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China's Open Door Policy, Urban Growth and Air Pollution

Pei Li

Yong Tu

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Pei Li [a, b, *], Yong Tu [b]

[a] Institute of Real Estate Studies, National University of Singapore, Singapore
[b] Department of Real Estate, National University of Singapore, Singapore

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This paper investigates how the different levels of openness resulted from the progressive China's open door policy across the Chinese cities impact their air quality. A city's openness stimulates its international trade, generating fast urban growth. Its full impacts on air quality are decomposed into scale effect, technique effect, composition effects and trade-induced composition effect. The empirical work concludes that the openness generates mixed consequences on city air quality. The overall effects are sensitive to the choices of pollutants and the measures of the openness levels. It is therefore implausible to draw any conclusion on if the China's open door policy is good or bad for the environment. In fact, the open and affluent cities are associated with a better air quality, while the relatively underdeveloped cities in China are likely to pursue economic growth at higher environment costs in order to catch up their counterparts. The challenge for China is to put in motion a transition to amore a secure and lower-pollutant energy system without undermining the economic and social development.

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[*] Corresponding author.
E-mail address: irslp@nus.edu.sg (Pei Li)

1. Introduction

The hundreds of cities that are part of China's rapid economic growth are far from homogenous. They differ in their economic scale, income, factor endowment as well as in their levels of openness. Stimulated by the China's open door policy initiated in 1978, the increasingly intensive international trade between the Chinese cities and the rest of the world has been witnessed by the establishments of the free trade zones started in Shenzhen in 1991, gradually extended to the other coastal cities as well as to the inner cities, which has become the main engine of urban growth since the 1990s. The trade liberation generates both the positive economic growth and the induced environment degradation (He, 2006, 2008; Shen, 2008; Cole *et al.*, 2011). The open and wealthy southern cities appear to be less polluted than the isolated and deprived northern cities according to the integrated air pollution indexes between 1996 and 2008. However, the gap between the south and north and the level of air pollution have significantly become narrower and lower since China entered the World Trade Organization in December 2001 (Fig. 1). Does it mean that the continuous deterioration of air quality is reversible in the course of China's further openness? Has the deterioration of air quality jeopardized the sustainable economic development in China? The issue is important as the combined rapid globalization and the transboundary nature of air pollution may result in tremendous environmental degradation both locally and globally in the future (Smith and Taylor, 2007). It is of paramount importance to gain deeper insight into the economic determinants of China air pollution.

The pioneering work by Grossman and Krueger (1991) has led to a burgeoning literature on the debate over the role of international trade liberation in determining a country's environment outcomes. Copeland *et al*. (1994, 1995) decompose the effects of international trade on environment into scale, technique and composition effects and theoretically predict that freer trade is bad for world environment when incentives to trade among multiple countries are created by income induced differences in environmental policy. Their prediction supports the pollution heaven hypothesis (PPH). PPH assumes that an open economy with relatively weak environmental policy (typically associated with low income) specializes in dirty-industry production. As defined in Grossman and Krueger (1991), scale effect measures the increase in pollution that would be generated by the trade induced expansion of economic scale. Technique effect measures a reduction in pollution that would be caused by the reduction in pollution emission intensity if foreign producers could transfer modern (cleaner) technologies to the local economy and if the politic would demand a cleaner environment as an expansion of national wealth due to the higher income generated by trade. Composition effect captures the environmental impacts on the change in the share of dirty goods production in national income. The change is induced by any change in trade policy that is further determined by a country's international comparative advantages.

Antweiler *et al*. (2001), hereafter ACT (2001), were the first to develop a general equilibrium model to decompose the full impacts of international trade on environment into four additive effects, namely, negative scale effect, positive technique effect, composition effects and trade induced composition effect of which the signs are determined by a country's comparative advantages. The model predicts that the trading pattern is determined by both income driven differences in pollution policy and factor abundance. The prediction is consistent with the pollution heaven hypothesis (PPH) as well as the factor endowment hypothesis (FEH). The FEH assumes that a capital abundant open economy (typically high income) tends to export capital-intensive dirty goods regardless of the differences in environment policy. However, the model is unable to predict if the full impact is positive or negative due to the existence of the opposite effects, leaving the full environmental impact to be determined by empirical results. Hence, although the paper empirically concludes that freer trade is good for world environment, its credibility is questioned because of international economic data incomparability (He, 2008; Shen, 2008). Cole and Elliot (2003) adopt the framework of ACT (2001) and finds that the empirical results are sensitive to the choice of pollutants. Managi *et al*. (2009) develop an environment quality equation under which the determinants of pollution emission is decomposed into scale-technique and composition effects. They argue whether trade has beneficial effect on environment depending on the choices of pollutants and the country-specific characteristics. However, the empirical evidences obtained from the cross country information provide very little knowledge and agreement on the nature of interactions between trade, growth and environment quality (Jayadevappa and Chhatre, 2000; Copeland and Taylor, 2004).

Recently, a rising number of papers examine the impacts of international trade liberation on environment degradation in China using regional or urban level panel data but provide conflicting evidences. Shen (2008) adopts the framework of ACT (2001) and finds that international trade liberation in the Chinese provinces increases the emissions in air pollutants, but reduces emissions in water pollutants. The evidence of factor endowment hypothesis is found in most of the pollutants, whilst there is little evidence of pollution heaven hypothesis. Adopting the Environmental Kuznets Curve (EKC) approach, He (2008) finds that the per capita SO_2 emission decreases as income increases, evidencing the pollution heaven hypothesis. He also finds that trade liberation plays a marginal but pollution-reducing role in most cases because most of China provinces are richly endowed in terms of labor forces. The factor endowment hypothesis seems not pertinent to the trade's impact on environment. Therefore, to some extent, freer trade is not likely to undermine China's sustainable development strategy. In his earlier paper, He (2006) discovers that the impacts of international trade on environment are small in China because the impact of FDI on economic growth and composition transformation (towards capital intensive dirty goods production) offsets the pollutant emission reduction due to the FDI's impact in reinforcing environmental regulation. However, Cole *et al*. (2011) show most air and water pollutant emissions rise with increases in economic growth at current income levels. Groot *et al*. (2004) warn that China's pollution situation is critical, especially in advanced regions.

The seemingly conflicting results may stem from the uses of the different pollutants and the different proxies to measure the three economic determinants of environment degradation (namely scale effect, technique effect and composition effect). It is therefore implausible to draw any conclusions pertaining to if freer trade is good for environment without conditioning on the choices of pollutants and proxies. Besides, in both cross countries' studies (*e.g.*, ACT 2001) and cross the Chinese provinces' analyses (He, 2006, 2008; Shen, 2008), a regression of city level pollutant emission or concentration on national or provincial level economic determinants is typically performed, giving rise to data inconsistency problem. In point of fact, since pollution happens at city level and trading is carried out between the cities, comparative advantages of an open economy are better measured at city level too. The concerns above call for further empirical studies with more precise measures of variables and more diversified pollutant indicators in order to comprehensively scrutinize how freer trade may influence environment.

This paper extends the literature in three ways. Firstly, we attempt to reconcile some conflicting conclusions in the current literature as well as to provide some explanations to them. To do so, we adopt the ACT (2001)'s framework to specify our econometric model. The empirical work is based on two carefully constructed city level datasets which avoids the data incomparability problem.

The first dataset covers the 286 cities in China at prefecture level between 2001 and 2008. The industrial SO_2 emission per capita is chosen as a pollutant indicator. The second dataset covers the 112 China's key environment protection cities out of the total 286 cities over the same period. In 2001, the central government identified 112 seriously polluted cities which were requested to disclose pollution data and to report their plans for meeting the national air quality standard. The central government also releases the official ambient air pollution index constructed by a series of air pollutant concentrations including SO_2, NO_2 and PM_{10} for these cities. In all 286 cities, the air pollution monitoring sites were carefully identified to fairly represent a city's pollution level which is closely related to its geographical and economic conditions. The measurement devices used in each city are highly comparable. The two datasets are different in the choices of air pollutants and the number of cities covered. Besides, the cities in the second dataset are under more stringent and consistent environment regulations while the cities in the first dataset are not. These features allow us to generate comparable econometric results which may offer some meaningful explanations to the conflicting results in the literature.

Secondly, we attempt to find evidence to show that it would be implausible to generate any conclusions on if freer trade is good or bad for environment because any relationships found between a pollutant indicator and its economic determinants pertaining to trade liberation only reflects a small part of the impacts of freer trade on the overall environment.

Thirdly, our data are superior to other datasets in terms of its spatial and temporal resolution. It contains rich city level social and economic information, allowing us to have a deeper insight into the relationships between environment and trade liberation.

The reminder of the paper proceeds as follows. Section 2 details the uneven urban development from the aspects of openness and economic growth as well as the environmental outcomes. Section 3 justifies the econometric specification, data collection and variable selection. Section 4 empirically scrutinizes the various effects of openness on air pollution. Section 5 investigates if our refined measurements of openness strengthen the robustness of the link between openness and pollution. Section 6 presents the major conclusions and limitations.

2. Regional disparity and air quality

Over the past few decades, China has witnessed fast but uneven urban growth, giving rise to the regional disparities as illustrated in Table 1. The 286 cities have been tiered by its levels of openness as well as income. Coastal cities are more affluent and enjoy higher level of international trade liberation. Between 2001 and 2008, the GDP per capita increased from RMB Yuan 5,350 to 14,120 among the cities in the eastern part of China, while the figures are RMB Yuan 2,450 and 6550 in the middle part of China and RMB Yuan 2,480 and 6,320 in the west part of China. In 2008, the monthly household disposable income in the east is 14% higher than the national average, while it is 33% higher than the cities in the west. In terms of trading intensity (the ratio of total imports plus exports to the GDP in a city), the cities in the east are 69% more intensive than the national average, and 3 times more intensive than cites in the west. The drastic difference in trading are attributed to the progressive China open door policy, particularly, the establishment of the special economic zones along with the coastal cities, which have been playing the dual roles in developing the international trade oriented economy through exporting products and importing advanced technologies and acting as the "radiators" in accelerating inland economic development.

The disparities in income and openness imply that the environmental policies are more stringent in those affluent Chinese cities than the poorer cities. This is evidenced by the lower SO_2 emission and concentration (see Table 1) as well as higher SO_2 removal rate found in these rich cities.

Although most of the Chinese cities are richly endowed by labor forces compared to their international counterparts, there is a significant gap in the factor endowment between the cities. The ratio of capital to labor at national average in 2008 is 2.4 times as much as the one in 2001. In 2008, the ratios of capital to labor across the 286 cities vary from 8.7 (RMB Yuan 10,000 per worker) for the cities in the east, to 5.2 in the middle of China and to 6.2 in the west. These figures compared to the international cases are much lower (Managi *et al*., 2009), indicating that China is still a labor intensive country.

∗∗Insert Table 1 about here∗∗

Hence, the pollution heaven hypothesis, rather than the factor endowment hypothesis perhaps play a more important role in directing international trading pattern between a Chinese city and the rest of the world. Thus, freer trade may bring more dirty goods production into China. However, the significant differences in income and the factor endowments among the Chinese cities imply that the impacts of imported dirty good production would be different for the different cities. Both the PPH and FEH may play a role in directing the dirty good production between the cities. On the one hand, a dirty good production is likely to be attracted to those capital abundant cities (FEH) due to the apparent differences in the factor endowment among the Chinese cities. On the other hand, these cities have higher income, and thus more stringent environment policies may be implemented. Consequently, the overall impact on the cities' environment depends on which impact is stronger.

Although the poorer cities is associated with lower level of openness and may not attract foreign capital investment as much as those coastal cities, the "radiator" impacts of the coastal cities accompanied by the market oriented reforms introduce strong profit incentives to both public, private as well as rural enterprises in the poorer cities. The profit driven incentives may unleash a productivity boom that propels both urban growth and fast urbanization in these cities as well as urban environment degradation due to weak environmental regulations and low public environment awareness.

The industrial SO_2 emissions mainly found in coal consumption are the leading cause of urban air pollution observed in most of the Chinese cities. The freer trade stimulates the rapid urban growth resulting in a staggering expansion of heavy industry and urbanization that requires colossal inputs of energy, almost all from coal that is the most readily available but the dirtiest. The coal consumption has been more than quadrupled since 1980, reaching nearly 2.81 billion tons of standard coal equivalents (SCE) in 2008 (see Fig. 1). The industrial sources (mining, manufacturing, and utilities) were responsible for 85.8 percent of the reported SO_2 emissions with electricity generation accounting for 45.7 percent (*China Statistical Yearbook* 2009).[1] Despite the government's efforts to improve fuel quality and to relocate some heavily polluted industrial activities, the industrial SO_2 emissions have been still increasing (Fig. 2) because of the increasing share of coal consumption in power generation and the lack of emissions control in the massive number of small furnaces and kilns (especially those operated by township and village industrial enterprises), as reflected in Fig. 1.

∗∗Insert Figure 1 about here∗∗

The concerns on the environmental degradation have been articulated into the official documents and protocols of the Chinese Five-Year Plan (FYP) announced by the central government.

Beginning with the 9th FYP between 1995 and 2000, the government began to set limits on total SO_2 emissions (TEC) rather than just setting emissions rates at the national level and to set more specific limits for the "Acid Rain Control Zones" and the "SO_2 Control Zones".[2] Interestingly, as shown in Fig. 2, a notable departure from the previous trend is that the government's effort in tackling environmental pollution has roughly paralleled with the changes of total SO_2 emissions since 1996.

∗∗Insert Figure 2 about here∗∗

While the total SO_2 emissions continue to increase, air pollutants concentrations have been decreasing (Fig. 3 and Fig. 4). The reduction of air pollutant concentration may be attributed to the gradual shift in economic structure, the adoption of cleaner technology and the way in which primary energy has been used. Furthermore, the air pollutant concentrations are higher in northern cities, due in part to industrial activity more dependent on coal consumption, but also to geographic and meteorological conditions that make these cities more vulnerable to certain pollutants than cities in the south of China, holding emissions constant.

∗∗Insert Figure 3 and 4 about here∗∗

In a conclusion, China's open door policy plays an important role in creating the regional disparities. The Chinese cities are tiered by their levels of openness, income, factor endowment as well as the levels of air pollution. In the rest of the paper, we will econometrically identify the impacts of openness on China air quality.

3. Econometric specification, data collection and variable selection

3.1 Model specification

ACT (2001) assume that there is a small open economy with identical agents producing two final good, dirty goods *X* and clean goods *Y*. Each is produced with a constant return to scale technology using two primary factors, capital (*K*) and labor (*L*). Under this framework, a reduced econometric model is specified in which pollutant emission (*Z*) is a function of six economic variables, namely, scale effect (*S*), technique effect (*I*), composition effect (*k*), trade friction (β), the world price of the polluted goods (p^w)and the characteristics of the open economy (*T*).

$$Z = \pi_1 S + \pi_2 k - \pi_3 I + \pi_4 \beta - \pi_5 T + \pi_6 p^w \quad (1)$$

where the coefficients of π_1, π_2, π_3 and π_6 are positive, while, the signs of π_4 and π_5 are not obviously. It is noted that in ACT (2001), equation (1) is derived as the percentage change of each variable. To simplify the discussion, we assume that the relationship holds for the absolute values too.

Both Shen (2008) and He (2008) adopt the ACT (2001)'s econometric specification with modifications to empirically model the relationships between pollutant emission and openness against China provincial level data. Following their work, we adopt the same econometric specification. Being different, we focus on a city, in which the pollution emission comes from both the dirty goods production resulted from the freer trade and the dirty goods production generated by the domestic economic activities. This model setup closely imitates the situation in a Chinese city as discussed in the previous section.

Some features in equation (1) necessitate further modifications before it can be applied to our city level data. First, we use subscript "*i*" to indicate a city in China. Z_i is the total pollutant emission in this city. It is apparent that all cities in China face one world price (p^w), hence, it is removed from equation (1). Second, as argued in ACT (2001), emission and those economic variables may be endogenous. However, emissions are determined endogenously and recursively. Thereafter, the economic factors are not simultaneously determined by the level of emission. Intuitively, pollutant emission is unlikely to take immediate effect on real economy. Besides, a reduced form equation provides us a simple, straightforward and parsimonious way linking pollution emission to its economic determinants.

Third, a city's trade friction is inversely related to the city's level of openness. It induces a composition effect on pollutant emission, namely trade-induced composition effect. If two cities differ only in their trade frictions and both cities export (import) the dirty goods, pollution is higher (lower) in the city with lower trade friction (see proposition 1 in ACT 2001).Take an example that a city exports dirty goods. Trade liberation lowers the trade friction, leading to higher demand for the dirty goods. It subsequently increases the demand for pollutant emission, raising the composition of dirty goods production in a city's total production as well as the government pollution tax to reduce the emission. ACT (2001) proves that the increase in pollution tax is less than proportional to the decrease in trade friction. As a result, trade-induced composition effect leads to rising pollution emission and π_4 is position. Conceivably, it would be negative if a city imported dirty goods.

Inspired by the econometric specification of ACT (2001), the trade-induced composition effect is measured by the cross term of trade friction and the comparative advantages of a city. Since a city's openness is unobservable, the best proxy is the observable trade intensity ("*TI*", which is the ratio of sum of imports and exports to the city's GDP). The comparable advantage of a city compared with the rest of the cities in China is better represented by a function of a city's relative advantages in its factor endowment ("*rk*") and its relative real income ("*rl*") to the national average. Equation (1) is rewritten as an estimable equation (2). It should be noted that λ takes the opposite sign of $\pi 4$ because trade friction is inversely related to trade intensity.

$$Z_i = \pi_1 S_i + \pi_2 k_i - \pi_3 I_i + \lambda TI_i \times \psi(rk_i, rl_i) - \pi_5 T_i + \varepsilon_i \tag{2}$$

$$\psi(rk_i, rl_i) = \psi_0 + \psi_1 rk_i + \psi_2 rk_i^2 + \psi_3 rl_i + \psi_4 rl_i^2 + \psi_5 rk_i \times rl_i \tag{3}$$

Although equation (2) isolates the trade-induced composition effect, any changes in the trade friction will alter the scale of output, income and the composition of the dirty goods output to the clean ones in a city. Therefore, to account for the full environment impact of a change in trade friction, we must also account for the accompany scale, technique effect and composition effects. "*T*" represents any other control variables that may affect pollutant emission and its sign depends on the choice of a variable. A few hypotheses are drawn from equation (2).

First, a city with larger economic scale produces more pollutant emission regardless the intensity of international trade. However, a fall in trade friction can generate economic growth and hence increases the size of a city's economic scale, reinforcing the pollutant emission in the same direction. The scale effect is expected to be significant and positive.

Second, the public environment awareness in an affluent city is expected to be stronger, which may force the government to implement stringent environment policies to minimize its pollutant emission. A city with higher income should be cleaner regardless the intensity of international trade. However, a fall in trade friction may bring in more foreign investors who may introduce newer and cleaner technologies to a city, and generates higher income. Rising income leads to more stringent environment policies and less pollutant emissions. The technique effect is expected to be significant and negative.

Third, the composition effect captures the effect of the share of dirty goods output in the total output of a city. It is proxied by the ratio of capital to labor in a city (a specification used in ACT 2001) because dirty goods production is typically capital intensive. Higher ratio refers to a higher share of dirty goods output in the total output in a city, therefore more pollutant emission regardless the intensity of international trade. The composition effect is expected to be positive and significant.

Fourth, trade-induced composition effect may alter the distribution of dirty goods production across the Chinese cities as well as pollutant emissions. If, for example, a city is more factor abundant, a fall in trade friction in this city puts the city in a better position to response to the foreign demand for dirty goods, increasing the city's pollutant emission, while a city that is less factor abundant may not be affected even if there is also a fall in trade friction in this city. Thus, the Factor Endowment Hypothesis holds among the Chinese cities, if $\lambda\psi_1 < 0$ and $\lambda\psi_2 > 0$ in equations 2 and 3. If a city has higher income and hence more stringent environment policies, a fall in trade friction is likely to put the city in a disadvantaged position to response to the foreign demand for dirty goods, decreasing pollution emission in this city. Instead, the dirty goods production may go to a poorer city. Thus the pollution heaven hypothesis holds among the Chinese cities with if $\lambda\psi_3 > 0$ and $\lambda\psi_4 < 0$.

While ACT (2001) estimated their specification across countries, the application of their method to different geographical scale (country versus city level) does not sit uneasy with the tendency of a “one size fits all” approach. In fact, because SO_2 concentration data were recorded at city level, while economic statistics were often or even only available at country level, this obliged ACT (2001) to carry out their regressions of each city’s SO_2 concentrations on its country’s average economic determinants. The city-level distinction therefore was blurred by averaging in their country-level dataset. As we discussed before, highly aggregated data are far off the real variable to be taken into account, it generally results in bias induced from measurement-error. A possible improvement should be that all variables are measured at a same disaggregated level.

Based on the specification proposed by ACT (2001) and a slight modification, our estimation function in this analysis is illustrated with equation (4).

$$\begin{aligned} E_{ij} &= \alpha + \pi_1 TECHNIQUE_{it} + \pi_2 TECHNIQUE^2_{it} + \pi_3 ECON\_SCALE_{it} + \pi_4 ECON\_SCALE^2_{it} \\ &\quad + \pi_5 KtoL_{it} + \pi_6 KtoL^2_{it} + \pi_7 KtoL_{it} \times TECHNIQUE_{it} + \pi_8 \vartheta_{it} OPEN\_TRADE_{it} + \mu_i + \delta_t + \varepsilon_{it} \\ \vartheta_{it} &= \omega_1 + \omega_2 RKtoL_{it} + \omega_3 RKtoL^2_{it} + \omega_3 RINCOME_{it} \\ &\quad + \omega_4 RINCOME^2_{it} + \omega_5 \times RKtoL_{it} \times RINCOME_{it} \end{aligned} \qquad (4)$$

where E_{ij} refers to the pollution indicators, i references a city and t indexes a year.[3] *TECHNIQUE* is one year lagged per capita disposable income, given the fact environmental regulation is likely to respond slowly, if at all, to changes in income levels. *ECON_SCALE* is defined as GDP per square kilometer and represents the scale of economic activity. The quadratic terms of income per capita ($TECHNIQUE^2$) and real GDP density ($ECON\_SCALE^2$) capture the possibility that the impact of technique and scale are non-linear, which is consistent with the EKC literature.[4] *KtoL* denotes the capital-labour ratio and its square is included to allow capital accumulation to have a diminishing effect at the margin. The cross product of *KtoL* and *TECHNIEQUE* captures the fact that the effect of income on the environment is likely to depend on the existing level of *KtoL*. *OPEN_TRADE* measures trade intensity, *RKtoL* represents domestic relative capital-labour ratio, and *RINCOME* refers to domestic relative per capita income.

Following standard practice, we exploit our panel data by including city-specific intercept (μ_i) in our equations. Hence, the city fixed effects remove permanent differences in air pollution across cities. Additionally, the model includes year fixed effect (δ_t) to control for the possible common macro-economic shocks happening to all Chinese cities in a particular year.

One difference with the model specification of ACT (2001) should be noted here. We use domestic relative capital-labour ratio (*K*/*L*) and domestic relative per capita income in the trade-related multiplicative terms instead of world relative *K*/*L* and world relative per capita income. It is due to the consideration that we are interested in international trade of each Chinese city with all foreign countries and in each Chinese city's comparative advantage in pollution-intensive production within China. This corresponds to the situation that, *ceteris paribus*, if a Chinese city's *K*/*L* is sufficiently lower with respect to that of its trade partners and that of many other Chinese cities, it does more possibly export less polluting good compared with its counterparts, and *vice versa*. Similarly, since there is a high correlation between a city's per capita income and the stringency of its environmental regulations, a Chinese city with a lower than the average national level of environmental regulations does more possibly specialize in some "dirty" sectors. Another reason for using domestic relative terms instead of the world average terms is that our estimation only covers 8 years. Since the world average terms are actually constant during this period, including them would only alter the scale of the coefficients for the multiplicative terms, but would not change their essential relationship.

3.2 Data sources

The dataset used in our analysis is obtained from a variety of official Chinese statistical publications (see Table A.2 for a description of our data source). Merging these data sources is a challenge. We have constructed two panel datasets with different observations. The first one recorded industrial SO_2 emissions in all of the Chinese cities at prefecture level spanning the years 2001-2008.[5] The second dataset is an unbalanced panel of 810 observations covering 112 national key environmental protection cities over the same period. This sample comprised 69 cities in 29 provinces in 2001 and 2002, and 112 cities in 30 provinces after 2002. In all cases, monitoring sites were chosen to be fairly representative of the geographical and economic conditions that exist in different regions of China, and the measurement devices used in each city are highly comparable. Fig. A displays the location of each city in our analysis.

Several reasons make a concentration on recent environmental situations interesting. First, this eight-year period does not only coincide with China's peak phase of urbanization and staggering expansion of heavy industry, but also covers the two recent Chinese Five-Year Plans (FYPs) when more regulations in place which internalize environmental externalities. Second, since 2001 the central government has required 112 seriously polluted cities (*i.e.*, national "key" environmental protection cities) to disclose pollution data and to report their plans for meeting the national air quality standard. Hence, during this period of time more pollution data became publicly accessible. Third, China's accession to WTO in 2001 codified existing openness to the global economy but also further accelerated integration into the global economy system, providing us a "natural experiment" to assess the impact of trade or the growing FDI flows on China's environment. In addition, since the early 2000s environmental pollution control has become more determined by the interactions of multiple agents (*e.g.*, economic sectors and NGOs) instead of only by the governments' efforts (Shi and Zhang, 2006), it suggests that we might get more comparable results to those in the existing literature.

3.3 Choice of environmental indicators

Since environmental quality has been typically viewed through multi-dimensions, an analysis on this topic should aim to be as comprehensive as possible. In this paper, we focus on two indicators relating to environmental quality, namely industrial SO_2 emissions and an air quality index.

Industrial SO_2 emissions were chosen as one of our environmental indicators because of its importance in contributing to China's environment degradation. SO_2 emitted from some industrial production process has caused domestic problems because such emissions directly damage human health, and indirectly damage buildings, forests and crops due to acid rain. In recent, SO_2 has been recognized by the Chinese government as the most serious air-pollutant to cause significant health and ecosystem damages, and monitoring apparatus have been widely installed across Chinese cities.

Previous papers have shown that the relationship between economic variables and pollution can vary depending on whether pollution is measured in terms of concentrations or emissions (Selden and Song, 1994; Cole *et al.*, 1997). Comparing with emissions data, as Cole and Elliott (2003) argued, city-level concentrations data provide more information regarding the impact on human health of a particular pollutant since the health of a city's population will be directly related to pollution concentrations within the city.

Two air pollution indices are regularly issued in China, namely the Integrated Air Quality Index (IAQI) and the Air Pollution Index (API). The higher values of these two indexes both indicate more pollution in relative terms. The IAOI is an index for reporting annual air quality, which tells us how clean or polluted a city is. It is the sum of three individual air pollution indexes (*i.e.*, SO_2, NO_2, and PM_{10}) calculated by normalizing the annual pollution concentrations to maximum permissible concentration. The API is an index for reporting daily air quality, which focuses on health effects a citizen may experience within a few hours or days after breathing polluted air. To calculate it, an individual score is assigned to the level of each pollutant measured at the monitoring stations throughout each city (*i.e*., SO_2, NO_2, PM_{10}, CO, and O_3) and the final API is the highest of those five scores.

Since the API discards the values of the other sub-indices and the harmful levels associated with other pollutants, this method does not includes the addictive effects of pollutants together on the human health. In contrast, the IAQI, which combines the synergistic effects of all the three criteria pollutants, could overcome this problem. These three pollutants used to construct the IAQI all have the following characteristics: (i) they have strong local effects; (iii) they are subject to local regulations due to their adverse effects; (iii) abatement technologies are available. Additionally, given the fact that the benchmark of API is a 24 hour target instead of an annual target, in this paper we employ the IAOI to characterize city *i*'s quality of the air.

A caveat should be noted here. Emissions data and concentrations data are both not free from imperfection. Using concentrations data might be problematic because air quality does not only depend on local emissions but is also a function of geo-spatial factors, site-specific effects and transboundary pollution. For emissions data, what is worrisome is that nearly 50 percent of industrial economic activities remain outside the monitoring of the Chinese Environmental Protection Bureaus at various levels (see Table A.1).

It is worthy to note that McAusland (2008) found that the relationship between trade and environment depended critically on pollution type, so using an aggregate emission level bundling both production-generated ("smokestack") and consumption-generated ("tailpipe") pollution would either fail to find or misestimate the relationship between environmental quality and trade flows. Our IAQI is more tied to a consumption activity (*e.g.*, private motor vehicle use), to some extent, making it an inappropriate pollutant for testing our model of smokestack pollution. In contrast, industrial SO_2 total derives from industrial sources, this is consistent with ACT (2001) in which pollution is investigated on the production side.

3.4 Choice of control variables

If there are any characteristics of the cities that influence pollution but are not included in our list of independent variables, standard error estimates of commonly applied covariance matrix estimation techniques will be biased and hence statistical inference that is based on such standard errors will be invalid. To limit these exclusions we control some factors frequently reported in the empirical literature to influence environmental quality.

Firstly, as many studies have shown, environmental degradation tends to increase as economic structure changes from agriculture to industry, but it starts to fall with another structural change from energy intensive industry to services (*e.g.*, Dina *et al*., 2000; Friedl and Getzner, 2003). To test for this hypothesis, we need a clearly defined set of "dirty" industries. Based on detailed emissions intensities by medium for Chinese industries at the 2-digit Standard Industrial Classification level, we define "dirty" sectors as those which rank high on actual emissions intensity (*i.e.*, manufacturing industry, mining and quarrying industry, production and supply of electricity, gas and water industry). We represent economic structure by the share of "dirty" industry in national employed persons and expect a positive relationship with environmental degradation (*DIRTY_SECTOR*).

Secondly, as we shown above, China’s high reliance on coal mirrors the unusually dynamic increase of its pollution. Thus, the use of locally available high sulfur coal for the domestic cooking and heating, small scale industrial boilers and power sector should be one of the major reasons why the air pollutant emissions are high in most of the Chinese cities. We investigate the effects of coal abundance on the environment by adding in our estimation equations the province-level coal endowment measured by ratio of net coal imports from other provinces and countries to total coal supply within the province which city *i* belongs to (*COALE_DEPENDENCE*).

Thirdly, in reality, both air pollutant emissions and concentrations are also largely influenced by geographical and climate conditions. For example, as demonstrated by Almond *et al*. (2009), ambient concentrations of total suspended particulates in the winter were dramatically higher across northern cities than southern cities partly due to China’s Huai River policy. Since such influence cannot be totally neutralized by using yearly average and/or modes, we therefore incorporate a city climate change index (*TEMP_INDEX*) into our equation.

Finally, as most of the previously cited works have noted that declining pollution at higher levels of development must be driven by how fast the economy grows, we also include the growth rate of a city’s total GDP (*GROWTH_RATE*). Table A.3 supplies the detailed statistical description for the variables used in this paper together with units of measurement for the data.

3.5 Measurement issues

In order to study city environment properly, it is necessary to delimit cities within meaningful geographical boundaries. For cities at the prefecture level and above, information on both “*Shiqu*” (city districts) and “*Diqu*” (urban area and rural counties) is reported in some of the statistical books which we refer to. Compared with “*Diqu*”, “*Shiqu*” is more in line with the definition of the “city proper” in the previous researches (see Chan 2007 for a detailed explanation). However, in this paper, we choose “*Diqu*” as the relevant on to represent city size. It is partly because some economic figures at “*Shiqu*”-level are not readily available or published officially in China, and partly because the administrative boundary adjustment of “*Diqu*” has less frequently happened compared with “*Shiqu*” during our targeted period. Therefore, only “*Diqu*” information is used here.

Construction of physical capital stock data is crucial for examining the capital-labor effect on environment. While working on China’s economic statistics, we have confronted a major problem, no capital stock data are reported in the Chinese statistical system. We instead calculate the capital stock of each city by perpetual inventory method (Goldsmith, 1951) and deflate it by the corresponding fixed investment price index. Due to Lack of data on initial capital stock of each city, we measure a city's initial capital stock by multiplying its province's initial capital stock in

2000 estimated by Zhang (2008) with its GDP share of its province's. The price index series for fixed asset investment and depreciation rates used in this paper are all province-specific, and the latter is directly collected from Wu (2008).

One of our critiques that come out of the current analysis regards the variables used to find the environmental consequences of economic growth and international trade. Due to the limited availability of income data, in previous literature, closest variable to income that has been found is the economic growth measured as GDP. However, doubts should be raised about the relevance of the GDP being a proxy of income since this is a variable of the production and not the income. Urban household disposable income instead of per capita GDP is used here also because suspected data problems are taken into consideration. The major suspicion has been over the GDP data, as GDP growth has been used for the promotion of governmental officials. In contrast, our income data are collected from the national household survey annually conducted by the National Bureau of Statistics (NBS).[6] Needless to say, income data are more reliable.

There is one issue to be noted here. As it is well known, during the period from 2001 to 2008 there are serious inflations in China, and inflation rates vary across cities. Therefore, adjustments must be made for all the variables measured in value. In our paper, urban household disposable income is adjusted by consumer price index, setting CPI for base year 2000 at 100. Total GDP and total industrial output are deflated by the corresponding indices into the Yuan of 2000 constant price. All these price deflators are also collected at the city level.

3.6 Estimation methods

When we allow for both city effect and time effect, in all cases Hausman test favors the fixed effects models over the random effects ones. Thus, results for the former only are provided below.

Given that erroneously ignoring cross-sectional correlation in the estimation of panel models can lead to severely biased statistical results, many tests are used to examine whether or not some of the underlying regression model’s assumptions are violated. First, a modified Wald test discussed in Wooldridge (2002) is used to test possible serial correlation in the idiosyncratic errors. Second, following Green (2000), a modified Wald statistic is used to test possible groupwise heteroskedasticity in the residuals. Finally, Frees (1995) test is used to test whether or not the residuals from fixed effects estimation are spatially independent.

To our surprise, the error structures in all of our cases are found to be heteroscedastic, autocorrelated up to some lag, and correlated between the groups. Since standard techniques in this line have failed to account for consistent variance estimators, previous studies might present statistically biased results. In order to ensure that statistical inference is valid, we employ a nonparametric covariance matrix estimator developed by Driscoll and Kraay (1998) which produces heteroskedasticity consistent standard errors that are robust to very general forms of spatial and temporal dependence.

4. Is trade liberalization good for China urban air quality?

Table 2 presents the results for equation (4). By using city-level data, our estimation results show relatively good stability for model and estimation method changes, and some of them are different from the estimation based on international experience. It is critical, therefore, to understand where the differences come from.

For industrial SO_2, estimated emissions initially rise with income growth, but eventually fall. This is consistent with the stylized picture in the EKC literature. However, according to the dichotomy between income and pollution predicted here, except for few cities which economic growth levels have surpassed the estimated turning point, most of these cities still stay on the increasing track of the EKC. One possible explanation for this contrary-to-intuition result is that technologies to reduce this kind of pollution are not already required in many Chinese cities or many facilities are lying idle due to the higher cost of operation than the pollution levy (Zhao and Gallagher, 2007). For IAOI, a U-shape curve is found over the relevant range of income levels, suggesting the difference between the turning points for emissions and for concentrations. Especially, though diverging, a few of the cities in the regions are scrambling in line with monotonously increasing pollution concentrations.

Why does the pollution level in the atmosphere continue to rise even when emissions are leveled off in rich cities? There are some reasons might be accountable for this. First, one of principles at work here is stock and flow. In other words, the inflow (the amount of pollutants going into the atmosphere) and outflow (the amount of pollutants removed from the atmosphere) are not sufficiently in balance to keep the pollution level within a stable range. For our targeted period, since each year more pollutants went into the atmosphere than were removed, the amount of pollutants in the atmosphere continued to rise. Second, the U-shaped relation between air pollution concentrations and per capita income can be explained by changes in energy use that generally accompany economic development. Although gas and electricity is becoming more widespread in Chinese urban areas, higher air pollution concentrations could be generated by increase in energy consumption that outweigh the effects of the ongoing shift towards energies with a lower pollution content. This rebound effect has also been found in some previous studies (Sanstad *et al*., 2006; Brännlund *et al*., 2007). Another explanation is that in the rich cities, the major threat to clean air is now posed by traffic emissions, especially in the swiftly motorizing megacities of China. It is predictable that once adequate infrastructure is in place, more rapidly motorizing cities are expected to experience a shift from coal-smog air pollution into a mixture of coal-smog and automobile exhaust, leading to increasing ambient pollution concentrations. Finally, although our focus has been on local effects, some emissions generate trans-boundary or even national damages.

For the latter, it is the national total emissions rather than their location that ultimately matters, though the two may not be independent when some cities are better able to regulate emissions.

Our results indicate a U-shaped relation between scale effects and industrial SO_2 emissions. However, based on our estimates, only few cities are to the right of the turning point and they are just barely past it. Thus the part of the curve to the right does not have too much economic meaning. In the case of IAOI, it is found that pollution increases with the spatial intensity economic activity at a descending rate. Again, this is actually in tune with what we have already ascertained that changes in pollution concentrations have not been subjected to the same reasons as pollution emissions.

For the composition effects both for industrial SO_2 emissions and IAOI, we identify a declining tendency at lower capital-labor ratio. Beyond this point it then increases air pollution at an increasing rate. This finding concurs with our prior expectations. Especially, in those Chinese cities endowed with high capital-to-labor ratios, rapid economic growth has been highly derived from a staggering expansion of heavy industry that causes wastes of toxic chemical substances and heavy metals, on one hand, and leads to larger energy consumption that results in increased air pollutants emissions, on the other hand.

In a nutshell, the overall picture depicted in Table 2 corresponds to the situation that the unbridled economic growth in China has moved the Chinese closer to industrial smokestacks and increased the number of people exposed to polluted urban air. A glimmer of hope is that few of Chinese developed cities has specialized relatively more in light industries, such as electronics, which are only moderately polluting and at the same time generate higher incomes, and these developed cities have already has the capacity and incentives to reduce their industrial SO_2 emissions. Besides the retreat of heavy industries in such rich cities, the growing population in their urban areas that prefers electricity, gas and LPG (liquefied petroleum gas) to direct use of coal has also contributed to the air quality improvement.

Turn now to the results of our trade variables. The inclusion of the structural and trade intensity variables, as shown in Table 2, does not affect the coherence of estimates of the trade-induced technology-scale-composition effects. Cities that have pursed more outward-oriented strategies in trade are estimated to have suffered more from growth in toxicity of their industrial mix, whilst for industrial SO_2 emissions a significant positive sign is estimated. The statistically positive relationship between trade intensity and industrial SO_2 emissions might be explained that as China shifted its trade portfolio towards cleaner production industries and adopted cleaner technologies, the negative environment effects of the vastly increased scale of trade far exceeded the positive.

As for the IAOI, the positive sign of the interaction between trade intensity and relative capital-to-labor ratio and negative sign of the interaction between trade intensity and relative income are consistent with FEH and PHH: further openness to trade will result in a reduction of pollution for those cities with low capital-to-labor ratio and for those with higher relative income, but more pollution for those cities with relatively higher capital-to-labor ratio and lower income.

However, one striking result in Table 2 is that for industrial SO_2 emissions the trade intensity interaction terms provide anti-evidence for PHH. This result is probably due to the fact that degree of aversion to stringent cities does not seem to increase for those contributors to industrial SO_2 emissions (see Levinson 1996 for a detailed explanation). This finding might suggest that the stringency proxies used are capturing some other city characteristics, or that pollution density is inversely correlated with omitted variables such as geographic footlooseness. A problem faced by our study is that we use aggregate data, which cannot distinguish among changes caused by births of new plants, expansions of existing plants, and plant closures, each of which will be affected differently by city characteristics. In addition, unlike the findings by Cole and Elliot (2003) we did not provide evidence that capital-labor endowment determine sulfur dioxide emissions.

Judging from Table 2, it appears that "Dirty" industry remains the principal culprit of air quality deterioration in China. The estimated coefficient on *COAL_DEPENDENCE* is positive and highly significant, reflecting the fact that economic growth in transitional China has relied heavily on inputs of production factor. Our model also confirms the common increasing tendency for industrial SO_2 emissions and air pollution concentrations in cities with higher economic growth rate (*GROWTH_RATE*). If this outlined path is followed, many Chinese cities may experience further environment degradation before reaching its spontaneous turning point. Therefore, as suggested by our results, among the changes that will reap the greatest benefits for China's environmental future are increasing substitutions of cleaner fuel, improving energy efficiency and adjusting industrial structure.

It is worth noting that the concentration data tend to be "nosier" than emission data and require controlling for the nature of the observation site, the type of measuring equipment, the average temperature of the site and the level of rainfall at the site. While we have incorporated *TEMP_INDEX* into our equations for controlling these possible "noises" and the coefficients of this variable in every related equation are statistically significant, site-effects (particularly the time-varying ones) could not be totally accommodated.

∗∗Insert Table 2 about here∗∗

5. Does a broader definition of openness matter?

5.1 The measurement of the openness

In section 4, we examined the impact of trade exposure on the environment. Due to the complex relationship between openness and the environment, focusing only on trade intensity may be misleading. For example, during our targeted period, FDI flows in many Chinese cities have been growing at a pace far exceeding their volume of international trade. In this context, compared with international trade, the surge in FDI inflows may capture more features of a city's openness. Besides, the trade-to-GDP ratio might be mis-measured partly due to under-reporting of trade. In this section, we carry our initial analysis a step further by investigating if a refinement of the measure of openness will substantially strengthen the robustness of the link between openness and the environment, conditioning on other controls.

Given the openness of an economy is difficult to qualify, even more so in China, we endeavor to examine several alternative measures capable of reflecting different aspects. Note that since whether each measure is satisfactory depends on the use to which it is put, we necessarily take an eclectic approach to the measurement of openness. In line with our previous analysis, we assume that the affects of openness on the environment via technique, scale and composition effects, and these effects can all be expected to vary across cities.

Firstly, given the obvious increase in the FDI inflow to China happened after WTO entry and its highly uneven distribution among industries and cities, focusing our analysis in the period of 2001-2008 will allow us to study principal influence of FDI on pollution situation. Here FDI can enter our regressions in one of two ways, as a share of the city's total investment or in absolute scale. If the role of FDI is merely as an infusion of capital into a city (*i.e.*, the technology it brings with it does not spill over to other firms in the city), and then its influence on the city's environment will be proportional to its share in the city's total capital stock (*OPEN_FDI_RATIO*). On the other hand, there may be a substantial amount of spillover across firms through agglomeration effects and backward economic linkages, and then the contribution of FDI to a city's environmental protection will be proportional to the total FDI the city receives. In other words, the presence of a scale effect signals the existent of positive spillover across firms in the same city. To investigate this issue we also incorporated FDI inward stock (*OPEN_FDI*) deflated by the GDP deflators (2000=1) into our equations.

Secondly, a number of recent studies have demonstrated a "pollution halo" effect suggesting that newer, cleaner technology and better environmental management systems, as well as demands by "green consumers" at home, made multinational corporations the vehicles for better performance than domestic firms (Eskeland and Harrison, 2003; Cole *et al.*, 2008). To show such differential effects, we separately examine the environmental impacts from industrial activities of domestic enterprises, from industrial activities of enterprises funded through Hong Kong, Macao and Taiwan (*OPEN_HMT*), and from industrial activities of enterprises funded from non-ethnically Chinese sources (*OPEN_FIND*).[7]

Third, many developed Chinese cities are tied to waterways such as harbors, rivers and canals (see

Fig. A). The average cost of processing freight falls sharply with the quantity processed at a particular port, creating substantial scale economies at harbors or river conjunctions with access to the sea. We take advantage of the special geographic features of the Chinese territory to construct another proxy for a city's openness, namely harbor accessibility index (*OPEN_HARBOR*) defined by a city's average weighted distance to its two closest harbors. *OPEN_HARBOR* highlights the importance of transportation costs in determining a city's participation in the international division of labor. If the "pollution heaven" hypothesis holds, increased accessibility to the main harbors with less rigorous environmental regulations should also lead to increased environmental damage for the case of Chinese cities, where increased scale of FDI to the coastal areas has led to the expression of "the workshop of the world".

Fourthly, trade intensity measured as the exports plus imports as a share of GDP is sometimes criticized for combining the effects of "natural" openness and trade policy (*e.g.*, Berg and Krueger, 2003). In our context, since we are both interested in exploring the environmental effect of "natural" openness and policy openness, a refinement to measure which can adjust the trade share for non-policy determinants of trade shares is needed. Fortunately, the rapid proliferation and economic impacts of designated economic zones (DEZs) established since 1980s provides us a good chance to construct openness policy variables based on their importance in terms of special treatment given to foreign investors.[8] The typical policy package implemented in these export-oriented zones (*e.g.*, import and export duty exemptions, streamlined customs, and income tax incentives) is intended to convey "free trade status" to export manufacturers, enabling them to compete in global markets and counterbalance the anti-export bias of trade policies. In this paper, the ratio of trade volumes in national level DEZs (*i.e.*, Special Economic Zones, Shanghai Pudong New Area, Economic and Technological Development Zones, Free Trade Zones, and Border Economic Cooperation Zones) of city *i* to total trade volumes in city *i* (*OPEN_POLICY*) is used to proxy policy openness. We are comfortable with the association of openness with "*OPEN_POLICY*" and accept that the two are hard to tell apart. In addition, the correlation between *OPEN_HARBOR* and *OPEN_POLICY* is only -0.132. It does not appear to be so close that disentangling geography and policy would be a hopeless task.

Finally, one further international catalyst for environmental protection might be the growing influence of the cultural openness. The cultural exchanges might enhance the role of informal social norms, rules and unwritten codes of conduct in propelling further restructuring Chinese eco-friendly actions.[9] Again, this dynamics of course do not operate either in the same way or with equal strength across cities. There are therefore reasons not to overestimate cultural factors in this context. Since 1973, many Chinese cities have enjoyed sister city relationships with their counterparts worldwide. The tally in 2008 has been around 1084 communities in overseas cities partnering with 229 Chinese cities at prefecture level and the number is growing.[10] One of stated goals in the official Sister City agreement is to solve environmental pollution together through reciprocal cultural, educational, municipal, business, professional and technical exchanges and projects. Based on this background, we use the total number of sister city relationships (*OPEN_FRIENDS*) adopted by city *i* as a measurement of its cultural openness. Moreover, given the lasting effects of tourism on the environment and balance of societies (Robinson and Picard, 2006), we introduce the ratio of foreign exchange earnings from tourism to GDP (*OPEN_TURISM*) as another proxy for China's international culture exchange, and expect a positive relationship with environmental quality.

5.2 Estimation results

Broadly speaking, as shown in Table 3 and Table 4, the environmental impacts of openness vary depending on the particular measurement of openness examined. As most of the estimated coefficients do show very incoherence between these two environmental indicators, once more the flow environmental damages distinguish themselves from stock environmental damages in terms of their determinants.

The estimated coefficients for *OPEN_HARBOR* show plus signs but it is not statistically significant in the IAQI estimates. As Grossman (1995) argued, countries that experienced industrialization at a later stage had been apt to succeed environmental preservation thanks to the experiences learned from the developed countries. Within a country, as implied from this *latecomer hypothesis*, cities experienced industrialization at a later stage would complete the process in a shorter time and/or with better performances.[11] Factors relating to this issue include not only the technology transfer, and the government or private enterprise initiatives, but also benefiting from the experiences of the developed cities. Given the fact that Chinese harbors are located in her eastern part, there seems anti-evidence of *latecomer hypothesis*. In fact, while technology transfer is often characterized as definitive of the advantage of latecomers, there do remain obstacles to such transfer partially due to the high cost of equipment and insufficient technical capability on the part of the receivers. As *latecomers* in China, most of the western and central cities tend to receive the transferred industries from eastern cities in accordance not only with their comparative advantage but with their acceptance of environmental degradation.

Concerning the effects of trade policy on the environment, we find no evidence that a more open policy regime could lead to better air quality. One explanation should be that the effect of trade policy changes may be conditional on other factors. For example, Damania *et al*. (2003) empirically found that a country with more open trade policy would tend to have stricter environmental standards (low lead content) on average, in particular where the level of corruption was high. If these other variables are omitted, *OPEN_POLICY* falsely may take the credit. Therefore, we accept the notion that the links between trade and the environment are hard to separate from the policies that typically accompany more open trading regimes, such as more openness to FDI and less rent-seeking, and so on. Another explanation is that with the significant easing of regulations on international trade and FDI in the interior cities in recent, the difference in the level of deregulation (“preferential treatment”) during our targeted period became small.

Next we turn to the environmental impacts of FDI inflows. The results relating to these two pollution indicators seem rather baffling. In both of the specifications for industrial SO_2 emissions and IAQI, *OPEN_FDI* have statistically insignificant effects. He (2006), using China’s provincial level panel data during 1994-2001, found that with 1% increase in FDI capital inflow, industrial SO2 emission will increase by 0.098%. Compared with the period prior to China’s WTO accession, the emergence of service FDI has been gradually supplanting the traditional manufacturing FDI after 2001. Meanwhile, since China’s accession to the WTO, the opinion has repeated its basic policy of promoting “quality rather than quantity. In keeping with this policy, FDI in energy-efficient and environmental clean industries have been encouraged. These recent inter-sectoral and intra-sectoral shifts in FDI may be partly accountable for our different findings.[12] Although the estimated coefficient on *OPEN_FDI_RATIO* for the case of industrial SO_2 emissions is insignificantly positive, the sign of *OPEN_FDI_RATIO* is negative with statistical significance in the IAQI. Given the fact that environmental problems that are due to stock pollution are much difficult to be controlled than those due to flow pollution, the economic significance of these results is substantial. If foreign investment from industrial countries provides cleaner technology and seeks rather than avoids locations with high regulatory standards, investment by high-income cities will have the potential to improve environmental outcomes.

When we take the additional step of identifying FDI by sources, as with the full sample, our results indicate that industrial activities of enterprises funded from non-ethnically Chinese economies lead to more industrial SO_2 emissions. The results in Table 4 suggest that industrial activities of enterprises funded from ethnically Chinese economies exert a negative and statistically significant impact on the urban air quality. One interpretation is that following co-ethnic networks and wider processes of globalization, the equity joint ventures funded from ethnically Chinese sources are more susceptible to reputation risks, foreign green consumerism and global standards. In contrast, as Dean *et al.* (2009) found, equity joint ventures funded from non-ethnically Chinese were not sensitive to environmental standards. A good case in point was the pronounced specialization occurred in the northwest region, where natural-resource based activities dominated. These firms subject to impediments in mobility might use time rather than location to mitigate the adverse effect of regulatory changes.

The result in Table 2 confirms that the international cultural exchanges play significant role in decreasing industrial SO_2 emissions. However, the estimated coefficient on *OPEN_FRIENDS* for the case of IAQI is significantly positive. It is likely that the variable used as a cultural exchange proxy may itself not reflect cultural exchange differences across cities since this source of variation may be swamped by their economic and institutional differences. Meanwhile, although the *OPEN_TURISM* variable has a negative coefficient in all preliminary regressions, it was not statistically significant for both of our environmental indicators, partly because city-specific differences in international culture exchange were captured by the fixed effects, and partly because our proxies were indicators of international tourism rather than measures of actual international cultural exchange. Actually, questions regarding the role of cultural exchange in environmental protection have been largely absent in economic research. This is primarily the result of the absence of an empirical methodology that can allow one to investigate this issue. In particular, it reflects the difficulty in finding an approach that is capable of distinguishing the effects of cultural exchange from those of the economic and institutional factors that also influence the environment.

∗∗Insert Table 3 and Table 4 about here∗∗

6. Conclusions

Currently, very little knowledge and agreement on the interactions between economic growth, openness and pollution exist. As an emerging global giant with a relatively uniform political system, China has performed as an excellent real-world test case in this line of literature. In this paper, we take a step in this direction by focusing on the environmental consequences of economic growth and openness at city level. Since we use variation within Chinese cities, many of the institutional, cultural, and policy variables that confound the environmental consequences of economic growth and international trade at the country level are held constant, it increases the inferential validity. Our empirical results provide strong evidence to illustrate how the choices of sample, pollutant, and the measure of openness affect the estimation results. It implies that we must be very cautious to derive any conclusion on if freer trade is good or bad for environment.

Combing with all the estimated coefficients, we find that while there have been, and continue to be, clear domestic, endogenous developments, pressures and triggers for environmental changes, the remarkable opening up of China to the outside world has also provides a powerful force for these changes. The environmental consequences of openness vary depending on how the environment damage and openness are measured. Our urban air quality data and aggregate emissions data yield different perspectives on the link between economic growth, openness and the environment. As a matter of fact, the distinction between flow pollution and stock pollution hinges on the length of the unit time period underlying the description as well as on the spatial size of the system under consideration. Our refinements to the measure of openness appear to substantially weaken the robustness of the link between openness and pollution. One implication is that what we mean by openness and how we measure deviation from free trade are keys.

Our panel data used in this study allowed inferences to be drawn beyond these *ceteris paribus* effects. In particular, our results suggest that the *latecomers* have a strong desire for economic growth at the cost of the environment in order to catch up with their counterparts. Meanwhile, it should be cautious here that the sheer scale of growth still has overshadowed potential improvements from these positive changes and the weakness in regulatory enforcement will continue to diminish the effects of legal advances. The challenge for China is to put in motion a transition to a more secure, lower-pollutant energy system, without undermining economic and social development. To successfully generate a deliberate push for corporate environmental stewardship would require many changes within the city industrial and political spheres.

Data reflecting China environment quality have always been doubted to be notoriously patchy in coverage or poor in quality. Apart from the reliability of the data, there is still much more work to be done on this issue. First, this study has only involved the analysis of city-level pollution data that did not exist for the period prior to the 2000s, and mostly included environmental problems that were local, easy and inexpensive to solve and data for which were well organized and available. The shortcoming of our paper regarding time-period and pollutants considered for analysis, cost and ease of environmental cleanup necessitates a closer examination. The second potential problem relates to the question of causality. Allowing for the endogeneity of openness and income could prove interesting (*e.g.*, Frankel and Rose, 2005; Managi *et al.*, 2009). Thirdly, openness and its environmental consequences are likely to high correlated with other determinants of pollution. If these other variables are omitted, openness falsely may take the credit. If they are included, multicollinearity may make it impossible to tell which really matters. The further research should aim to tell whether openness or some other aspect of the "package" is what matters, or indeed whether the different components are too interrelated to assign an independent benefit to one piece. Finally, it does not seem implausible to suggest that the environmental performance of cities measured in terms of emissions or concentrations is dependent on the characteristics of neighboring cities. In particular, pollution control in China is essentially a hybrid of centralized standard setting and city-level implementation and enforcement. Consequently, it appears that transboundary pollution and the nature of current environmental regulation leave cities considerable incentive and latitude to act strategically. Thus, besides controlling these possible spatial effects by the use of some econometric techniques, it seems interesting to know whether these possible spatial effects are due to governments mimicking each other's environmental policy or whether these are purely incidental effects caused by the geographical diffusion of technologies, products and lifestyles.

Notes

1. China's primary energy demand is projected to more than double from 1,742 million tons of oil equivalent (TOE) in 2005 to 3,819 million TOE in 2030 with an average annual rate of growth of 3.2%, which is predicted to push up emissions of SO_2 from 26 million tones in 2005 to 30 million tones by 2030 (IEA 2007).
2. "Acid Rain Control Zones" comprise areas in southern China where acid rain has been severe, while "SO_2

Control Zones" include cities in northern China with high ambient concentrations of SO_2. The main source of these emissions is the power sector, which naturally receive the lion's share of attention from researchers and regulating authorities.

3. The logarithmic transform of the industrial SO_2 emissions is employed, since the distribution of yearly summary statistics for this environmental indicator appears to be lognormal.
4. Although a cubic function is also considered by us, the fact that every higher-order polynomial term necessarily extends to plus or minus infinity is deemed to be unrealistic. Given no consensus over the best function either, our study only concentrates on quadratic relationships.
5. The capital of Tibetan, Lasa, has not been included in our sample due to lack of continuous data on it.
6. Chinese national urban household survey had only covered non-farm households before 2002. Since 2002, the survey has begun to cover all households in district areas of cities and towns. Households are selected using a multistage, stratified and systematic sampling method. At the end of 2008, the national sample includes 64,675 urban households.
7. According to NBS (2001, 2009), during our targeted period, most FDI inflows originated from ethnically Chinese economies concentrated in the southern coastal region of China and in the vertical category which involved labor-intensive processing of imported inputs for re-export. In contrast, FDI flows from non-ethnically Chinese economies were split more equally across cities and more heavily in the horizontal category, which sought to exploit the Chinese domestic market.
8. Based on the number of economic zones in each province and the extent of the preferential treatment, Démurger *et al*. (2002) constructed the provincial preferential policy index during 1978-1998 to reflect the differences in provincial trade policies. In our paper, we prefer another proxy to this index partly because this variable does not vary after 1995 since the various types of economic zones have been set up in the early 1990s, and partly because this identification strategy is vulnerable to its arbitrary weights assigned to each economic zone with different degrees of preferential policies.
9. The effects of cultural exchange on the environment depend on how quickly social beliefs and preferences change over time, which in turn depends on the environment broadly speaking, including the opportunities which determine individuals' learning pace, their interactions with others, and particular historical experiences.
10. This arrangement was originally established in reorganization of opportunities for city official and citizens to experience and explore international cultures through long-term community partnerships, and has fostered a number of cultural exchanges and business ventures.
11. The notion of the latecomer's advantage originated from Gerschenkron (1962), who argued that different periods exhibit different types of economic development. Thus, given the coexistence of developed and developing countries, the latter can skip several stages of economic development that the former had to go through, by adopting new advanced technology.
12. From 2001 to 2008, China's FDI in the service sector rose by 17.2 percent to $37.9 billion, while the "dirty sector" dropped 16.05 percent. The service industry accounted for 41.07 percent of investment in 2008 (NBS 2002, 2009).

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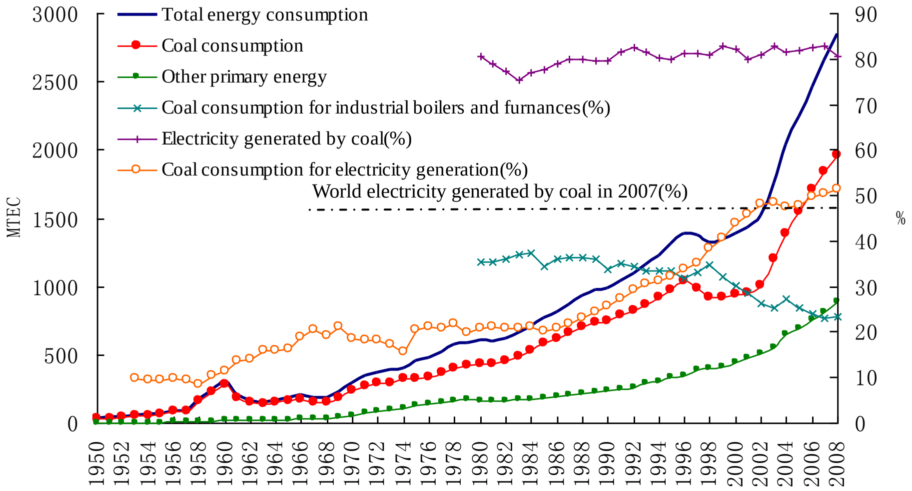

Fig. 1. Coal dependence of China

Notes: (1) MTCE stands for one million metric tons of standard coal equivalent (SCE). (2) The coefficient for each primary energy conversion into SCE has not been constant across this period.

Data sources: *China Compendium of Statistics 1949-2008*, *China's 50-Year Statistical Data Collection on Industry, Transportation and Energy*, *China Coal Industry Statistical Compendium 1949-2004*, *China Energy Statistical Yearbook* 2006-2009 and *World Development Indicator* 2010.

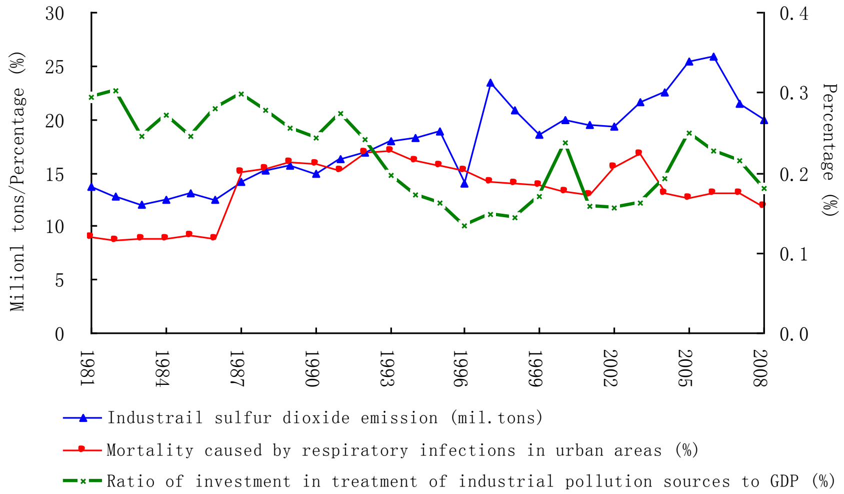

Fig. 2. Industrial SO_2 emission, mortality and pollution abatement

Note: From 1997, statistical coverage of emission of industrial water and SO_2 emission are widened from industrial enterprises with pollution emission at county level and above to those at township level and above.

Data sources: *China Statistical Yearbook* 1983-2009, *China Statistical Yearbook on Environment 2009*, *China Environment Yearbook* 1991-2000, *China Compendium of Environmental Statistics 1981-1990*, *Yearbook of Health in the People's Republic of China* 1983-2000 and *China Health Statistics* 2003-2009.

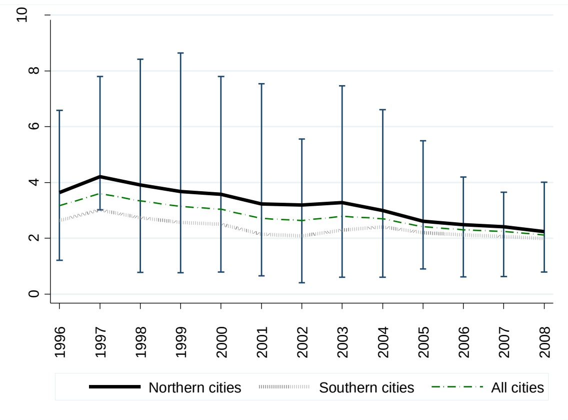

Fig. 3. Ambient air quality levels in China's key environmental protection cities

Notes: (1) Vertical bars indicate range of values for all cities; the highest horizontal mark shows the most polluted of the Chinese cities, and the lowest horizontal mark shows the lest polluted of the Chinese cities. (2) The numbers of the key environmental protection cities are different across years.

Data sources: *China Environment Yearbook* 1997-2009.

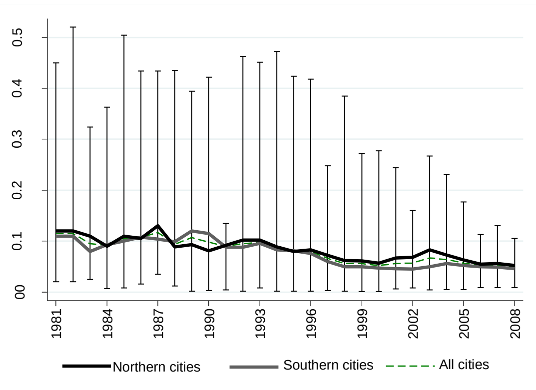

Fig. 4. SO_2 concentration in China's key environmental protection cities

Notes: (1) Vertical bars indicate range of values for all cities; the highest horizontal mark shows the most polluted of the Chinese cities, and the lowest horizontal mark shows the lest polluted of the Chinese cities. (2) The numbers of the key environmental protection cities are different across years.

Data sources: *China Environment Yearbook* 1990-2009.

Table 1

Regional disparity and air pollution.

Indicators	All cities (n=286)		Eastern (n=132)		Middle (n=70)		Western (n=84)	
	2001 Year	2008 Year	2001 Year	2008 Year	2001 Year	2008 Year	2001 Year	2008 Year
Total population (billion)	1.167	1.233	0.566	0.600	0.314	0.331	0.286	0.303
GDP per capita (10,000 Yuan)	0.380	0.998	0.535	1.412	0.245	0.655	0.248	0.632
Household disposable income (Yuan)	0.561	1.187	0.738	1.356	0.569	1.068	0.581	1.022
Trade intensity	0.160	0.235	0.270	0.396	0.050	0.096	0.060	0.098
Total inward FDI inflows (million $)	4.900	14.577	4.400	11.470	0.318	1.891	0.182	1.216
Capital-labor ratio (10,000 Yuan per worker)	2.971	7.087	3.746	8.655	1.976	5.188	2.581	6.204
Ambient air quality index	2.801	2.126	2.627	2.043	2.813	2.242	3.106	2.194
SO_2 emissions per capita (kg)	15.928	20.332	15.239	18.527	9.930	14.643	22.009	27.910
SO_2 concentration (mg/m^3)	5.642	4.869	5.450	4.416	5.608	5.119	6.010	5.474
SO_2 removal rate	17.632	41.880	15.541	44.337	16.429	37.193	23.004	39.773

Note : See Table A.2 for the data sources and Fig. A for the delimination of the three regions.

Table 2

Antweiler et al. (2001) structural model: trade-environmental nexus request.

Independent variable	Log (Industrial SO_2 emissions per capita)			Integrated air quality index		
	Model 1	Model 2	Model 3	Model 8	Model 9	Model 10
Constant	1.936***	1.763***	1.303***	2.399***	2.964***	2.345***
	(0.158)	(0.168)	(0.212)	(0.150)	(0.164)	(0.274)
TECHNIQUE	0.880***	1.084***	1.145***	-0.841**	-1.455***	-1.312***
	(0.238)	(0.248)	(0.310)	(0.374)	(0.341)	(0.390)
$TECHNIQUE^2$	-0.210***	-0.243***	-0.256***	0.233**	0.436***	0.401***
	(0.057)	(0.061)	(0.085)	(0.117)	(0.112)	(0.135)
ECON_SCALE	-0.890***	-0.763***	-1.041***	4.261***	3.955***	3.069***
	(0.135)	(0.092)	(0.118)	(0.433)	(0.571)	(0.588)
$ECON\_SCALE^2$	0.184***	0.314***	0.367***	-1.135***	-1.075***	-0.898***
	(0.053)	(0.056)	(0.067)	(0.151)	(0.168)	(0.178)
KtoL	0.030***	0.032***	0.019***	-0.061	-0.086	-0.113*
	(0.005)	(0.006)	(0.007)	(0.041)	(0.053)	(0.061)
$KtoL^2$	0.001***	0.001***	0.001***	0.002***	0.002***	0.001**
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)
$KtoL \times TECHNIQUE$	-0.035***	-0.042***	-0.027***	0.003	0.022	0.059**
	(0.002)	(0.004)	(0.004)	(0.010)	(0.023)	(0.028)
OPEN_TRADE		0.525***	0.577***		-0.182	-0.049
		(0.063)	(0.065)		(0.279)	(0.261)
$OPEN\_TRADE \times RKtoL$		-0.031	-0.068		-0.607***	-0.769***
		(0.085)	(0.088)		(0.215)	(0.229)
$OPEN\_TRADE \times RKtoL^2$		-0.007	0.008		0.113*	0.160***
		(0.010)	(0.011)		(0.040)	(0.043)
$OPEN\_TRADE \times RINCOME$		-0.608***	-0.615***		0.476***	0.501***
		(0.118)	(0.110)		(0.148)	(0.128)
$OPEN\_TRADE \times RINCOME^2$		0.103***	0.106***		-0.175***	-0.168***
		(0.034)	(0.033)		(0.035)	(0.033)
$OPEN\_TRADE \times RKtoL \times RINCOME$		0.072*	0.055		0.124***	-0.071
		(0.039)	(0.037)		(0.042)	(0.053)
COAL_DEPENDENCE			-0.052***			-0.128*
			(0.014)			(0.069)
DIRTY_SECTOR			0.005***			0.014***
			(0.001)			(0.003)
GROWTH_RATE			0.007***			0.026***
			(0.002)			(0.008)
TEMPERATURE_INDEX			0.106***			-0.148***
			(0.037)			(0.030)
Within R-squared	0.256	0.260	0.272	0.311	0.320	0.344
F test	13642.67***	211.25***	383.59***	1555.21***	4078.84***	401.87***
Hausman test	55.18***	59.24***	170.81***	36.19***	35.56**	28.03*
Frees test	41.14***	40.07***	35.62***	12.82***	12.62***	11.08***
Wooldridge test	48.89***	49.63***	49.27***	73.53***	73.94***	77.75***
Wald test for heteroskedasticity	9.9×10^4***	9.6×10^4***	9.1×10^4***	9.5×10^3***	1.3×10^4***	8.6×10^3***
Wald test for year dummies	9.3×10^4***	1.7×10^6***	1.6×10^6***	2.7×10^4***	1.2×10^5***	1.7×10^3***
City dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2288	2288	2288	810	810	810
Cities	286	286	286	112	112	112

Note : *, **, and *** stand for Statistically significance level at 10%, 5%, and 1% respectively.

Table 3

ACT (2001) structural model: alternative specifications (dependent variable: logarithmic industrial SO_2 emission per capita).

Independent variable	Geography and policy		FDI		HMT and foreign funded enterprises			Culture	
	Harbor	Trade policy	Real value	Ratio	All	H-M-T	Foreign	Sister cities	Foreign turism
Constant	1.612***	1.493***	1.490***	1.454***	1.556***	1.540***	1.484***	1.654***	1.491***
	(0.264)	(0.202)	(0.204)	(0.226)	(0.210)	(0.212)	(0.186)	(0.210)	(0.202)
TECHNIQUE	0.852**	0.925***	0.930***	0.871***	0.958***	1.013***	0.931***	0.870***	0.929***
	(0.337)	(0.293)	(0.298)	(0.270)	(0.300)	(0.259)	(0.296)	(0.303)	(0.298)
$TECHNIQUE^2$	-0.202**	-0.217***	-0.219***	-0.198***	-0.234***	-0.257***	-0.219***	-0.213**	-0.218***
	(0.088)	(0.079)	(0.081)	(0.069)	(0.081)	(0.067)	(0.082)	(0.084)	(0.081)
ECON_SCALE	-1.326***	-1.111***	-1.110***	-0.892***	-1.184***	-1.433***	-1.107***	-1.040***	-1.114***
	(0.096)	(0.126)	(0.121)	(0.138)	(0.113)	(0.142)	(0.096)	(0.116)	(0.121)
$ECON\_SCALE^2$	0.289***	0.241***	0.239***	0.184***	0.247***	0.303***	0.239***	0.247***	0.239***
	(0.041)	(0.053)	(0.050)	(0.029)	(0.045)	(0.045)	(0.043)	(0.052)	(0.050)
KtoL	0.020***	0.021***	0.021***	0.024***	0.017***	0.019***	0.021***	-0.015***	0.022***
	(0.006)	(0.007)	(0.006)	(0.005)	(0.006)	(0.006)	(0.007)	(0.005)	(0.006)
$KtoL^2$	0.001***	0.001***	0.001***	0.001***	0.001***	0.001**	0.001***	0.002	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$KtoL \times TECHNIQUE$	-0.026***	-0.025***	-0.025***	-0.026***	-0.020**	-0.019***	-0.025***	-0.012**	-0.024***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.003)	(0.005)	(0.003)
COAL_DEPENDENCE	-0.055***	-0.052***	-0.052***	-0.056***	-0.054***	-0.052***	-0.052***	-0.058***	-0.052***
	(0.003)	(0.003)	(0.013)	(0.014)	(0.013)	(0.014)	(0.013)	(0.012)	(0.013)
DIRTY_SECTOR	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
GROWTH_RATE	0.007***	0.008***	0.007***	0.008***	0.007***	0.008***	0.008***	0.008***	0.008***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
TEMPERATURE_INDEX	0.094**	0.106***	0.106***	0.111***	0.105***	0.101***	0.106***	0.108***	0.106***
	(0.038)	(0.035)	(0.035)	(0.037)	(0.035)	(0.034)	(0.035)	(0.035)	(0.036)
OPEN_HARBOR	0.010***								
	(0.006)								
OPEN_POLICY		0.001							
		(0.001)							
OPEN_FDI			0.034						
			(0.061)						
OPEN_FDI_RATIO				0.425					
				(0.279)					
OPEN_TFIND					-0.004***				
					(0.002)				
OPEN_HMT						-0.011**			
						(0.005)			
OPEN_FIND							0.001		
							(0.002)		
OPEN_FRIENDS								-0.040***	
								(0.005)	
OPEN_TURISM									-0.005
									(0.012)
Within R-squared	0.270	0.268	0.267	0.270	0.269	0.273	0.267	0.274	0.268
F test	117.12***	887.06***	589.43***	852.34***	798.88***	310.46***	233.41***	551.40***	449.96***
Hausman test	200.23***	143.80***	150.80***	166.46***	101.75***	206.56***	188.00***	118.34***	187.86***
Frees test	35.75***	37.71***	37.41***	38.81***	37.77***	35.75***	37.24***	37.30***	37.56***
Wooldridge test	48.63***	48.39***	48.52***	49.01***	48.67**	48.78***	48.48***	48.08***	48.28***
Wald test for heteroskedasticity	1.1×10^5***	1.0×10^5***	9.8×10^4*	8.1×10^4***	1.2×10^5*	9.0×10^4***	9.9×10^4***	1.5×10^5***	1.0×10^5***
Wald test for year dummies	2.4×10^5***	8.6×10^5***	1.5×10^5*	3.9×10^5***	8.9×10^6*	7.5×10^5***	3.5×10^4***	3.6×10^5***	1.5×10^5***
City dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2288	2288	2288	2288	2288	2288	2288	2288	2288
Cities	286	286	286	286	286	286	286	286	286

Note : *, **, and *** stand for Statistically significance level at 10%, 5%, and 1% respectively.

Table 4

ACT (2001) structural model: alternative specifications (dependent variable: integrated air quality index).

Independent variable	Geography and policy		FDI		HMT and foreign funded enterprises			Culture	
	Harbor	Trade policy	Real value	Ratio	All	H-M-T	Foreign	Sister cities	Foreign turism
Constant	1.832***	1.687***	1.651***	1.919***	1.515***	1.658***	1.527***	1.329***	1.656***
	(0.458)	(0.241)	(0.245)	(0.251)	(0.231)	(0.234)	(0.262)	(0.221)	(0.245)
TECHNIQUE	-0.712*	-0.668*	-0.608	-0.634	-0.658	-0.624*	-0.595	-0.509	-0.623*
	(0.416)	(0.396)	(0.374)	(0.396)	(0.401)	(0.364)	(0.385)	(0.375)	(0.363)
$TECHNIQUE^2$	0.196	0.191	0.170	0.205	0.196	0.178	0.173	0.151	0.178
	(0.130)	(0.127)	(0.115)	(0.132)	(0.130)	(0.115)	(0.122)	(0.111)	(0.116)
ECON_SCALE	3.200***	3.619***	3.690***	3.082***	3.704***	3.593***	3.430***	3.564***	3.597***
	(0.695)	(0.312)	(0.252)	(0.426)	(0.264)	(0.368)	(0.352)	(0.301)	(0.338)
$ECON\_SCALE^2$	-0.847***	-0.942***	-0.957*	-0.811***	-0.946***	-0.937***	-0.886***	-0.940***	-0.938***
	(0.175)	(0.122)	(0.105)	(0.144)	(0.110)	(0.138)	(0.129)	(0.123)	(0.126)
KtoL	-0.072	-0.070	-0.072	-0.069	-0.065	-0.069	-0.069	-0.058	-0.069
	(0.047)	(0.046)	(0.044)	(0.047)	(0.048)	(0.045)	(0.047)	(0.043)	(0.046)
$KtoL^2$	0.001***	0.001***	0.001***	0.001***	0.002***	0.001***	0.002***	0.002***	0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
$KtoL \times TECHNIQUE$	0.023**	0.022***	0.026***	0.019***	0.016	0.022**	0.019	0.010	0.022**
	(0.011)	(0.011)	(0.008)	(0.011)	(0.014)	(0.010)	(0.012)	(0.010)	(0.011)
COAL_DEPENDENCE	-0.107	-0.095	-0.098	-0.094	-0.095	-0.097	-0.092	-0.090	-0.097
	(0.072)	(0.073)	(0.073)	(0.073)	(0.073)	(0.074)	(0.075)	(0.073)	(0.074)
DIRTY_SECTOR	0.015***	0.014***	0.015***	0.012***	0.014***	0.015***	0.014***	0.016***	0.015***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
GROWTH_RATE	0.023**	0.024***	0.024***	0.023***	0.024***	0.024***	0.024***	0.023***	0.024***
	(0.009)	(0.008)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.083)	(0.008)
TEMPERATURE_INDEX	-0.175***	-0.150***	-0.160***	-0.170***	-0.144***	-0.153***	-0.150***	-0.164***	-0.152***
	(0.047)	(0.022)	(0.027)	(0.026)	(0.023)	(0.022)	(0.024)	(0.028)	(0.023)
OPEN_HARBOR	0.017								
	(0.020)								
OPEN_POLICY		0.002							
		(0.002)							
OPEN_FDI			-0.331						
			(0.387)						
OPEN_FDI_RATIO				-1.151***					
				(0.258)					
OPEN_TFIND					0.007*				
					(0.004)				
OPEN_HMT						-0.0002			
						(0.004)			
OPEN_FIND							0.010*		
							(0.006)		
OPEN_FRIENDS								0.033***	
								(0.011)	
OPEN_TURISM									-0.001
									(0.011)
Within R-squared	0.333	0.331	0.331	0.335	0.332	0.331	0.333	0.334	0.331
F test	800.64***	632.58***	1553.70***	430.67***	499.85***	2234.96***	438.12***	574.27***	504.27***
Hausman test	27.40***	45.60***	34.99***	28.82***	45.00***	31.74**	49.78***	36.54***	37.88***
Frees test	11.42***	12.04***	12.39***	12.28***	12.88***	11.78***	12.79***	11.67***	11.78***
Wooldridge test	79.39***	77.84***	78.27***	76.76***	77.51***	77.57***	77.65***	78.05***	77.55***
Wald test for heteroskedasticity	2.3×10^4***	2.9×10^4***	4.3×10^4***	7.9×10^4***	3.3×10^4***	3.2×10^4***	2.8×10^4***	4.3×10^4***	1.2×10^4***
Wald test for year dummies	1.3×10^4***	1.5×10^4***	4.6×10^4***	6.1×10^3***	1.7×10^4***	1.2×10^4***	9.6×10^4***	6.5×10^4***	1.5×10^5***
City dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	810	810	810	810	810	810	810	810	810
Cities	112	112	112	112	112	112	112	112	112

Note : *, **, and *** stand for Statistically significance level at 10%, 5%, and 1% respectively.

Appendix

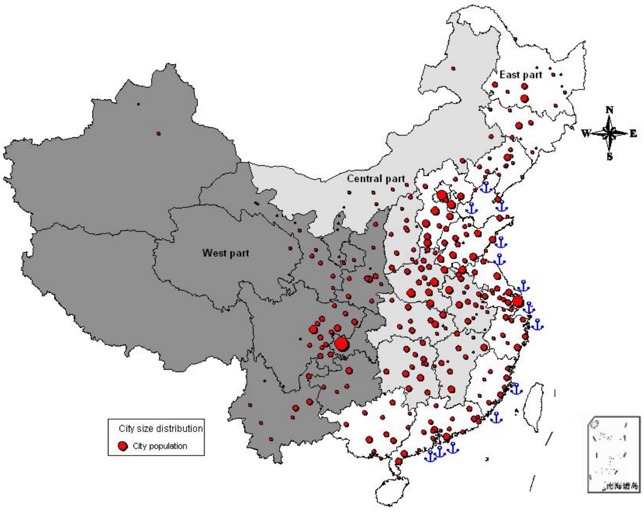

Fig. A. Sample city spatial distribution

Table A.1

Number of enterprises under national economic and environmental annual surveys.

Year	Number of enterprises (unit)		Industrial output value (billion Yuan)		Ratio (%)	
	Total (A1)	Under environmental monitoring (A2)	Total (B1)	Under environmental monitoring (B2)	A2/A1	B2/B1
2001	171256	71425	9545	5382	41.71	56.39
2002	181557	70831	11078	6076	39.01	54.85
2003	196222	69904	14227	7093	35.62	49.85
2004	276474	70630	20172	8984	25.55	44.54
2005	271835	70612	25162	11209	25.98	44.55
2006	301961	76185	31659	14260	25.23	45.04
2007	336768	106457	40518	18332	31.61	45.24
2008	426113	110373	50745	22026	25.90	43.41

Note: Before the year 2007, industrial statistics have been collected from all state-owned industrial enterprises and other industrial enterprises with revenue from principal business over 5 million Yuan. After the year 2007, the scope of industrial statistics has been changed to be all industrial enterprises with revenue from principal business over 5 million Yuan.
Source: *China Statistics Yearbook* 2002-2009 and *China Environment Yearbooks* 2002-2009

Table A.2

Main data sources

Code	Name of statistical yearbooks or databases	Issue time
1	*China Ports Yearbook*	2002-2009
2	*China Commercial Yearbook*	2005-2009
3	China Meteorological Database	2001-2008
4	*China Environmental Yearbook*	2001-2009
5	*China City statistical Yearbook*	2001-2009
6	*China Customs Statistical Yearbook*	2002-2009
7	*China Environmental Statistical Yearbook*	2001-2009
8	A collection of some Chinese cities' yearbooks	2001-2009
9	*China Urban Construction Statistical Yearbook*	2002-2009
10	*China Statistical Yearbook for Regional Economy*	2001-2009
11	A complete collection of provincial statistical yearbooks	2001-2009
12	A collection of some Chinese cities' statistical yearbooks	2001-2009
13	*China Special Economic Zone and Development Area Yearbook*	2002-2003
14	*Statistical Materials on the Population of Counties and Cities of the People's Republic of China*	2000-2008
15	A collection of some Chinese cities statistical communiqués on economic and social development	2001-2009

Note: The calibers of Chinese city-level data among different sources are not completely uniform. See Zhou and Ma (2005) for a detailed description of scope and characteristics of the major sources of Chinese urban statistics.

Table A.3

Variable description and descriptive statistics

Variable	Definition	Sample size	Mean	Std dev	Minimum	Maximum
PSO2	Industrial SO_2 emission per capita (kg)	2288	19.57	26.88	0.06	310.18
IAQI	Integrated air quality index	810	2.50	0.93	0.09	7.46
TECHNIQUE	One period lagged urban household disposable income (10,000 Yuan)	2288	0.82	0.32	0.33	2.76
RINCOME	Urban household disposable income relative to the national average	2288	1.00	0.33	0.13	3.70
ECON_SCALE	City economic intensity calculated as units of GDP per sq.m (100 Yuan/m^2)	2288	0.08	0.16	2×10^{-4}	2.62
KtoL	Captial-to-labor ratio (10,000 Yuan per worker)	2288	0.46	0.40	0.05	4.18
RKtoL	Captial-to-labor ratio relative to the national average	2288	1.00	0.82	0.16	11.37
DIRTY_SECTOR	Proportion of employed persons in "dirty sectors" to total employed persons (%)	2288	34.34	13.40	5.21	78.17
TEMP_INDEX	Temperature index defined by $average_{temp}/(max_{temp}-min_{temp})$	2288	1.78	0.86	-0.08	4.77
COAL_DEPENDENCE	Ratio of net coal imports from other provinces and countries to total coal supply within the province which city *i* belongs to	2288	0.16	1.14	-7.15	4.91
GROWTH_RATE	Real GDP per capita growth rate (%)	2288	13.02	3.66	-7.80	37.00
OPEN_TRADE	Trade intensity measured by ratio of imports plus exports to GDP	2288	0.21	0.42	0.00	3.48
OPEN_POLICY	Ratio of trade volumes in natinal level DEZs of city *i* to total trade volumes in city *i*	2288	5.58	16.67	0.00	100.00
OPEN_HARBOR	Harbor accessibility index defined by average weighted distance to the two closest harbors	2288	3.50	3.98	0.02	27.31
OPEN_FDI	Total inward FDI inflows (million $)	2288	0.03	0.08	0.00	1.01
OPEN_FDI_RATIO	Ratio of inward FDI to fixed investment	2288	0.06	0.09	0.00	0.94
OPEN_HMT	Ratio of industrial output for firms funded by HMT to total industrial output	2288	6.55	10.00	0.00	62.64
OPEN_FIND	Ratio of industrial output for firms funded by foreign countries to total industrial output	2288	8.54	10.93	0.00	77.99
OPEN_TFIND	Sum of "*FENHMT*" and "*FENO*"	2288	15.10	17.34	0.00	93.83
OPEN_FRIENDS	Total number of sister city relationships adopted	2288	3.10	4.90	0.00	54.00
OPEN_TURISM	Ratio of foreign exchange earnings from tourism to GDP	2288	0.65	1.72	0.00	28.93

Notes: (1) All the variables measured in value are converted into the Yuan of 2000 constant price unless otherwise specified. (2) National averages are calculated as the average of all cities for whom data are reported in the year t. (3) "Dirty sectors" include manufacturing industry, mining and quarrying industry, production and supply of electricity, gas and water industry. (4) Weights for measuring variable *OPEN_HARBOR* are the harbors' annual container handling capacity. (5) The distance is computed with the "Oblique Spherical Triangle Method" using the latitudes and longitudes of the cities and the harbors (Wei and Wu 2001).