of each province in each year deflated by the corresponding fixed investment price index. More details avout the permanent inventory method are in Wu (1999).

(3) The export and import data are on the whole provincial economy level instead of the provincial industrial economy level. As we are actually interested in the impact of international trade on emission, we do not think it is necessary to use the industrial economy-level trade data.

(4) Data sources: China Statistic Yearbook (1985-2004).

Table 2. EKC Industrial SO2 emission per capita

	Simple Model: Squared		AR(1,0): Squared		Simple Model: Cubic		AD(1,0): Cubic	
	RE	**FE**	**RE**	**FE**	**RE**	**FE**	**RE**	**FE**
GDPPC	2.090	2.159	1.339	1.523	3.573	4.529	4.199	5.699
(1/1000)	(4.04)***	(4.49)***	(2.72)***	(2.89)***	(3.13)***	(3.50)***	(4.01)***	(3.51)***
GDPPC^2	-0.117	-0.122	-0.075	-0.083	-0.270	-0.349	-0.349	-0.463
(1/1000)^2	(5.41)***	(6.41)***	(3.48)***	(3.52)***	(2.52)**	(2.99)***	(3.73)***	(3.28)***
GDPPC^3					0.005	0.007	0.008	0.012
(1/1000)^3					(1.45)°	(2.04)**	(2.84)***	(2.74)***
so$_2$pc$_{t-1}$			0.670	0.621			0.500	0.472
			(4.34)***	(4.09)***			(3.72)***	(3.75)***
trend	-0.090	-0.095	0.180	0.145	-0.248	-0.379	-0.143	-0.366
	(0.67)	(0.48)	(1.49)°	(1.24)	(1.44)°	(1.59)°	(0.91)	(1.99)**
Constant	9.556		0.329		7.254		-2.043	
	(5.38)***		(0.14)		(3.04)***		(0.72)	
R-squared	0.0059	0.1716	0.1028	0.3029	0.0076	0.1810	0.0601	0.3156
F test		4.88		9.26		4.82		9.09
AR(1)	1.6996	1.4437	1.5158	1.5297	1.7017	1.4448	1.5410	1.5475
Breuch-pagan	1269.76 (0.000)		1290.93 (0.000)		1241.11 (0.000)		1265.77 (0.000)	
Hausman	63.80 (0.000)		1.50 (1.000)		1.45 (1.000)		6.61 (0.949)	
Province Turning point (Peak)	8931.62 (1057)	8848.36 (883)	8926.67 (1338)	9174.70 (954)	8803.51 (12894)	9081.50 (10926)	8909.64 (9307)	9618.82 (13117)
Province Turning point (Trough)	--	--	--	--	26634.08 (37377)	22825.79 (26706)	18542.61 (18932)	17084.25 (22866)
Observations	348	348	319	319	348	348	319	319
Provinces	29	29	29	29	29	29	29	29

Note:

- Absolute value of z statistics in parentheses, ° significant at 15%, * significant 10%, ** significant 5%, *** significant 1%.
- The standard error of the turning point is indicated in the parenthesis below. They are calculated by Delta method. See Greene (2002, pp. 913-914) for details.
- FE means fixed effect, and RE means random effect.
- AR (1) is the Durbin-Watson statistics for first order serial correlation. Breush-Pagan is used to test the group specific effect. Hausman test is used to compare the efficiency between fixed and random panel data estimator.
- The instrumentation method employed in AD (1,0) model for SO$_2$PC$_{t-1}$ is developed by Balestra-Nerlove (1966) for the “fixed effect of the dynamic linear penal model”.

Table 3. Nexus between industrial SO_2 emission density and per capita GDP

	Whole Sample			26 provinces		3 cities	Combined model	
	FE	**FE**	**FE**	**FE**	**AB**	**FE**	**FE**	**AB**
GDPPC (1/1000)	0.935	0.420	0.391	2.305	2.372	4.055	1.085	2.310
	(1.50)°	(1.01)	(2.45)**	(4.63)***	(2.30)**	(2.05)*	(1.38)	(2.14)**
$GDPPC^2$ $(1/1000)^2$	-0.051	-0.004		-0.333	-0.309	-0.075	-0.123	-0.198
	(0.78)	(0.16)		(4.71)***	(2.35)**	(1.26)	(1.08)	(2.18)**
$GDPPC^3$ $(1/1000)^3$	0.002			0.017	0.015		0.007	0.008
	(0.62)			(4.85)***	(2.52)**		(1.18)	(2.58)***
City×GDPPC							2.055	2.006
							(1.17)	(3.65)***
City×$GDPPC^2$							-0.133	-0.103
							(1.27)	(3.22)***
$SO_{2d}den_{t-1}$	0.057	0.087	0.036	0.172	0.116		0.055	-0.019
	(0.28)	(0.40)	(0.30)	(1.64)°	(0.72)		(0.34)	(0.14)
popden	-0.022	-0.021	-0.023	0.023	0.018	-0.019	-0.022	-0.024
	(2.62)***	(2.50)**	(5.90)***	(5.68)***	(2.82)***	(3.22)***	(2.87)***	(5.92)***
trend	-0.031	0.030	0.033	-0.158	-0.175	-1.743	-0.011	-0.207
	(0.41)	(0.37)	(0.61)	(3.46)***	(1.79)	(2.11)**	(0.17)	(1.21)
R-squared	0.5420	0.5420	0.5403	0.5011		0.8338	0.5522	
F test	21.70	23.33	25.05	16.40		6.81	19.80	
AR(1)	1.9831	1.9907	1.9768	1.4745	-2.96 (0.0031)	2.5005	2.0349	-1.75 (0.0803)
AR(2)					1.36 (0.1745)			0.84 (0.4011)
Breuch-pagan	765.33 (0.000)	854.17 (0.000)	943.16 (0.000)	1163.54 (0.000)		13.41 (0.0003)	574.83 (0.000)	
Hausman	138.11 (0.000)	152.86 (0.000)	400.86 (0.000)	15.37 (0.000)		--	180.36 (0.000)	
Sagan					18.24 (1.000)			21.00 (1.000)
Province Turning point (Peak)	--	52500	--	--	--		--	--
Province Turning point (Trough)	--	--	--	--	--		--	--
City Turning point (Peak)	--	52500	--			27033.33	--	--
Observations	319	319	319	286	260	36	319	290
Province	29	29	29	26	26	3	29	29

- Absolute value of z statistics in parentheses, ° significant at 15%, * significant 10%, ** significant 5%, *** significant 1%.
- The standard error of the turning point is indicated in the parenthesis below.
- In the spline model, we distinguish the coefficient of income terms between cities and province. The income coefficients for province are those before the simple GDPPC terms. But to obtain coefficients of income term for 3 cities, we need to add the GDPPC and GDPPC×city together.
- AB means Arellano-Bond (1991) dynamic GMM estimator for fixed-effect panel data. In this estimation method, the statistic value of AR(2) denotes the second order serial correlation.

Table 4. Provincial per capita GDP, geographical area statistics and emission density

Province	GDPPC (Yuan, 1990 price)	Surface (km^2)	SO2 density (kg/km^2)
SHANGAI	19054	6200	50.909
TIANJIN	13242	11302	20.366
BEIJING	13133	16814	6.781
ZHEJIANG	11000	101792	6.948
GUANGDONG	10799	177806	5.929
JIANGSU	9944	102578	11.488
FUJIAN	8482	121471	2.413
SHANDONG	8436	153126	10.058
LIAONING	8303	145803	4.371
HEILONGJIANG	5587	473414	0.603
JILIN	5572	188000	0.630
HUBEI	5482	191389	2.836
HAINAN	5405	33977	0.661
HEBEI	5394	187964	6.357
INNER MONGOLIA	4889	1204642	0.945
XINJIANG	4647	1635210	0.137
SHANXI	4376	156120	6.619
ANHUI	4196	139510	2.906
JIANGXI	4152	166758	2.349
QINGHAI	4052	779141	0.065
HUNAN	3947	210151	3.195
HENAN	3799	166867	5.404
GUANGXI	3637	230512	3.603
SICHUAN	3483	566553	2.936
SHAANXI	3466	204996	3.176
NINGXIA	3463	66027	3.913
YUNNAN	3139	392215	0.971
GANSU	3028	455099	0.969
GUIZHOU	2016	176253	3.235

Table 5. Correlation between emission densities, per capita emission and population density

	so2den	so2pc	popden
so2den	1.0000		
so2pc	0.4083	1.0000	
popden	0.9374	0.2379	1.0000

Table 6. Total industrial SO_2 emission EKC reduced model

	Whole sample		26 provinces		3 cities		Combined model	
	RE	FE	RE	FE	RE	FE	RE	FE
GDPPC	91.306	101.129	335.081	334.236	77.556	158.464	353.002	347.223
(1/1000)	(2.20)**	(2.07)**	(4.03)***	(2.97)***	(1.54)°	(5.84)***	(4.53)***	(3.20)***
$GDPPC^2$	-7.024	-7.777	-49.068	-50.251	-2.989	-8.477	-51.168	-51.710
$(1/1000)^2$	(1.87)*	(1.90)*	(4.18)***	(3.43)***	(0.66)	(4.89)***	(4.64)***	(3.63)***
$GDPPC^3$	0.158	0.178	2.610	2.623	0.055	0.185	2.705	2.689
$(1/1000)^3$	(1.31)	(1.49)	(4.29)***	(3.65)***	(0.43)	(4.21)***	(4.71)***	(3.81)***
City×GDPPC							-267.903	-278.504
							(3.50)***	(3.16)***
City×$GDPPC^2$							45.878	47.510
							(4.13)***	(3.53)***
City×$GDPPC^3$							-2.592	-2.599
							(4.57)***	(3.76)***
trend	2.686	4.292	-13.391	-8.586	-32.136	-43.197	-15.349	-10.255
	(0.43)	(0.69)	(1.59)°	(0.85)	(6.52)***	(6.59)***	(1.95)*	(1.07)
SO_{2t-1}		-0.001		0.353				0.341
		(0.01)		(2.37)**				(2.45)**
Constant	290.328		31.867		-72.339		-0.305	
	(2.93)***		(0.24)		(0.44)		(0.00)	
R-squared	0.0060	0.2628	0.0386	0.3570	0.8250	0.8241	0.0821	0.3535
F test		5.54		7.95	23.74	18.38		
AR(1)	1.1586	1.0145	1.2215	1.1233	2.1826	2.2386	1.2278	1.1502
Breuch-pagan	1640.98		1409.14		104.05		1564.57	
	(0.000)		(0.000)		(0.000)		(0.000)	
Hausman	1.55		0.97				1.70	
	(1.000)		(1.000)				(1.000)	
Province Turning point (Peak)	9626	9797	--	--			--	--
	(21693)	(21166)						
Province Turning point (Trough)	20010	19330	--	--			--	--
	(44421)	(40689)						
City Turning point (Peak)	9626	9797			--	--	--	--
	(21693)	(21166)						
City Turning point (Trough)	20010	19330			--	--	--	--
	(44421)	(40689)						
Observations	348	319	312	286	36	36	348	319
Province	29	29	26	26	3	3	29	29

- Absolute value of z statistics in parentheses, ° significant at 15%, * significant 10%, ** significant 5%, *** significant 1%.
- The standard error of the turning point is indicated in the parenthesis below.
-

Table 7. Relationship between per capita GDP and Industrial SO_2 intensity

	Whole Sample		26 provinces		3 cities		Combined model	
	RE	FE	RE	FE	RE	FE	RE	FE
GDPPC (1/1000)	-12.114	-11.903	-22.812	-22.547	-1.627	-1.508	-12.466	-13.195
	(10.36)***	(6.95)***	(9.13)***	(6.54)***	(7.00)***	(11.03)***	(10.35)***	(6.72)***
GDPPC^2 (1/1000)^2	1.212	1.187	3.490	3.457	0.048	0.039	1.191	1.393
	(7.80)***	(6.00)***	(6.75)***	(5.80)***	(4.71)***	(7.14)***	(6.89)***	(5.29)***
GDPPC^3 (1/1000)^3	-0.037	-0.036	-0.170	-0.169			-0.028	-0.042
	(6.40)***	(5.33)***	(5.42)***	(5.25)***			(3.30)***	(3.47)***
City×GDPPC							1.626	-3.392
							(0.95)	(1.09)
City×GDPPC^2							-0.217	0.085
							(1.60)°	(0.45)
Constant	40.593		53.864		15.883		41.403	
	(14.02)***		(13.35)****		(13.09)***		(13.60)***	
R-squared	0.3574	0.3114	0.3694	0.3680	0.8449	0.8935	0.3619	0.3246
F test		47.63		54.92		130.03		30.19
AR(1)	1.4631	0.8541	1.5364	0.9034	1.7203	1.8035	1.4824	0.8768
Breuch-pagan	729.53 (0.000)		683.40 (0.000)		18.44 (0.000)		733.72 (0.000)	
Hausman	1.19 (0.7563)		0.93 (0.8190)				2.15 (0.8287)	
Province Turning point (P)	13901.28	13869.77	8231.33	8238.38			25251.25	15332.45
	(8384)	(9709)	(7502)	(5141)			(12520)	(11804)
Province Turning point (T)	7802.18	7853.56	5420.73	5398.82			6944.50	6856.59
	(5013)	(5978)	(4902)	(7712)			(4123)	(5489)
City Turning point (P)	13901.28	13869.77			--	--	13695.00	14315.97
	(8384)	(9709)					(31163)	(--)
City Turning point (T)	7802.18	7853.56			16947.92	19333.33	9370.18	9231.41
	(5013)	(5978)			(1424)	(1029)	(23099)	(--)
Observations	348	348	312	312	36	36	348	348
Provinces	29	29	26	26	3	3	29	29

- Absolute value of z statistics in parentheses, ° significant at 15%, * significant at 10%** significant at 5%; *** significant at 1%.
- The standard error of the turning point is indicated in the parenthesis below. The -- that appearing in the last colomn shows the non-convergency of the results due to the very low significance of the estimated coefficients.

Table 8. Structural model and decomposition results (Industrial SO_2 emission density)

Variables	FE	AB	FE	AB	FE	AB
GDPPC (1/1000)	-0.506	-1.020	-0.462	0.124	-0.160	-0.455
	(0.57)	(1.43)	(1.75)*	(0.26)	(1.23)	(1.68)*
$GDPPC^2$ $(1/1000)^2$	0.025	0.096	0.019	-0.033		
	(0.21)	(1.40)	(1.19)	(1.07)		
$GDPPC^3$ $(1/1000)^3$	-0.000	-0.006				
	(0.05)	(2.41)**				
City×GDPPC	2.469	2.465	2.528	3.462	2.331	3.869
	(1.94)*	(1.96)**	(3.14)***	(2.54)**	(2.86)***	(2.71)***
City×$GDPPC^2$	-0.150	-0.120	-0.154	-0.178	-0.138	-0.207
	(1.90)*	(1.58)°	(3.29)***	(2.32)**	(2.96)***	(2.60)***
K.L (1/10000)	-0.147	-0.154	-0.146	-0.151	-0.145	-0.154
	(6.03)***	(2.15)**	(6.22)***	(1.95)*	(6.18)***	(2.04)**
Scale	1.416	2.383	1.407	2.068	1.411	2.065
	(3.29)***	(4.57)***	(4.11)***	(3.08)***	(4.14)***	(3.05)***
Popden	-0.034	-0.049	-0.034	-0.046	-0.034	-0.046
	(5.52)***	(10.71)***	(5.53)***	(9.83)***	(5.56)***	(9.66)***
trend	0.254	0.344	0.250	0.213	0.207	0.301
	(2.79)***	(2.84)***	(5.02)***	(2.15)**	(5.75)***	(3.50)***
SO_2den_{t-1}		-0.258		-0.223		-0.218
		(3.52)***		(3.40)***		(3.40)***
R-squared	0.6167		0.6167		0.6158	
F test	25.41		26.90		28.48	
AR(1)	2.1021	-1.61 (0.1082)	2.0903	-1.60 (0.1093)	2.0776	-1.60 (0.1096)
AR(2)		0.18 (0.8610)		0.35 (0.7276)		0.38 (0.7016)
Breuch-pagan	88.78 (0.000)		101.56 (0.000)		109.09 (0.000)	
Hausman	1981.25 (0.000)		1752.54 (0.000)		1588.17 (0.000)	
Sagan		19.77 (1.000)		18.91 (1.000)		22.06 (1.000)
Observations	348	290	348	290	348	290
Provinces	29	29	29	29	29	29

- ° significant at 15%, * significant at 10%** significant at 5%; *** significant at 1%. Absolute value of z statistics in parentheses.
- The standard error of the turning point is indicated in the parenthesis below.
- FE means fixed-effect estimator for panel data. AB represents Arellano-Bond (1991) dynamic GMM estimator for fixed-effect panel data.

Table 9. Structural model and decomposition results

(Total industrial SO_2 emission)

	Structural model	
	RE	**FE**
GDPPC (1/1000)	170.706	228.012
	(2.35)**	(2.04)**
$GDPPC^2$ $(1/1000)^2$	-35.019	-37.462
	(3.34)***	(2.86)***
$GDPPC^3$ $(1/1000)^3$	1.743	1.872
	(3.14)***	(3.12)***
City×GDPPC	-154.380	-178.999
	(2.42)**	(1.96)*
City×$GDPPC^2$	34.064	34.124
	(3.39)***	(2.75)***
City×$GDPPC^3$	-1.777	-1.820
	(3.30)***	(3.12)***
K/L (1/10000)	-6.368	-3.287
	(1.66)	(0.87)
Scale	2.096	1.065
	(6.21)***	(2.27)**
trend	2.475	-1.663
	(0.32)	(0.14)
$so2_{t-1}$		0.262
		(3.40)***
Constant	227.421	-7.117
	(2.08)**	(0.04)
R-squared	0.4863	0.4300
F test		13.67
AR(1)	1.3298	1.2583
Breuch-pagan	1098.43	
	(0.000)	
Hausman	417.4	
	(0.000)	
Province Turning point (Peak)	3204 (2531)	4697 (5020)
Province Turning point (Trough)	10191 (6759)	8644 (9228)
City Turning point (Peak)	6376 (35561)	9411 (39593)
City Turning point (Trough)	--	33383 (129414)
Observations	348	319
Provinces	29	29

- ° significant at 15%, * significant at 10%** significant at 5%; *** significant at 1%. Absolute value of z statistics in parentheses.
- The standard error of the turning point is indicated in the parenthesis below.

Table 10. ACT (1998) structural model: trade-environment nexus request (29 provinces, 1992-2003)

Industrial SO$_2$ emission density	**Model (1)**		**Model (2)**		**Model (3)**		**Model (4)**	
	FE	**AB**	**FE**	**AB**	**FE**	**AB**	**FE**	**AB**
GDPPC (1/1000)	-0.165	-0.460	-0.554	-0.916	-0.491	-0.598	-0.480	-0.611
	(1.32)	(1.80)	(3.03)***	(2.93)***	(2.49)**	(1.94)*	(2.85)***	(1.98)**
City×GDPPC	2.308	3.785	2.482	3.893				
	(2.68)***	(2.39)**	(2.49)**	(1.85)*				
City×GDPPC^2	-0.136	-0.201	-0.137	-0.196				
	(2.72)***	(2.23)**	(2.30)**	(1.53)°				
K.L (1/10000)	-0.143	-0.148	-0.094	-0.089	-0.087	-0.046	-0.084	-0.035
	(6.24)***	(1.88)*	(3.15)***	(1.12)	(2.66)***	(0.52)	(3.04)***	(0.40)
Scale	1.391	1.995	1.325	2.024	1.021	1.301	1.004	1.308
	(3.67)***	(2.48)**	(3.22)***	(3.73)***	(2.75)***	(6.41)***	(3.02)***	(6.33)***
Open	0.003	0.006	-0.012	-0.016	-0.035	-0.066	-0.035	-0.067
	(0.24)	(0.44)	(0.77)	(0.70)	(1.86)*	(2.13)**	(1.89)*	(2.14)**
Open×K/L			-0.003	-0.003	-0.0016	-0.00095	-0.0014	-0.00094
			(1.47)	(1.47)	(0.80)	(0.72)	(1.92)*	(0.83)
Open×(K/L)^2			0.000013	0.000036	8.94×10^{-6}	4.32×10^{-6}		
			(0.23)	(0.53)	(0.14)	(0.13)		
Open×GDPPC			0.007	0.008	0.016	0.022	0.016	0.022
			(1.36)	(0.71)	(3.15)***	(2.68)***	(3.18)***	(2.80)***
Open×GDPPC^2			-0.0002	-0.0002	-0.001	-0.001	-0.001	-0.001
			(0.35)	(0.39)	(2.22)**	(3.53)***	(2.19)**	(3.72)***
Popden	-0.034	-0.046	-0.034	-0.045	-0.033	-0.039	-0.033	-0.039
	(5.53)***	(8.37)***	(4.88)***	(12.03)***	(4.38)***	(14.50)***	(4.66)***	(15.75)***
trend	0.207	0.300	0.261	0.366	0.228	0.215	0.224	0.214
	(5.71)***	(3.50)***	(5.08)***	(4.26)***	(4.26)***	(2.80)***	(5.56)***	(2.69)***
SO$_2$den$_{t-1}$		-0.209		-0.187		-0.095		-0.095
		(3.43)***		(3.94)***		(1.11)		(1.12)
R-squared	0.6160		0.6442		0.6147		0.6146	
F test	26.82		24.44		23.85		25.18	
AR(1)	2.0730	-1.60 (0.1091)	2.1947	-1.56 (0.1199)	2.1635	-1.56 (0.1180)	2.1594	-1.56 (0.1179)
AR(2)		0.45 (0.6488)		0.63 (0.3271)		0.35 (0.7245)		0.35 (0.7271)
Breuch-pagan	111.86		159.92		158.65		190.62	
	(0.000)		(0.000)		(0.000)		(0.000)	
Hausman	1445.61		1141.57		802.06		888.81	
	(0.000)		(0.000)		(0.000)		(0.000)	
		18.91		14.08		16.47		16.31
Sagan		(1.000)		(1.000)		(1.000)		(1.000)

Table 11. ACT (1998) structural model: trade-environment nexus request (29 provinces, 1992-2003)

Total industrial SO2 emission	**Model (1)**		**Model (2)**		**Model (3)**		**Model (4)**		**Model (5)**	
	RE	**FE, AD(1,0)**	**RE**	**FE, AD(1,0)**	**RE**	**FE, AD(1,0)**	**RE**	**FE, AD(1,0)**	**RE**	**FE, AD(1,0)**
GDPPC (1/1000)	183.588	229.828	184.733	274.854	-76.980	-54.161	-76.798	-61.667	-36.165	-39.383
	(2.49)**	(1.95)*	(2.44)**	(2.47)**	(4.27)***	(2.19)**	(4.27)***	(2.53)**	(3.08)***	(3.49)***
GDPPC^2 (1/1000)^2	-37.061	-38.933	-37.165	-44.656						
	(3.45)***	(2.77)***	(3.26)***	(3.44)***						
GDPPC^3 (1/1000)^3	1.862	1.986	1.771	2.154						
	(3.25)***	(3.08)***	(2.83)***	(3.65)***						
City×GDPPC	-149.057	-165.956	-158.326	-221.906	44.242	21.015	44.132	26.967		
	(2.39)**	(1.68)*	(2.52)**	(2.04)**	(2.98)***	(1.04)	(2.98)***	(1.34)		
City×GDPPC^2	34.517	34.059	34.389	38.683						
	(3.46)***	(2.55)**	(3.44)***	(2.93)***						
City×GDPPC^3	-1.845	-1.887	-1.724	-1.947						
	(3.39)***	(3.01)***	(3.12)***	(3.33)***						
K.L (1/10000)	-6.370	-3.222	-4.925	1.301	-7.721	-4.374	-7.489	-5.094	-11.127	-6.795
	(1.66)*	(0.84)	(1.07)	(0.30)	(1.69)*	(1.11)	(1.71)*	(1.48)	(2.62)***	(1.72)*
Scale	2.156	1.120	2.087	0.928	2.044	1.007	2.040	1.167	1.262	0.805
	(6.36)***	(2.34)**	(5.80)***	(2.00)**	(5.61)***	(1.87)*	(5.63)***	(2.18)**	(4.69)***	(2.48)**
Open	-0.801	-0.472	-1.609	-3.263	-0.511	-1.123	-0.584	-0.888	-1.074	-1.020
	(0.96)	(0.92)	(0.95)	(2.47)**	(0.42)	(1.27)	(0.50)	(0.98)	(0.92)	(1.00)
Open×K/L			-0.131	-0.031	-0.124	-0.063	-0.104	-0.125	-0.021	-0.085
			(0.93)	(0.39)	(0.91)	(0.60)	(1.24)	(1.95)*	(0.27)	(1.57)°
Open×(K/L)^2			0.001	-0.001	0.001	-0.001				
			(0.35)	(0.53)	(0.19)	(0.50)				
Open×GDPPC			0.428	0.743	0.245	0.386	0.246	0.431	0.191	0.370
			(0.91)	(2.11)**	(1.14)	(2.07)**	(1.14)	(2.37)**	(0.89)	(1.97)*
Open×GDPPC^2			-0.015	-0.032	-0.010	-0.013	-0.010	-0.014	-0.004	-0.010
			(0.51)	(1.60)°	(1.09)	(2.18)**	(1.12)	(2.36)**	(0.50)	(1.39)
trend	1.157	-0.831	0.731	-7.298	23.924	24.587	23.791	26.162	19.560	23.745
	(0.15)	(0.07)	(0.09)	(0.63)	(5.24)***	(4.68)***	(5.32)***	(5.14)***	(4.62)***	(5.59)***
so2$_{t-1}$		0.239		0.318		0.220		0.138		0.105
		(2.45)**		(4.02)***		(2.45)**		(1.58)		(1.13)
Constant	226.271	8.649	231.180	-59.524	556.442	408.893	555.921	452.017	537.461	454.552
	(2.10)**	(0.05)	(2.17)**	(0.35)	(9.74)***	(5.47)***	(9.71)***	(6.19)***	(8.94)***	(6.53)***
R-squared	0.5117	0.4217	0.4797	0.4607	0.4605	0.4004	0.4612	0.3905	0.3865	0.3783
F test		11.69		11.20		13.34		12.32		12.15
AR(1)	1.3307	1.2527	1.3500	1.3395	1.3375	1.2364	1.3375	1.2108	1.3080	1.1947
Breuch-pagan	983.99		885.21		871.80		894.56		1070.78	
	(0.000)		(0.000)		(0.000)		(0.000)		(0.000)	
Hausman	77.25		132.36		226.63		214.31		58.51	
	(0.000)		(0.000)		(0.000)		(0.000)		(0.000)	

Note: Arellano and Bond (1991) dynamic GMM estimation method is not used in these table due to their significant incapability in removing the serial correlation between the time serials of the same group.

Table 12. Scale, composition, technique and trade elasticity

	Industrial SO_2 emission density							
	Fixed effect				Arellano-Bond GMM dynamic fixed effect			
	Scale	Composition	Technique	Trade	Scale	Composition	Technique	Trade
Elasticity	0.233	-0.137	-0.146	0.049	0.470	-0.107	-0.262	0.002
Stand. Err.	0.000***	-0.001***	-0.001***	-0.001***	0.030**	0.149	0.141	0.054*
Max	0.233	-0.138	-0.147	0.048	0.499	0.039	-0.124	0.055
Min	0.232	-0.136	-0.145	0.049	0.441	-0.252	-0.400	-0.051
	Total industrial SO_2 emission							
	Fixed effect				**Random effect**			
	Scale	**Composition**	**Technique**	**Trade**	**Scale**	**Composition**	**Technique**	**Trade**
Elasticity	0.002	-0.113	-0.255	-0.010	0.003	-0.146	-0.262	-0.027
Stand. Err.	0.001***	0.075*	0.078*	0.039**	0.001***	0.092*	0.080*	0.053*
Max	0.003	-0.040	-0.178	0.028	0.005	-0.055	-0.183	0.025
Min	0.001	-0.187	-0.332	-0.049	0.002	-0.236	-0.340	-0.080

- *** indicates significance at 1% confidence level. ** indicates significance at 5% confidence level. * indicates significance at 10% confidence level.
- Elasticities are evaluated at the average of the independent variables.

Figure 1. Evolution of SO_2 emission in China during economic reform period

Data Sources: China Energy Databook 6.0 and China Statistic Yearbook (various issues)

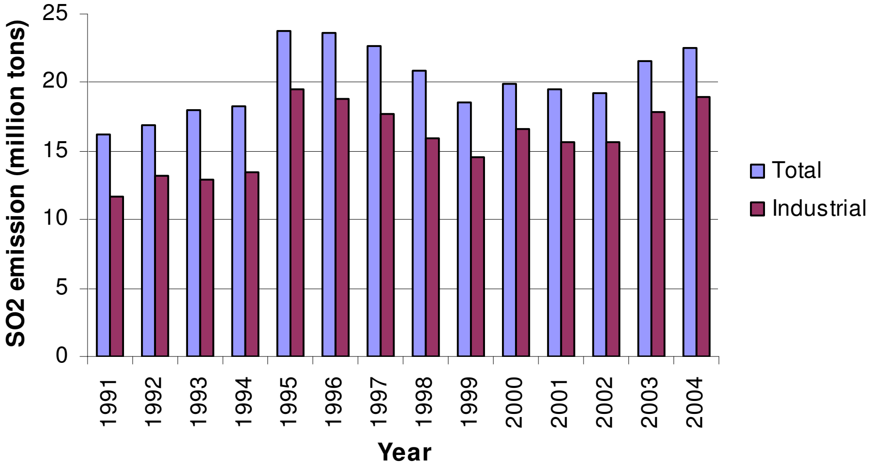


Figure 2. Estimated EKC for per capital industrial SO_2 emission and the actual location of the 29 provinces in 2003

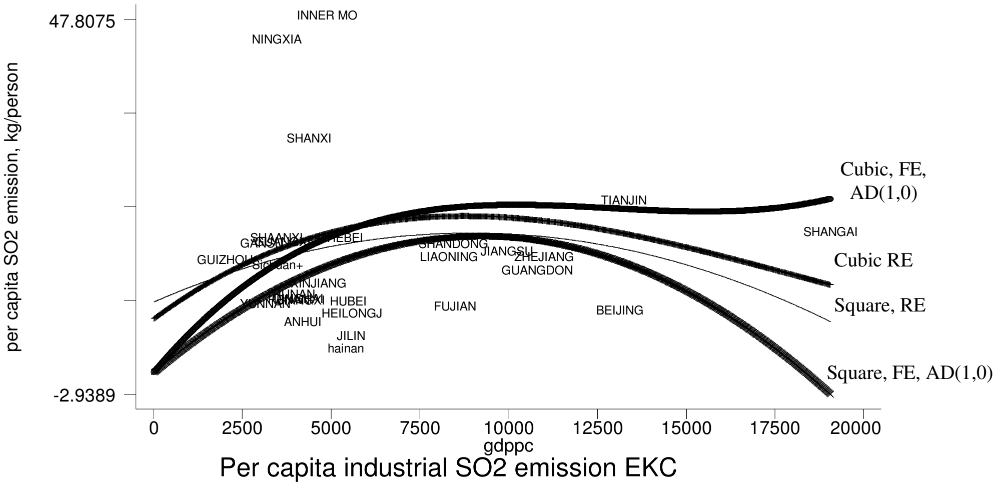
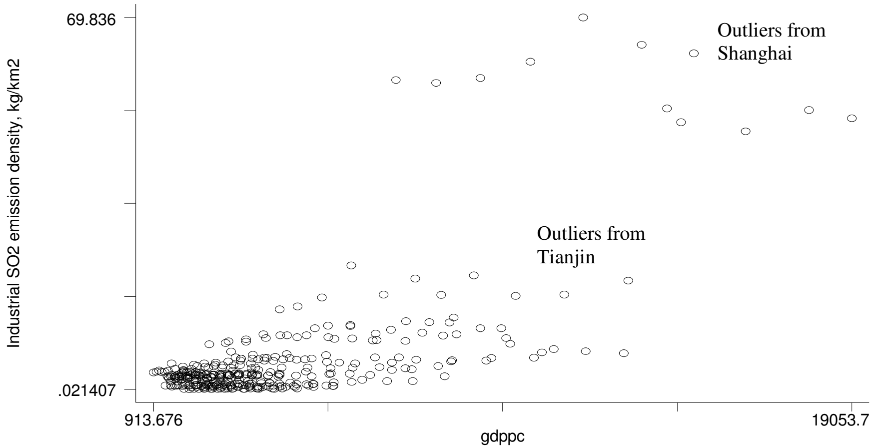
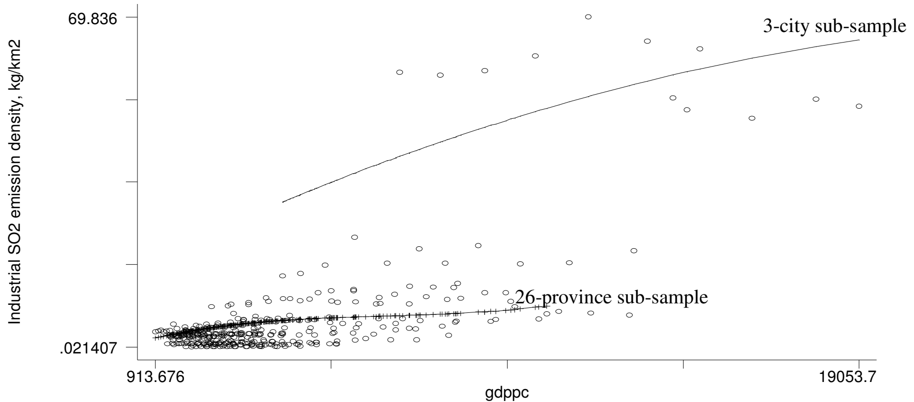


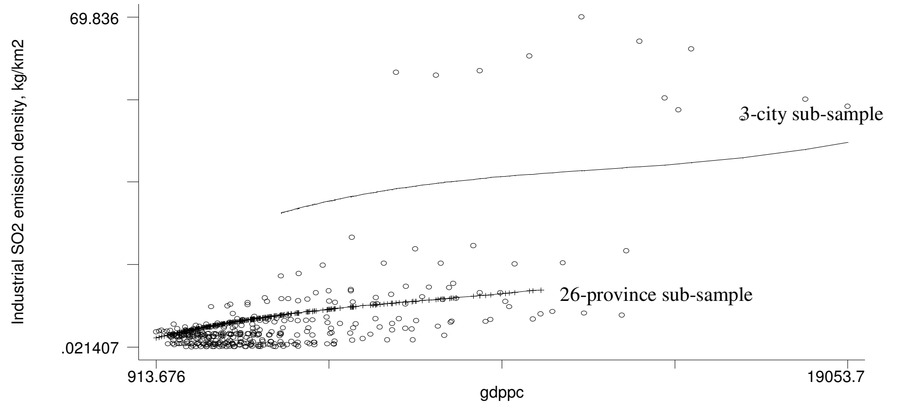
Figure 3. EKC estimations for the industrial SO_2 emission density



Panel a. Observations of the whole sample

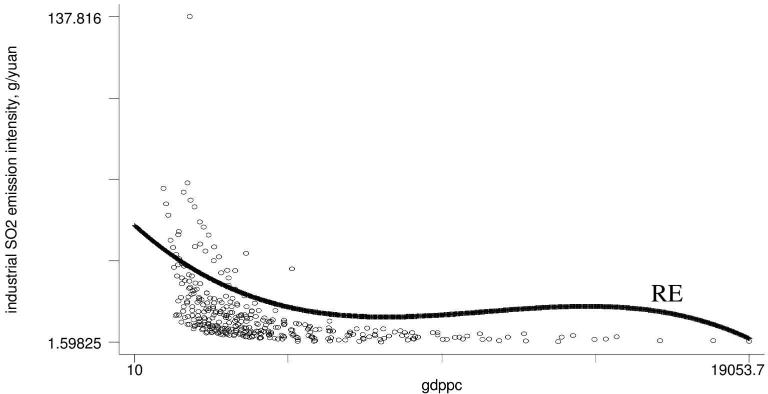


Panel b. Estimated EKC for the two sub-samples

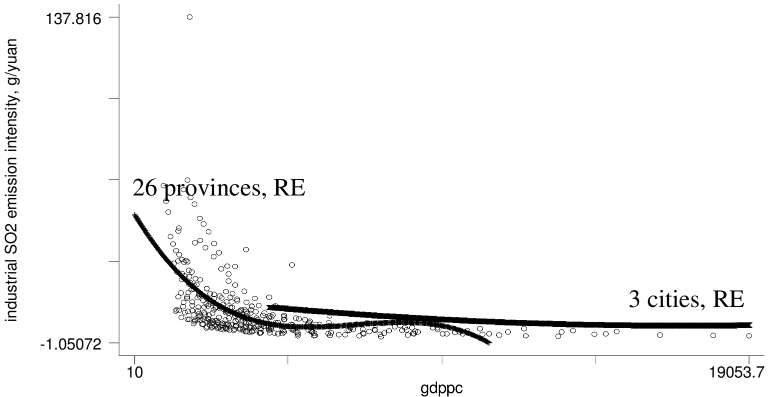


Panel c. Estimated EKC for the combined model

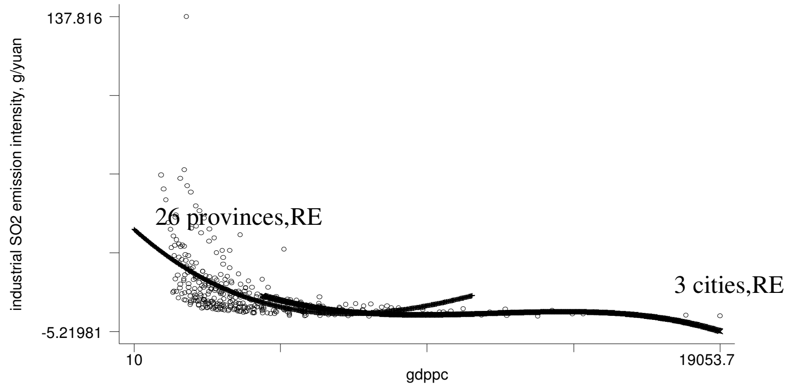
Figure 4. Correlation between GDPPC and industrial SO_2 emission intensity



whole sample model



Sub-sample model



Whole sample combined model

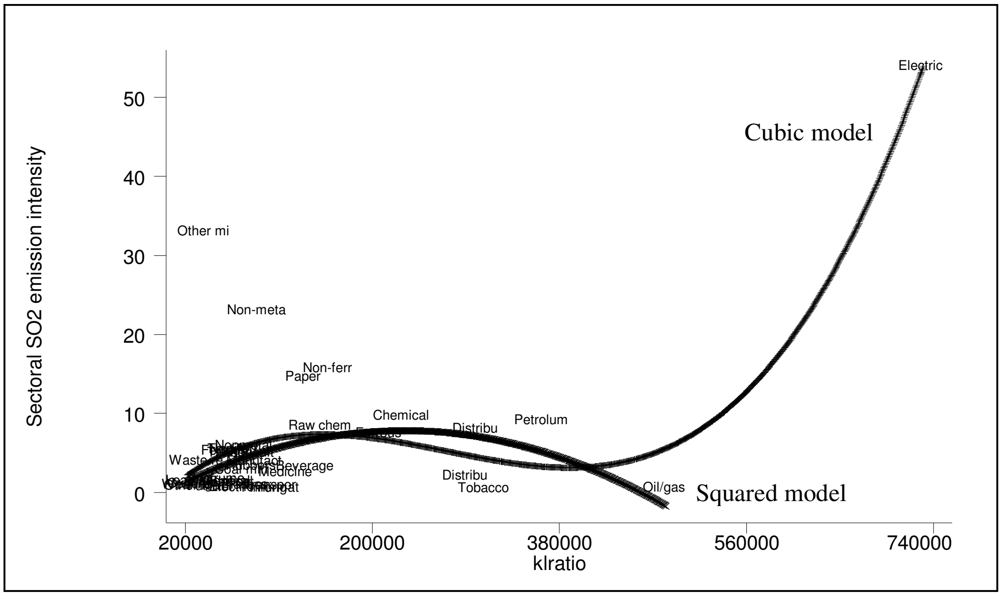
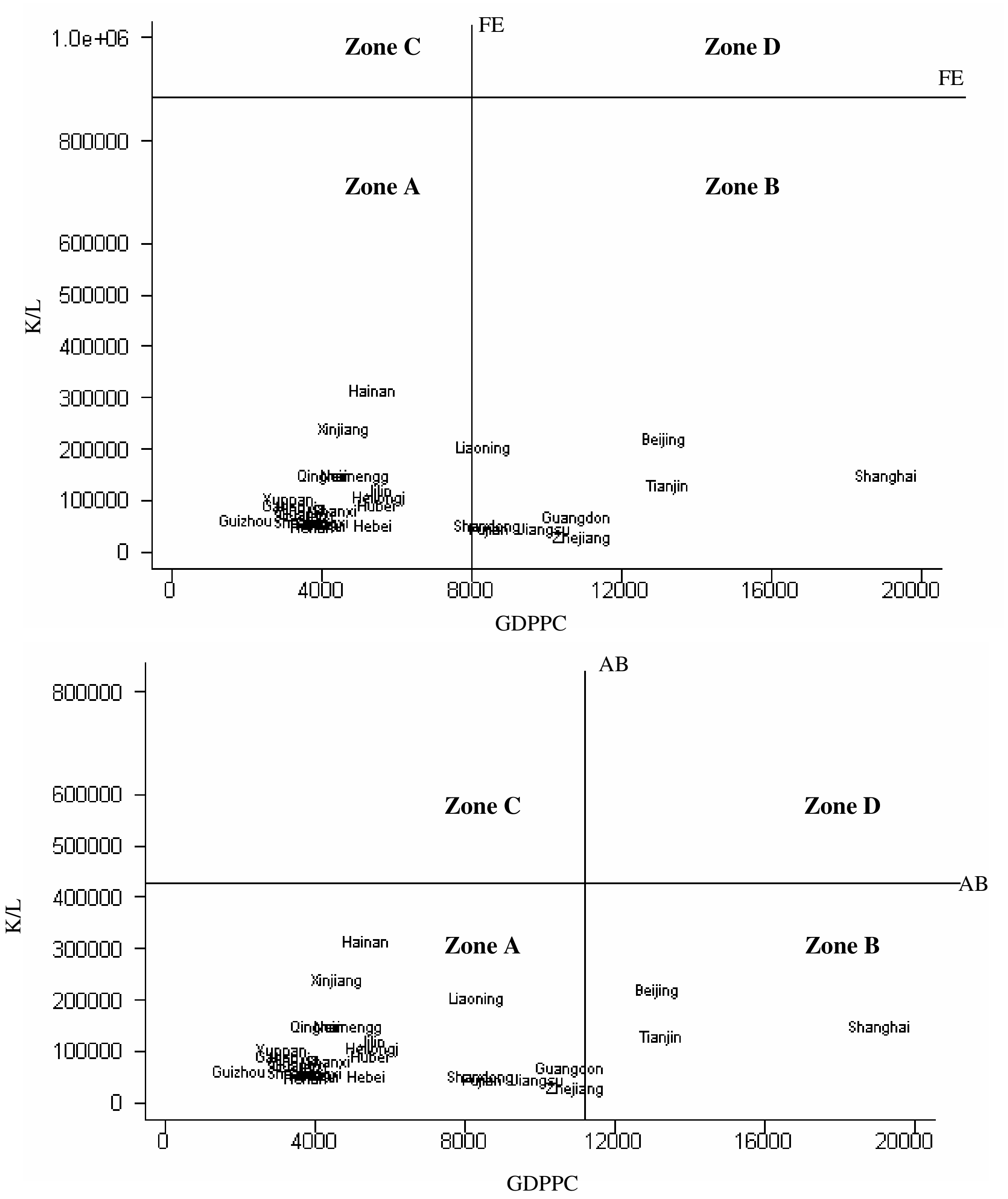


Figure 5. Correlation between sector-level capital abundance ratio and SO_2 emission intensity

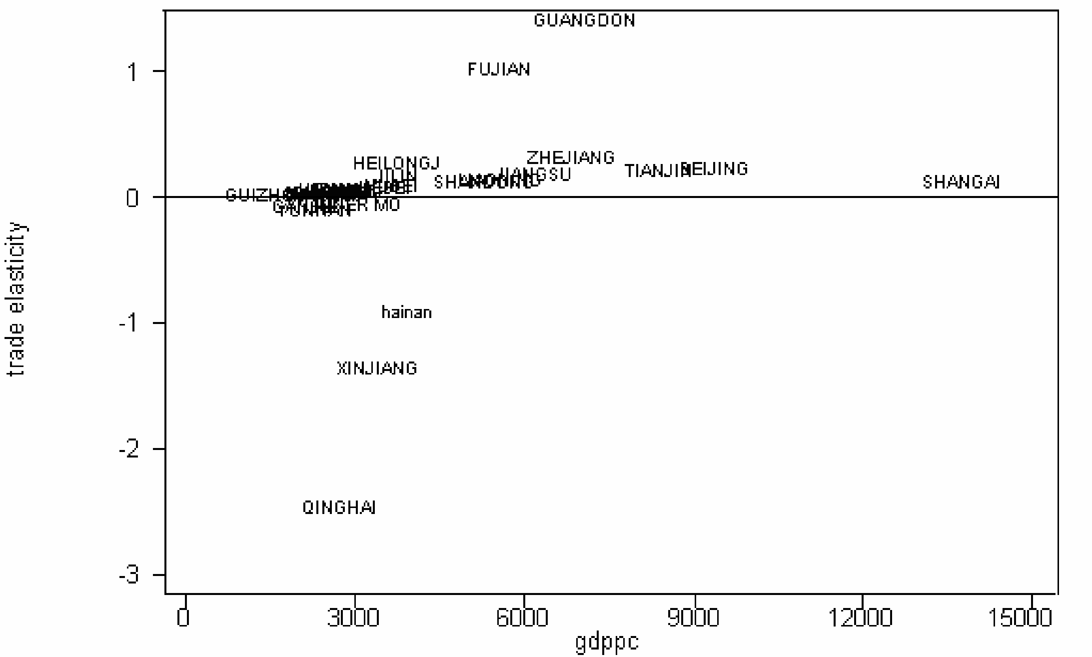
Figure 6. Actual K/L and per capita GDP situation of the 29 Chinese provinces (2003)



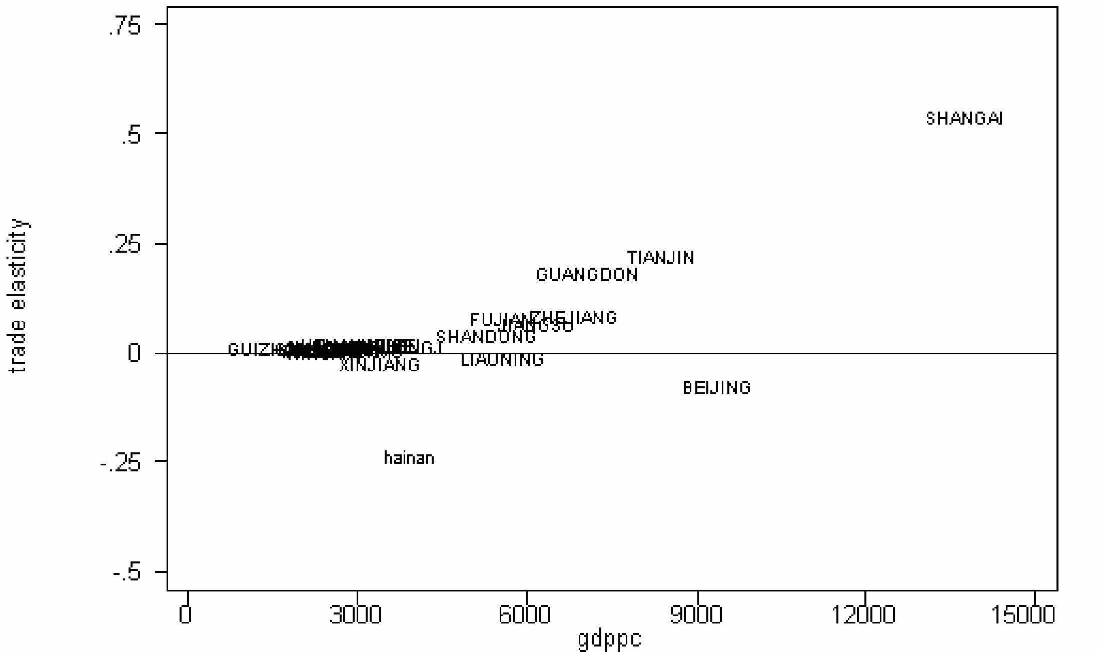
Zone A: Pollution haven comparative advantage cancelled out by factor-endowment comparative advantage in cleaner industry
Zone B: Factor-endowment comparative advantages in cleaner industry reinforced by pollution haven comparative disadvantage
Zone C: Pollution haven comparative advantage reinforced by factor-endowment comparative advantage in polluting industry
Zone D: Factor-endowment comparative advantages in polluting industry cancelled out by pollution haven comparative disadvantage

Figure 7.a. Correlation between provincial-specific trade elasticities and per capita GDP

(Based on model (4, FE) of Table 10 and model (5,FE) of Table 11)



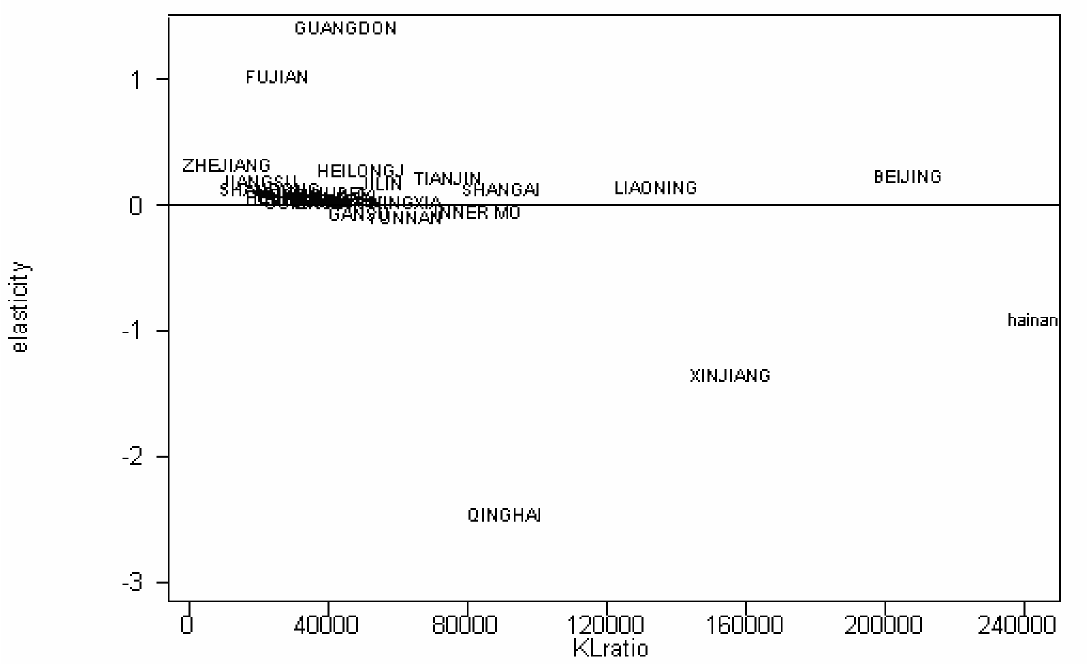
GDPPC-Trade elasticity for industrial SO2 emission density



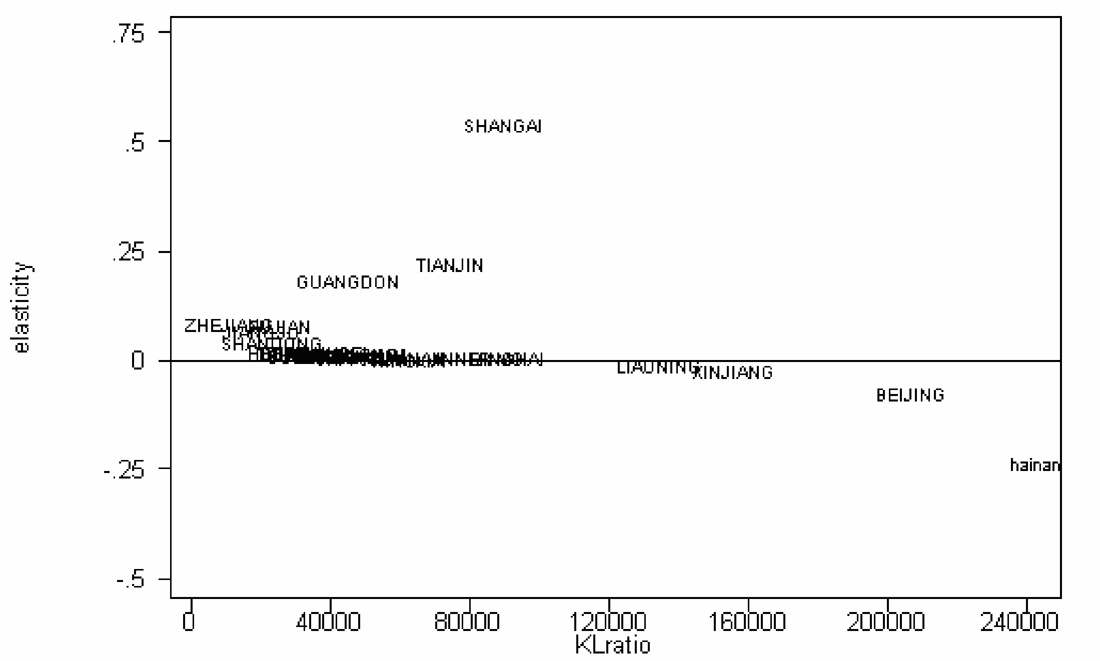
GDPPC-Trade elasticity for industrial total SO2 emission

Figure 7.b. Correlation between provincial-specific trade elasticities and capital/labor ratio

(Based on model (4, FE) of Table 10 and model (5,FE) of Table 11)



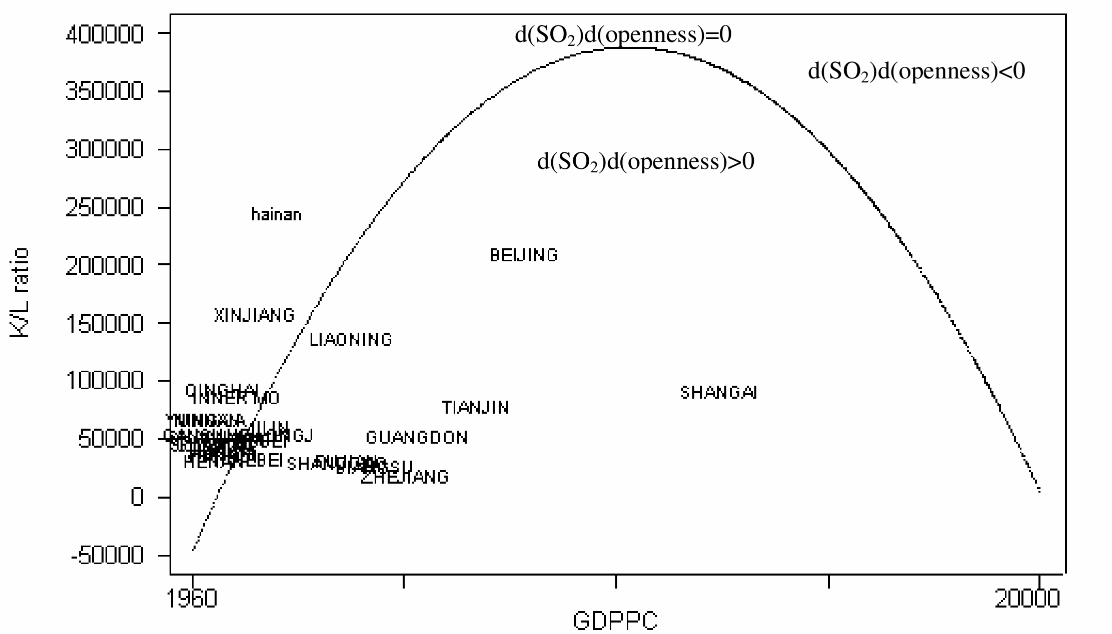
K/L-Trade elasticity for industrial SO2 emission density



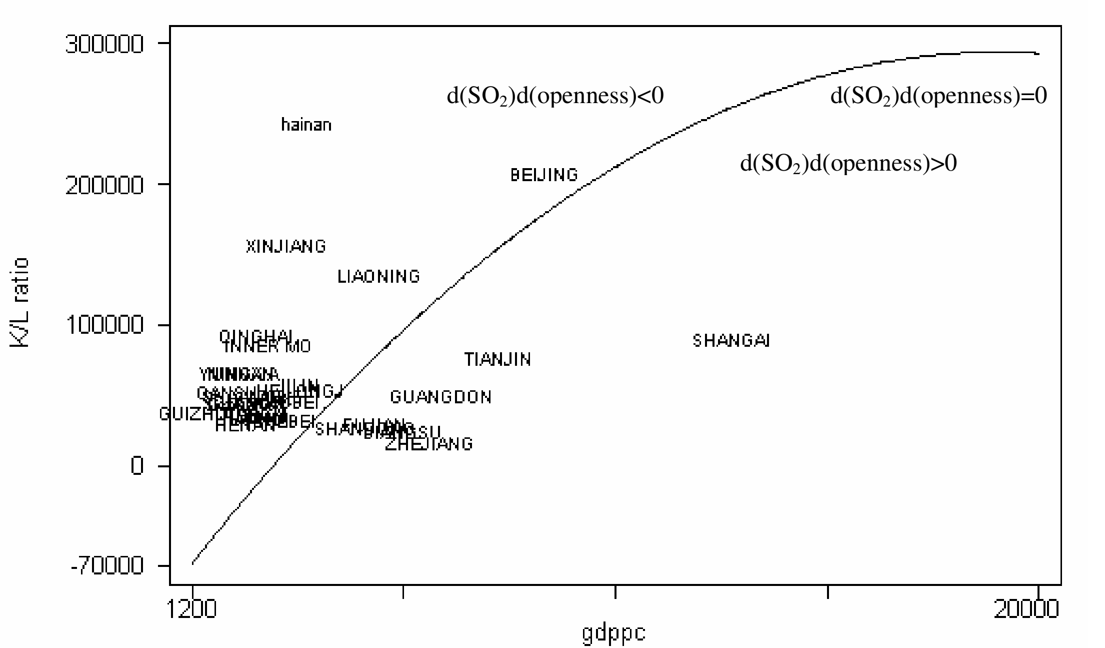
K/L-trade elasticity for total industrial SO2 emission

Figure 8. Evolution of the relationship between industrial SO_2 emission and its determinants

(Based on results of Model (4, FE) of Table 10 and Model (5, FE) of Table 11)



GDPPC-K/L combination: emission density



GDPPC-K/L ratio combinaison: total emission