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Industrial Air Pollution in Chinese Cities: A Perspective of Economic Transition

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Industrial Air Pollution in Chinese Cities: A Perspective of Economic Transition

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Abstract

China has received constant attention for both its remarkable growing economy and its serious environmental degradation. Economic transition has posed a serious contradiction for environmental protection efforts in China. This study investigates the different environmental effects of the triple transition process of marketization, globalization and decentralization using data on industrial SO2 emission and dusts at the city level in China. Overall, China's industrial production has been cleaner and pollution intensive industries have become increasingly pollution effective. Panel data regression results confirm the EKC effect in Chinese cities. There is weak evidence to show that economic liberalization has improved environment quality. Dominance of SOEs however has degraded China's environment. No evidence is found to support the pollution heaven hypothesis. Participation in economic globalization in turn is largely beneficial to environment. Decentralization has induced the race to the bottom competition by lowering environmental regulations to attract taxable and high value added pollution intensive industries. There however remain significant regional differences in the environmental effects of economic transition. The results imply that the institutional perspective provide an important angel to understand the issue of environmental degradation in China.

Key Words: Industrial pollution, economic transition, SO2 emission, industrial dust, China.

Industrial Air Pollution in Chinese Cities: A Perspective of Economic Transition

Introduction

China has received constant attention for both its rapidly growing economy and its serious environmental degradation since the 1980s. There are almost daily media reports of rivers and lakes poisoned by pollution, farmlands tainted by industrial pollution and fertilizers and cities choking on smog in China (Dean and Lovely, 2008). The high-growth, resource-intensive and export-oriented development strategy that China has pursued, coupled with the norms and institutional relationship designed to support this development strategy, have no doubt played a critical role in deteriorating environmental quality of Chinese cities (Jahiel, 1997,1998; Chan and Yao, 2008). The growth in industrial and municipal wastes, vehicle emissions, energy consumption and deforestation cast serious doubt on the sustainability of China's development path. As Naughton (2007) noted "the challenges of water availability, resilience of the natural environment and atmospheric degradation and climate change are among the most serious that China confronts".

Since the late 1970s, China has experienced a triple process of economic transition, that is, marketization, globalization and decentralization. The economic transition however has posed a serious contradiction for environmental protection efforts in China (Jahiel, 1997). The contradiction has arisen from their different environmental effects. This study is to investigate the different environmental effects of the triple process of economic transition. In particular, has marketization and regional decentralization increased industrial pollution in Chinese cities? What is the possible relationship between globalization and air pollution in China? Those questions deserve further and thorough empirical investigations.

There are limited studies of air pollution across Chinese provinces and industries using the framework of Environmental Kuznets Model using provincial and industrial level data (Poon et al, 2006; He, 2006,2009, 2010) Other studies explored the environmental performance of enterprises using micro-level data (Wang, 1999, 2000; Wang and Wheeler, 2000; Dasgupta et al., 2001; Wang et al., 2001; Wang et al., 2002; Wang and Jin, 2002). The working paper series of the World Bank studied the influence of pollution charge, environmental subsidies, enforcement of environmental regulations, ownership and bargain power of factories and community pressures on the emission behavior of industrial polluters in China. Those studies certainly have advanced the knowledge of industrial pollution in China. There however lacks a systematic investigation about the relationship between economic reform and industrial pollution. China's economic transition includes a two-pronged decentralization process: power and fiscal decentralization from the central to local governments and decentralization of decision-making from governments to firms and households (Qian and Weingast, 1997; He, 2006). China has increasingly integrated into the world economy through international trade and utilization of foreign direct investment since the late 1970s. The triple process of marketization, globalization and decentralization has different impacts on the environment performance of industrial enterprises through scale, composition and technique effects.

Marketization has gradually introduced market forces to allocate resources across sectors and cities, and allows multiple ownerships in the Chinese economy. State-owned enterprises (SOEs) have more bargaining power than privately owned enterprises and strong connections with local government and have less incentive to reduce their pollution. As a consequence, less economically liberalized cities may host more pollution intensive industries. On the other hand, private sectors are solely profit oriented, SOEs normally take more social impacts into their decision-making processes and their environmental performance could be theoretically better than private sectors. Globalization has also ambiguous impacts on industrial pollution in Chinese cities. Pollution haven thesis proposes that international trade and foreign investment are harmful to a country's environment, especially in developing countries whose environmental regulations are weak. International fragmentation of production would allow China to specialize in cleaner stages of production. Trade, FDI and international fragmentation would help clean the air in China (Dean and Lovely, 2008). Globalization encourages technological and managerial innovation beneficial to environmental improvement and the diffusion of global environmental norms, helping to improve local environment quality (Shin, 2004). Decentralization results in insufficient authority and lack of co-ordination between institutional factors in China's environmental protection apparatus (Jahiel, 1998). Economic decentralization has given local officials the means and incentives to develop their local economies. The pervasive emphasis on development, consumerism and profit in government proclamations has further provided local governments to intervene against regulations such as environmental protection—deemed unfavorable to growth (Oi, 1995). Fiscal decentralization would trigger "race to the bottom competition", in which cities lower their environmental standards to compete for capital and even attract pollution intensive industries. Regional decentralization would thereby be responsible for the environmental degradation in Chinese cities. In addition, facing fierce interregional competition, some developed regions may have strong incentives to improve environmental quality to attract high value added industries or high-tech industries. As a consequence, how and whether economic reform should be responsible for China's environmental degradation remains an empirical question.

Using data on industrial SO2 emissions and dusts in Chinese cities during 2004-2007, this study first maps the city distribution of industrial pollution and identifies the hot spots of industrial pollution. This study then performs a systematic investigation on the economic and institutional determinants of industrial pollution in Chinese cities by testing a variety of theoretical propositions, with a special attention to the impacts of economic transition. It is worthy to mention that this study applies the plant level dataset to compute the industrial composition at the two digit level for all 287 Chinese cities and to control the effects of industrial structure in the empirical analysis. Statistical results find evidence of Environmental Kuznets Curve in Chinese cities and economic reform consists of the institutional root of environmental issues in China.

The paper is structured as follows. After this introduction, the next section examines industrial pollution in the context of the transition economy of China. The third session maps the spatial pattern of industrial pollution and identifies the pollution clusters. This paper then investigates the determinants of industrial pollution using a panel data modeling technique and concludes with a summary of major findings.

Industrial Air Pollution in China: A Perspective of Economic Transition

Economic development is nonlinearly associated with industrial pollution. As a region develops, industrializes and urbanizes, industrial pollution level increases, but at some level of income, industrialization and urbanization, this upward trend reverses and pollution levels decline as regions attain higher levels of economic development. This inverted U-shaped relationship between economic development and industrial pollution has been coded as Environmental Kuznets Curve in a sizeable literature (Grossman and Krueger, 1991; Selton and Song, 1994; Holtz-Eakin and Selden, 1992; World Bank, 1992; Cole et al., 1997; Moomaw and Unruh, 1997; Panayotou, 1997; Harbaugh et al., 2002; Cole, 2003; Poon et al., 2006; He, 2009, 2010). Using industrial or provincial data, literature intends to test the existence of EKC in China. Poon et al. (2006) found the presence of EKC for SO2 emission but not for soot particulates controlling for energy, transportation and exports. He (2009b) supported the existence of EKC for SO2 emission at the provincial level and found that the EKC curve for China's per capita industrial SO_2 emissions predicts the turning point at 10,000 yuan (3,085 US$ (PPP)). Wen and Cao (2009) however found that the relationship between China's emission of main pollutants and the national income per capita does not follow a typical EKC. Economic growth indeed has both harmful effects on environmental quality and beneficial effects. The harmful effects come via the scale effect and the beneficial effect come via shifts toward cleaner sectors and cleaner production techniques (Grossman and Krueger, 1991).

Panayotou (1997) argued that policies and institutions can significantly reduce environmental degradation at lower income levels and speed up improvement at higher income levels, thereby flattening the EKC and reducing the environmental price of economic growth. Better policies such as more secure property rights and better enforcement of contracts and effective environmental regulations can help flatten the EKC and reduce the environmental price of economic growth. Economic transition is the institutional environment for industrial pollution in China. Pollution demand and supply is no doubt affected by the institutional changes associated with economic transition, which has been conceptualized as a triple process of marketization, globalization and decentralization. The triple process has been found to shape the economic geography and industrial restructuring of Chinese manufacturing industries (He and Zhu, 2007;He et al., 2008). Marketization, globalization and decentralization would exert different direct and indirect impacts on the environmental behavior of industrial enterprises and on the local government's attitudes towards environmental regulations. The triple process may contribute to industrial pollution in Chinese cities by moderating the scale, composition and technique effects.

Marketization and Industrial Air Pollution

Institutionally, economic transition is to transform the Chinese economic system from a command economy to a market-oriented economy. In the command economy, governments distributed resources and firms were executors of state-orders. There were literally no well-functioning markets of goods and factors. As economic transition proceeds, market forces and competition are progressively introduced and markets have played an increasingly important role in resource allocation. The establishment of market systems has encouraged the development of non state-owned enterprises including privately owned, collectively owned, and foreign-owned enterprises and other types of enterprises. Meanwhile, facing fierce competition from non state-owned enterprises, state-owned enterprises have gradually withdrawn from certain industries such as labor-intensive industries. Currently, state-owned enterprises (SOEs) largely remain in the heavy and capital-intensive industries, such as the energy sector, machinery and equipment manufacturing, ferrous and nonferrous metal smelting and pressing, petroleum refining and coking, and chemical industries. Less liberalized regions and cities are dominated or controlled by SOEs while privately owned enterprises agglomerate in regions which have significantly benefited from economic liberalization.

Private enterprises are able to utilize resources more efficiently and produce less pollution with the same resources. They may also have lower bargaining power with local environmental authorities with respect to the enforcement of pollution charges and regulations (Wang et al., 2002). A better environmental quality could be achieved with greater existence of private sector. For instance, using annual data for 44 developing countries from 1987 to 1995, Talukdar and Meisner (2001) showed a significantly negative relationship between the degree of private sector involvement in terms of its investment in the total domestic investment, national GDP, or its value of output share in the national GDP and Co2 emission levels, suggesting that an increased role by the private sector in an economy is more likely to help the environment of the economy. However, although private owned enterprises may have higher efficiency in resource utilization, they are solely profit-oriented and may not seek to internalize environmental externalities and may compromise the environment to avoid the potential cost of environmental investments (Eiser et al., 1996). China's non state-owned sector has been the most rapidly growing, which implies that it will become more and more difficult to enforce policy as institutional channels of state control over industry become weaker and weaker (Jahiel, 1997).

On the contrary, SOEs have their incentives to internalize the environmental costs resulting from their pollution discharge in order to obtain higher national or local social welfare. SOEs normally take more social impacts into their decision-making processes and their environmental performance could be theoretically better than private sectors. While responding to the market, SOEs are supposed to internalize their environmental externalities for the local communities and for the whole nation. Furthermore, SOEs are also more likely to be furnished with advanced technological capabilities to deal with air pollution. The dominance of SOEs may provide opportunities to clean the air in Chinese cities controlling for the structural effects of

SOEs.

On the other hand, as Wang et al. (2001) argued that SOEs have stronger bargaining power with central and local governments regarding environmental regulations in contrast to the privately owned enterprises. SOEs in China have strong connections with the governments and some managers of SOEs have higher political status than the local environmental authorities. As a result, SOEs are able to elicit a lower pollution payment or punishment and have less incentive to decrease their pollution and reduce the pollution intensity. Existing studies do provide evidence to support the argument that the dominance of SOEs in a city may deteriorate its environmental quality and fuel environmental degradation. Using plant level data, Wang and Wheeler (2000) found that SOEs are more likely to pollute than private enterprises. Wang and Jin (2002) found that foreign-own enterprises and collectively owned enterprises have better environmental performance in terms of water pollution discharge intensity while SOEs and privately owned enterprises in China are the worst performers. Less liberalized cities in China are thereby more polluted due to the structural and institutional effects. How economic liberalization affects industrial pollution indeed depends on other economic and institutional conditions.

Economic Globalization and Industrial Air Pollution

China has participated in the globalization process through utilization of foreign investment and international trade. Since the 1990s, China has been the largest FDI host among developing countries and the second most attractive location for multinational corporations. The net environmental effect of globalization in developing economies is debatable. Assuming that regions are identical except for exogenous differences in pollution policy, the pollution haven hypothesis proposes that it is cheaper to produce dirty goods in the region with weaker environmental regulation. Trade and investment induced by environmental regulation differences create a pollution haven in the poor regions. Pollution intensive industries would migrate to regions or cities that have weaker environmental regulations mostly to save production costs. Meanwhile, governments in developing regions may hold their lax environmental policies to give their domestic producers an advantage in the competitive international market, generating the so-called eco-dumping hypothesis (Christmann and Taylor, 2001). Both pollution haven hypothesis and eco-dumping hypothesis argue that globalization is harmful to the environment of developing countries whose environmental regulations are weak. The simple factor endowment hypothesis however suggests that dirty capital-intensive processes would relocate to the relatively capital-abundant developed regions (Antweiler et al., 2001). Cole (2003) further argued that the impact of trade liberalization on the environment depends on whether or not they have a comparative advantage in pollution-intensive production. It depends on a region’s relative factor endowments and/or its relative environmental regulations. However trade and investment policies and environmental policies are not separate. Many factors drive trade and investment policies and environmental policies simultaneously. Developed regions are likely to be both capital abundant and have stricter pollution policy while poor regions are likely to be the opposite.

However, globalization is likely to help the environment in developing regions through technique effects. Openness would encourage technological and managerial innovation beneficial to environmental improvement as well as economic progress, facilitating an international ratcheting up of environmental standards. Increasing trade and investment liberalization can provide favorable conditions for the diffusion of global environmental norms and standards by creating opportunities and necessities for environmental institution-building and policy processes (Shin, 2004). Opportunities that more globalized economies can bring about include (a) foreign advanced technology transfer, (b) exposure to environmental practices of advanced economies and (c) learning and adopting new policy instruments, eco-labeling, and the cleaner production. Trade liberalization may push governments to ensure the compliance of their export products with the environmental quality standards of importing countries and international standards. FDI may induce policy changes as a responding strategy of developing countries to cope with possible environmental damage. In addition, multilateral trade agreements such as WTO require environmental commitments for exporting countries. Advanced technology and international environmental standards brought through international trade and foreign investment provide globalized regions improved environment and less pollution.

There are some studies providing supportive evidence for a pollution haven (Hettige et al., 1992; Birdsall and Wheeler, 1993; Suri and Chapman, 1998; Xing and Kolstad, 2002; Cole, 2004a,b; Jorgenson, 2007). More studies prove insignificant results or opposite impacts (Jaffe et al., 1995; Smarzynska and Wei, 2001; Antweiler et al., 2001;Wheeler, 2002; Frankel and Rose, 2005; Kellenberg,2008). Freer trade and openness appear to be good for the environment even in the developing countries. The existing literature has generated mixed results regarding the relationship between globalization and pollution emission in China. Wang and Jin (2002) found that foreign invested firms have better environmental performances than state-owned and privately owned firms. They suggest that foreign firms pollute less because they use superior technology in production and are more energy efficient. Shin (2004) examined the effects of trade and investment liberalization on the environment in two Chinese cities—Shenyang and Dalian, and found that economic openness positively affected domestic environmental policy by providing the necessity and opportunities for strengthening environmental institutions. However, Dean (2002) estimated the effect of trade liberalization on water pollution in China’s provinces using a simultaneous equation system and suggests that trade aggravates pollution via the improved terms of trade but mitigates it via income growth. He (2006, 2009) provided convincing supportive evidence for pollution haven hypothesis.

Regional Decentralization and Industrial Air Pollution

Economic transition in China has resulted in considerable decentralization of power from the central government to a more regional locus. As a result, local governments have a primary responsibility and great autonomy for economic development in their jurisdictions (He et al., 2008). Fiscal decentralization in particular has enhanced the importance of local revenues (Zhao and Zhang, 1999; Young, 2000). Fiscal decentralization inherently and explicitly emphasized autarchic development because the localities had to self-finance their budgets and their own development (Zhao and Zhang, 1999). Fiscal decentralization and designated local tax structures generate strong incentives and pressure to develop manufacturing industries to enhance local revenues.

Since the late 1980s, the Chinese central government has also given much autonomy and responsibility in environmental policy to local authorities so that each provincial and municipal government has to compete with each other in environmental as well as economic performance (Jahiel, 1997, 1998). Environmental protection agencies now report to the administratively higher levels of the national environmental protection apparatus and the local governments where they reside. Decentralization has removed central government guarantees of financial resources for floundering localities and has deprived localities of the financial security they once had. It is the local government that provides environmental agencies with their annual budgetary funds, approves institutional advancements in rank and determines increases in personnel and even allocation of such resources as cars and office buildings. Increasingly hard budgets particularly make the local environment protection agencies difficult. As a consequence, China's environmental protection apparatus has suffered from two lingering problems: insufficient authority and lack of co-ordination between institutional actors (Jahiel, 1998). Fragmented authority structure undermines the effective enforcement of environmental policies in China. Van Rooij and Lo (2010) found considerable regional variations in the enforcement of environmental pollution violations with coastal areas having more and higher punishments than those inland in China and such factors as central government support, community pressure, local government commitment, enforcement capacity, regulated firm characteristics and general economic conditions are responsible for the variations. The root of enforcement problems of environmental policies lies with the institutional arrangement in which the local governments pay and directly manage China's main local environmental enforcement authorities (Jahiel, 1998;Van Rooij and Lop, 2010).

The effect of fiscal and environmental decentralization has been that many local officials have become entrepreneurial tying to promote growth in their particular locality. While this entrepreneurship by local leaders have translated into an economic boom for many localities, its effect on regulations has been far less beneficial. As Oi (1995) observed, "with the transformation from administrators to entrepreneurs, local governments are shifting from regulators to advocates of their local enterprises". Meanwhile, fiscal decentralization has induced fierce interregional competition, which may trigger the "race to the bottom competition" in which regions lower environmental standards to compete for investments and firms. Decentralization of economic decision-making to local governments and factory managers, combined with calls for rapid economic growth and production for profit, has created further incentives for local governments and managers to pursue economic growth and profitability at the expense of environmental degradation (Jahiel, 1997). For local governments, there are strong incentives to circumvent those policies that might constrain local growth, such as environmental regulations (Lieberthal, 1995). Reform incentives thus "have actually distorted the role of local governments as agents of the central state", making the local authorities more lax with enforcement of environmental regulations (Jahiel, 1997). Destructive regulatory competition in the form of a race to the bottom would lower environmental quality with decentralization. Existing studies have reported that local governments have consistently undermined pollution enforcement in order to protect local economic interests (Ma and Ortolano 2000; Jahiel 1998, 1997; Sinkule and Ortolano 1995; Tang, Lo, Cheung, and Lo 1997; Swanson, Kuhn, and Xu 2001; Tang, Lo, and Fryxell 2003; Van Rooij 2006). With decentralization, pollution intensive industries gain opportunities to grow in regions facing hard budgets with limited local revenues. Regional decentralization thereby may be harmful to environment through scale and composition effects in China.

Overall, economic transition in China has gradually introduced market forces and global forces and resulted in economic decentralization, which shapes the scale, composition and technique effects of economic development on industrial pollution. Marketization has significantly stimulated economic growth and changed the ownership structure of Chinese economy with growing share of non state-owned enterprises and decreasing status of SOEs. Globalization has been a key factor contributing to China's rapid economic expansion, dramatic industrial restructuring and substantial technological progress while introducing global environmental norms. Decentralization has stimulated industrial growth and triggered race to the bottom competition with regard to environmental regulations. The net effects of marketization, globalization and regional decentralization on industrial pollution in Chinese cities however remain empirical questions, which deserve a thorough investigation. The following session is first to describe the structural and spatial patterns of industrial pollution and investigate the driving forces of industrial pollution in Chinese cities, with a special attention to the impacts of economic transition.

Structural and Spatial Patterns of Industrial Air Pollution in China

Industrial patterns of pollution in Chinese cities

There have been some structural changes in industrial air pollution in the last decade (Figure 1). The total industrial So2 emissions decreased from 15.87 million tons in 1998 to 13.46million tons in 2001 and went up to in 20.42 million tons in 2006. The rising trend has been reversed recently, with 18.39 million tons of So2 in 2008. Industrial dusts showed a clear decreasing trend, dropping from 11.64million tons in 1998 to 60.44 million tons in 2008. Both pollutant intensities have been reducing during 1998-2008, indicating that industrial production in China has been cleaner. So2 emissions per industrial output dropped from 2.38tons/Million Yuan to 0.36tons/Million Yuan. Industrial dust per industrial output decreased from 1.75tons/Million Yuan to 0.12tons/Million Yuan. The decreasing trend of SO2 and dusts emissions and reducing intensities are highly expected in the future.

(Figure 1 about here)

Industrial pollution in China is however concentrated in several pollution intensive industries (Table 1 and Table 2). Power, natural and water production is the most pollution intensive industry. In 1998 and 2008, this industry is responsible for 6.9679million tons and 10.6279million tons of So2 emissions respectively, accounting for 43.92% and 57.79% of total industrial SO2 emissions in China. Its So2 emission intensity topped all industries, reaching 1746tons/100million Yuan in 1998 and 327.22tons/100million Yuan in 2008. Other important So2 emitters and So2 intensive industries include non-metal mineral products, chemical materials and products, ferrous metal smelting and rolling processing, non-ferrous metal smelting and rolling processing, petroleum refining and coking, mining, papermaking and paper products, food, drinks and tobacco manufacturing. Those industries are resource processing and heavy industries, demanding a large amount of energy inputs. During 1998-2008, all industries have been much less So2 intensive. Petroleum refining and coking, ferrous metal smelting and rolling processing industry, plastic products, papermaking and paper products experienced a significant growth of So2 emissions. The annual growth rate of So2 emissions is 8.38% for petroleum refining and coking, and 7.36% for ferrous metal smelting and processing. Fortunately, many more industries have successfully cut their So2 emissions. Machinery, electrical equipment and electronics, printing and copying, rubber plastics, fabricated metal products and non-metal mineral products saw the fastest decrease in So2 emissions, with an annual decreasing rate of greater than 3%.

The structural pattern of industrial dusts is similar to that of So2 emissions. Power, natural and water production has dominated industrial dusts emission, accounting for 29.36% in 1998 and 41.79% in 2008, followed by non-metal mineral products (22.92%, 16.30%), mining (8.52%, 3.07%), chemical materials and products (4.44%, 7.77%) and ferrous metal smelting and processing (3.04%, 9.44%). Except petroleum refining and coking, plastic products, and ferrous metal smelting and processing, all industries witnessed significant drop of industrial dusts during 1998-2008. Mining, printing and copying, nonmetal mineral products experienced the fastest decrease.

(Table 1 and Table 2 about here)

There have been remarkable changes in the intensities of So2 and dust emissions in China during 1998-2008. This study compares the pollution intensive and less pollution intensive industries. Figure 2 shows the changes in the sectoral So2 intensity. Most pollution intensive industries have been increasingly and significantly cleaner and more pollution intensive industries underwent considerable decreases in So2 intensity. For instance, nonmetal mineral products decreased its intensity from 7.11 tons/million Yuan to 0.80 tons/million Yuan, and nonferrous metal smelting and processing from 4.30tons/million Yuan to 0.32tons/million Yuan. For less pollution intensive industries, it is also true that more pollution intensive industries experienced more considerable reduction in So2 emission intensity. Production in rubber products, textiles, food and drinks manufacturing, medical and pharmaceutical industry has significantly been cleaner in the last decade. Other less pollution intensive industries kept much stable So2 emission intensity. Large sectoral variations in So2 intensity still exist.

(Figure 2 about here)

As a dust intensive industry, nonmetal mineral products experienced the most dramatic reduction in dust intensity during 1998-2008, decreasing from 8.33 tons/million Yuan to 0.47tons/million Yuan. The decline largely occurred during the period of 1998-2001. All other dust intensive industries also made significant progress in reducing dust emissions, particularly mining and papermaking and paper products realizing more significant achievements. By 2008, all dust intensive industries bear dust intensities lower than 0.50 tons/million Yuan. Among the relative less dust intensive industries, food, drinks and tobacco manufacturing, medical and pharmaceutical industry, textiles and garment making, rubber products and fabricated metal products have significantly brought down their dust intensities during 1998-2008. For instance, food, drinks and tobacco manufacturing reduced its dust intensity from 0.40tons/million Yuan to 0.059tons/million Yuan, rubber products from 0.37tons/milion Yuan to 0.043 tons/million Yuan, and medical and pharmaceutical industry from 0.36 tons/million Yuan to 0.058tons/million Yuan. By 2008, all less dust intensive industries have intensities lower than 0.10tons/million Yuan. Similarly, industries still differ significantly in their dust intensities.

(Figure 3 about here)

Industrial Air Pollution in Chinese Cities

This study covers 287 cities, including prefecture cities, subprovincial cities and centrally administered cities of Beijing, Tianjin, Shanghai and Chongqing. The China Urban Statistical Yearbook started to report data on industrial air pollution for Chinese cities from 2003. Data is however missing in 25 cities in the western provinces including Shannxi, Gansu, Qinghai, Ningxia, Xinjiang and Tibet in 2003. Only Lasha did not report data since 2004. This study compares the spatial distribution of two typical industrial pollutants of So2 and Dusts and their intensities in 2004 and 2007.

Figure 4 shows the distribution of the total So2 emissions in Chinese cities. In 2004, Chongqing topped the city list, emitting 0.64 million tons of So2, followed by Shanghai (0.35million tons) and Tangshan (Hebei) (0.28million tons). Other heavily polluted cities generating more than 0.20 million tons of So2 include Weinan (Shaanxi), Ordos (Inner Mongolia), Suzhou (Jiangsu), Guiyang (Guizhou), Luoyang (Henan), Tianjin and Ningbo (Zhejiang). Those are large cities with a large industrial production or heavy industrial structure. The least So2 emitter is Ningde (Fujian), with So2 emissions of 64 tons, followed by Sanya (305 tons) and Haikou (454 tons) in Hainan. Guyuan (Ningxia) and Bazhong (Sichuan) emitted less than 1000 tons of So2 in 2004. Those cities are small and with very few industrial activities. In 2007, Chongqing and Shanghai remained the top two So2 emitters, with 0.68 and 0.36 million tons, respectively. The other heavy So2 polluters with more than 0.20 million tons, include Weinan (Shaaxi), Tangshan (Hebei), Luoyang (Henan), Ordos (Inner Mongolia), Laibing (Guangxi), Suzhou (Jiangsu), Tianjin and Chifeng (Inner Mongolia). Laibing and Chifeng replaced Guiyang and Ningbo in 2007 and were added to the top list. The least So2 emitters in 2007 basically remained the same.

Overall, So2 emissions are distributed in clusters. The global Moran's I is 0.1394 and 0.1514 in 2004 and 2007, respectively, indicating a significant spatial autocorrelation pattern. The Yangtze River Delta, the Shandong Peninsula, the Capital region (Beijing-Tianjin-Tangshan), the Central-Northern China (including Southern Hebei, Henan and Shanxi), the Sichuan Basin, and the Pearl River Delta are the hotpots. In 2007, the northern China became more polluted and formed a new industrial pollution belt from Chifeng (Eastern Inner Mongolia) to Zhangjiakou

(Northern Hebei) to Baotou and from Shizuishan in Ningxia to Baiyin in Gansu. Meanwhile, the Northeast China showed the trend of increasing industrial So2 emissions. Moreover, there has been a clear pollution dispersion process during 2004-2007.

(Figure 4 about here)

The good news is that So2 emissions intensity has been significantly reduced (Figure 5). During 2004-2007, many cities, especially the most polluted cities, significantly reduced So2 emissions per industrial output. The coastal cities bear the lowest So2 emissions per industrial output. The central part of China however has experienced the most environmental degradation. The Yangtze River Delta and the Pearl River Delta are particularly more So2 effective, with much lower So2 intensity.

(Figure 5 about here)

There are some differences in the spatial distribution of industrial dusts from So2 emissions in Chinese cities (Figure 6). In 2004, Chengdu (Sichuan), Karamay (Xinjiang) and Ordos (Inner Mongolia) ranked as the top three industrial dust emitters, followed by Leshan (Sichuan), Tangshan (Hebei), Luoyang (Henan), Linfen(Shanxi), Chongqing, Datong(Shanxi) and Weinan (Shaanxi), all emitting more than 100 thousands tons of industrial dusts. In 2007, only Tangshan, Chongqing and Linfen emitted more than 100 thousands tons of industrial dusts. The major dust polluters remained in the top. The least polluted cities by industrial dusts include Sanya (Hainan), Haikou (Hainan), Lincang (Yunnan), Lijiang (Yunnan) and Guyuan (Ningxia) in both years.

Like So2 emissions, industrial dusts are also agglomerated in certain city clusters. The global Moran's I is 0.1994 and 0.2786 in 2004 and 2007, respectively, implying stronger spatial autocorrelation pattern than So2 emissions. The largest concentration of industrial dusts is the central-northern China covering cities in Tianjin, Shanxi, Henan and Hebei provinces. Unlike industrial So2 emissions, industrial dusts are widely distributed in the Northeast China. Harbin, Jilin, Tieling, Qiqihar, Jiamusi,Jingzhou and Daqing are heavily polluted by industrial dusts. Other dispersed clusters include the Yangtze River Delta, the Guangdong-Guangxi (along Guangzhou, Shenzhen, Nanning, Liuzhou, Guigang and Yulin), the east Sichuan Basin, the Wuhan city region in Hubei, and the Chang-Zhu-Tan city region in Hunan province.

(Figure 6 about here)

The spatial pattern of industrial dust intensity is similar to that of So2 emission intensity. During 2004-2007, most cities in central China significantly reduced industrial dusts per industrial output (Figure 7). Industrial production in the Northeast China however remained largely dust-intensive, especially in cities with heavy industrial structure, such as Jiamusi, Yichun, Jixi, Fuxin, Mudanjiang, baishan, Qitaihe, Heihe, Shuangyashan, Hegan, Baicheng, and Qiqihar. In addition, Guangxi, Shanxi, the northwest Shan-Gan-Ning, and the east Sichuan Basin are also still dust intensive. Comparatively, the coastal cities are much cleaner, generating much fewer industrial dusts per industrial output. The Yangtze River Delta and the Pearl River Delta are particularly more dust-effective in their industrial production, with much lower industrial dust per industrial output. Overall, due to the scale, structural, technological, institutional and locational differences, Chinese cities suffer differently from industrial pollution.

(Figure 7 about here)

Empirics and Results

Variables and Models

To understand the significant intercity variation in industrial air pollution intensity, this study conducts a systematic investigation of determinants of industrial air pollution applying for a panel data regression model during 2004-2007. The particular focus is on the effects of the triple process of economic transition and the explanatory variables include proxies for marketization, globalization and fiscal decentralization controlling for industrial composition. The model is as follows,

$$LnTSO2_{it}(orLnTDUST_{it}) = \beta_1 LnPGDP_{it} + \beta_2 (LnPGDP_{it})^2 + \beta_3 LnPRIV_{it} + \beta_4 LnCOES_{it}$$
$$+\beta_5 LnSOES_{it} + \beta_6 LnFIES_{it} + \beta_7 LnEXPORT_{it} + \beta_8 LnIMPORT_{it} + \beta_9 LnLEXRE_{it}$$
$$+\beta_{10} LnVALTAX_{it} + \sum_{k=1}^{9} \beta_k LnINDU_{itk} + \lambda_t + \nu_{it}, i = 1, ..., N, t = 1, 2, 3, 4.$$

That is, the pollution intensity (TSO2 or TDUST) in city *i* in year *t* is a function of theoretically discussed variables. *i* and *t* denotes city and time, λ_t the unobservable time effect, ν_{it} the remainder stochastic disturbance term. Note that λ_t is city-invariant and it accounts for any time-specific effect that is not included in the regression. The inclusion of per capita GDP and its square is to test the existence of environmental Kuznets Curve (EKC) at the city level. The use of per capita GDP and squared per capita GDP to capture scale and technique effects is consistent with the environmental Kuznets curve literature, within which the inverted U shaped relationship between per capita GDP and pollution is explained largely in terms of the dominance of scale effects at low levels of income and the dominance of technique effects at high income levels.

The particular interest of this study is the environmental effects of economic transition. As discussed, marketization has played a significant role in changing industrial pollution intensity in Chinese cities although the net effect is unclear. The consequence of marketization is to diversify the ownership structure of the Chinese city, with growing shares of non SOEs. We entertain the percents of state-owned enterprises (SOES), collectively-owned enterprises (COES) and privately-owned enterprises (PRIV) in gross industrial output to test the environmental impacts of economic liberalization. To investigate the environmental impacts of globalization in Chinese cities, we introduce three variables to quantify trade and investment liberalization, including the percent of industrial output by foreign-invested industrial enterprises (FIES) in gross industrial output, the percent of exports in GDP (EXPORT) and the percent of imports in GDP (IMPORT) in the models. If the pollution haven hypothesis holds, the coefficients on FIES and EXPORT would be positive and IMPORT will have a negative coefficient. Regional decentralization is likely to be harmful to the local environment. This study includes the percent of local expenditure in local revenue (LEXRE) and percent of value-added tax in local revenue (VALTAX) to test the impacts of regional decentralization.

Finally, this study intends to control industrial composition in Chinese cities by including the percents of gross industrial output of the pollution intensive industries (INDU). They include mining, papermaking and paper products, petroleum refining and coking, chemical materials and products, chemical fiber, nonmetal mineral products, ferrous metal smelting and pressing, nonferrous metal smelting and pressing, and power, natural and water production. All variables are summarized in table 3.

(Table 3 about here)

Empirical Results

Considering the significant declining trend of industrial air pollution intensity during 2004-2007, this study applied the time fixed effect model to estimate the coefficients of explanatory variables. The panel data regression results for both industrial So2 and industrial dusts intensities are presented in table 4. The Breusch-Pagan tests indicate the existence of heteroscedasticity and all estimates are corrected for heteroscedasticity. This study also separately estimates the impacts of marketization, globalization and decentralization controlling for the EKC effect and industrial structural effects.

Statistical results provide strong evidence to support the EKC effect in Chinese cities. There is a statistically significant inverted U shaped relationship between LnPGDP and LnTSO2 (Or LnTDUST). Pollution intensity is lower in under-developed cities. As cities grow economically, their economies become increasingly pollution intensive. When per capita GDP reach a certain level, pollution intensity gradually reduces. The EKC effect suggests that economic development and economic restructuring would do good to improve the environmental quality in Chinese cities.

(Table 4 about here)

There is weak evidence to show that economic liberalization influences China's environment controlling for industrial structural effects and the EKC effect. The coefficients on LnPRIV and LnCOES are negative while LnSOES has a positive coefficient in the SO2 models. Results based on the model 1 indicate that developing privately owned enterprises would help to reduce So2 emissions per output. The dominance of state owned enterprises would increase So2 emissions per output and hurt the environment. The DUST models confirm a significant positive coefficient on LnSOES. This is consistent with Wang and Wheeler (2000), which found that SOEs are more likely to pollute than privately owned enterprises. As Wang et al. (2001) argued that SOEs have stronger bargaining power with local governments regarding environmental regulations in contrast to the privately owned enterprises and SOEs are able to elicit a lower pollution payment or punishment and have less incentive to decrease their pollution. The effect of economic liberalization remains the expected sign but turn insignificant when controlling for globalization and decentralization proxies in both SO2 and DUST models.

There is no statistical support for the pollution heaven hypothesis in Chinese cities. Both coefficients on LnFIES and LnEXPORT are negative and significant in model 2 and model 4 in the SO2 and DUST models. More outputs by foreign-invested enterprises and higher shares of exports in GDP are associated with lower levels of pollution intensity, implying that dependence on international investment and international markets are more pollution effective. Clearly, economic globalization has indeed been beneficial to China's environment. Foreign investments and exports are mainly in the labor intensive and light industries. Foreign investors bring advanced technology to utilize resources more efficiently. Xu et al.(2006) reported that foreign enterprises perform better than domestic enterprises. The results occur inconsistent with He (2009, 2010), which found some evidence of the pollution heaven hypothesis. It however confirms the argument by Wang and Jin (2002) that foreign-owned enterprises have better environmental performance. LnIMPORT has a negative and insignificant coefficient in the DUST models but has a positive and significant coefficient in the SO2 models. China largely imports resources and advanced equipments from abroad. More imports possibly reduce the industrial dust emissions since more advanced technologies are embedded in the imported equipments and machinery. Imports mainly go to cities with relative heavy industrial structures or resource-processing economies, generating So2 emissions.

As expected, regional decentralization has indeed played a significant role in deteriorating China's environment. Both LnLEXRE and LnVALTAX have positive coefficients controlling for pollution intensive industries. LEXRE, the percent of local expenditures in local revenues, quantifies the difficulty of local budgets. VALTAX, the percent of value added tax in local revenues, measures the dependence of local revenues on industrial development. Fiscal decentralization requires the localities to self-finance their budgets and their own development (Zhao and Zhang, 1999). Fiscal decentralization and designated local tax structures create strong pressure and incentives to develop industries and to enhance local revenues. Fiscal decentralization has triggered the race to the bottom competition to lower environmental regulations and standards to attract highly taxable and value-added industries, which are typically pollution intensive. Cities suffering from had budgets are also more lax with the enforcements of environmental regulations.

Pollution intensity in Chinese cities is apparently associated with their industrial composition. Resource-based industries including mining, chemical materials and products, ferrous and nonferrous metal smelting and rolling processing industries, power, natural gas and water production significantly increase pollution intensity in Chinese cities. Interestingly, papermaking and paper products and chemical fibers have been deviated from heavily polluted cities.

There are remarkable regional differences in economic development, geographical location, industrial structure, technology, institutional environment and government policies in China. To check the robustness of the estimations, this study further divides Chinese cities into three groups: cities located in the coastal, central and western provinces*. Both SO2 and DUST models are estimated for the three sub-samples. The statistical results are reported in table 5-table 7. All models are

* Coastal provinces include Liaoning, Hebei, Beijing, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, Hainan; Central provinces cover Heilongjiang, Jilin, Inner Mongolia, Shanxi, Henan, Anhui, Jiangxi, Hubei, Hunan; Western provinces include Xinjiang, Tibet, Qinghai, Shaaxi, Gansu, Ningxia, Sichuan, Chongqing, Guizhou, and Yunnan.

highly significant. The models perform the best in the coastal cities and poorest in the western cities. The R-squares in the coastal full models are 0.4694 and 0.5666 for So2 and dusts, respectively. The values in the western full models are 0.2412 and 0.3124. Panel data regressions reveal some significant differences in the impacts of economic transition on industrial air pollution.

There is a U-shaped rather than inverted U shaped relationship between LnPGDP and LnTSO2 and LnTDUST in the coastal cities. The EKC effects are more likely to occur in the western cities. Controlling for the effects of economic transition and industrial composition, no significant relationship between LnPGDP and pollution intensity can be found in the central cities. The inverted EKC effect is possibly related to the recent heavy industrialization in some coastal cities by developing chemical materials and products, steel making and machinery and equipment. The EKC effect is likely to hold in the western cities, providing that western cities could improve environmental quality by facilitating economic growth.

(Table 5-table 7 about here)

Three proxies for economic marketization have different effects on urban environment quality. LnPRIV has negative but insignificant coefficients in all three sets of So2 models, indicating that economic liberalization is likely to make industrial production less So2 intensive and cleaner. LnPRIV has positive coefficients in the DUST models in the coastal and central cities, and negative coefficients in the western cities. The coefficient in the coastal model is significant in model 1, suggesting that privately-owned enterprises are associated with more industrial dusts. Collectively owned enterprises have different environmental behaviors in the central cities than other cities. Coefficients on LnCOES are positive in the coastal models and but only significant in the So2 model, implying that collectively owned enterprises in the coastal cities are environmentally harmful. Some collectively owned enterprises in the coastal cities are previous township enterprises, relatively small and poorly equipped compared with SOEs and foreign enterprises. They are not environment effective. LnCOES is negative and significant in both SO2 and DUST models in the central cities but is insignificant in the western cities. In the less developed central cities, the state still controls the heavy and high value added pollution intensive industries. Collectively owned enterprises are largely in the market driven light industries and thereby more pollution effective. Statistical results clearly suggest that SOEs hurt the environment in the coastal cities but improve the environment in the western cities controlling for industrial composition. In the coastal cities, SOEs are largely in the heavy industries such as chemical materials and chemical products, and ferrous metal mineral smelting and processing, equipment and machinery. They are more likely to pollute. In the underdeveloped western cities, SOEs are relatively more technologically advanced and largely in high value added industries compared with non-SOEs, generating less pollution.

Foreign investment and exports help to improve environment quality in the coastal cities. Both LnFIES and LnEXPORT have significant and negative coefficients in both SO2 and DUST models. LnIMPORT has an insignificant positive coefficient in SO2 models but insignificant negative coefficients in DUST models.

Overall, dependence on international investment and markets are beneficial for environment in the coast region. Foreign investment, exports and imports however show mixed impacts on the environment in the central cities. Utilization of foreign investment and imports may reduce pollution intensity but exports are likely to deteriorate the environment in the central cities. Foreign investments in the central cities are either in labor-intensive light industries or in high-tech industries such as electronics, lowering pollution emissions. Imports in the central cities are mainly advanced equipments, which would improve the efficiency and productivity and reduce pollution intensity. Exports in the central cities are largely in resource-intensive products, which are more pollution intensive. LnFIES, LnEXPORT and LnIMPORT have positive coefficients in both SO2 and DUST models in the western cities and LnIMPORT has significant coefficients. The results indicate that pollution haven hypothesis may hold in China’s inland regions, especially the landlocked western region. The pressure and incentives in economic development in China’s inland region have imposed serious challenges on the environment protection.

Fiscal decentralization has significant impacts on urban environment only in the central cities. Coefficients on LnLEXRE and LnVALTAX are barely significant in the coastal and western models. Both variables are highly significant and hold expected signs in the central models. Incentives in economic development and pressure in local revenues would induce the development of pollution intensive industries in the central cities. In the past couple of years, the central region has gained favorable policy support from the central government and thereby realized rapid economic growth. The central cities have competed to attract the relocated industries from the coastal cities, which are often forced to relocate because of environmental pollution. The regression results suggest the interregional competition associated with decentralization may deteriorate the environment in the central cities.

Regarding the impacts of industries, mining, chemical materials and products, ferrous and nonferrous metal smelting and pressing have indeed made industrial production dirtier in the coastal cities. Petroleum refining and coking, nonmetal mineral products and power, natural gas and water production are not located in heavily polluted cities. Mining, ferrous and nonferrous metal smelting and pressing, and power, natural gas and water production have deteriorated urban environment in the central cities. Industrial structural effects are not very significant in the western cities.

Summary

The institutional innovations in the last three decades have liberalized the Chinese economy, resulting in eye-catching economic performance. The high-growth, resource-intensive and export-oriented development strategy, coupled with the norms and institutions designed to support this development strategy have certainly played a critical role in deteriorating environmental quality of Chinese cities and imposed a serious challenge on environment protection in China. This study made a special effort to investigate the different environmental effects of marketization, globalization and decentralization using data on industrial SO2 emission and dusts at the city level.

Empirically, China’s industrial production has been cleaner, with decreasing pollution intensity during last decade. Industrial air pollution has been concentrated in several pollution intensive industries, including power, natural and water production, chemical materials and products, ferrous and nonferrous metal smelting and pressing, nonmetal mineral products, petroleum refining and coking. Pollution intensive industries particularly have made significant achievements in reducing pollution intensity. Industrial pollution is clustered in some Chinese cities. The Yangtze River Delta, the Shandong Peninsula, the Capital region, the Central-Northern China, Northeastern China, the Sichuan Basin, and the Pearl River Delta are the hotpots. The coastal region is much less pollution intensive compared to the inland region.

Statistical results confirm the EKC effect in Chinese cities, implying that economic development is possible to mitigate industrial pollution. The triple process of economic transition shows different environment effects in Chinese cities. There is only weak evidence that economic liberalization has improved environment quality. Dominance of SOEs however has contributed to environmental degradation in Chinese cities. No evidence is found to support the pollution heaven hypothesis in China. Participation in economic globalization in turn is beneficial to environment. More foreign invested enterprises and exports are found to be associated with lower pollution intensity. It is likely that decentralization has induced the race to the bottom interregional competition by lowering environmental regulations to attract taxable and high value added pollution intensive industries. There however remain regional differences in the environmental effects of economic transition. The EKC effect is more likely to occur in the western region. Economic liberalization has made industrial production less So2 intensive and cleaner. Collectively owned enterprises are environmentally harmful in the coastal cities but environmentally beneficial in the central cities. SOEs hurt the environment in the coastal cities but improve the environment in the western cities. Globalization clearly helps to improve environment quality in the coastal cities. Pollution haven hypothesis holds in China's inland regions, especially the landlocked western region. Decentralization has significantly contributed to environmental degradation only in the central cities.

As known, China's economic development is accompanying with serious environmental degradation. Existing studies found the effects of scale, technology and structure on industrial pollution. This study identified the institutional effects. The significant EKC effect indicates that economic growth may help to improve environment quality in Chinese cities. Further economic liberalization seems necessary to mitigate environmental degradation. The environmental effects of SOEs and fiscal decentralization are associated with lower environmental standards and lax environmental enforcement and implementation. The direct solution is to strengthen the authority and independence of local environment protection agencies. It is urgent to enhance the importance of environmental performance in the evaluation system of local officials and grant locales fiscal and tax incentives to pursue environment friendly economic development models.

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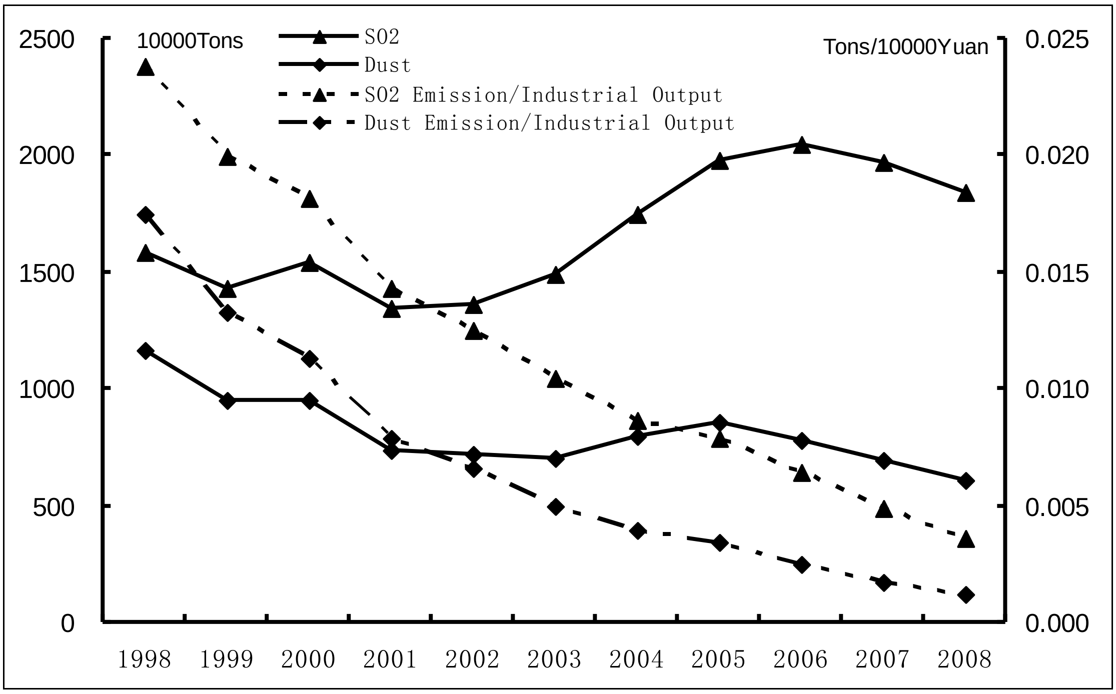


Figure 1 Industrial So2 and Dust and Their Intensities in China

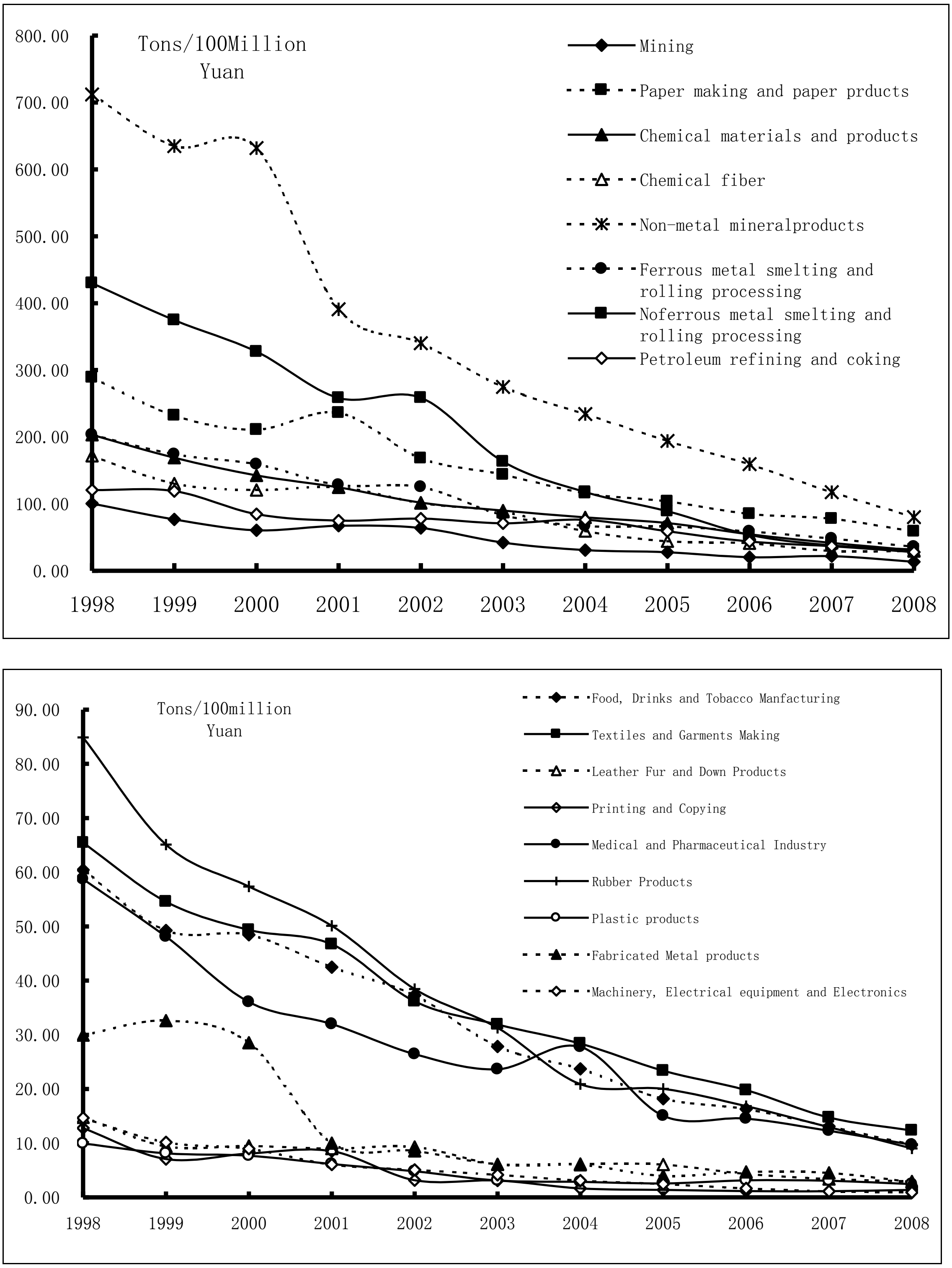
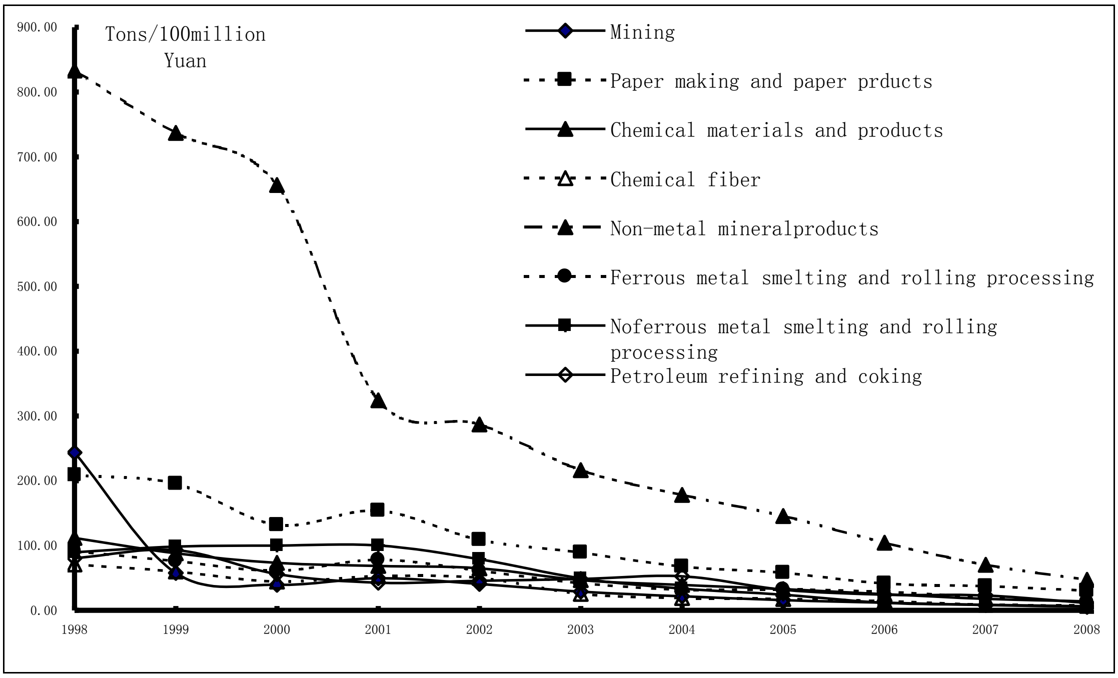


Figure 2 Industrial So2 Intensity Change in High (Top) and Low (Bottom) Pollution Intensive Industries during 1998-2008



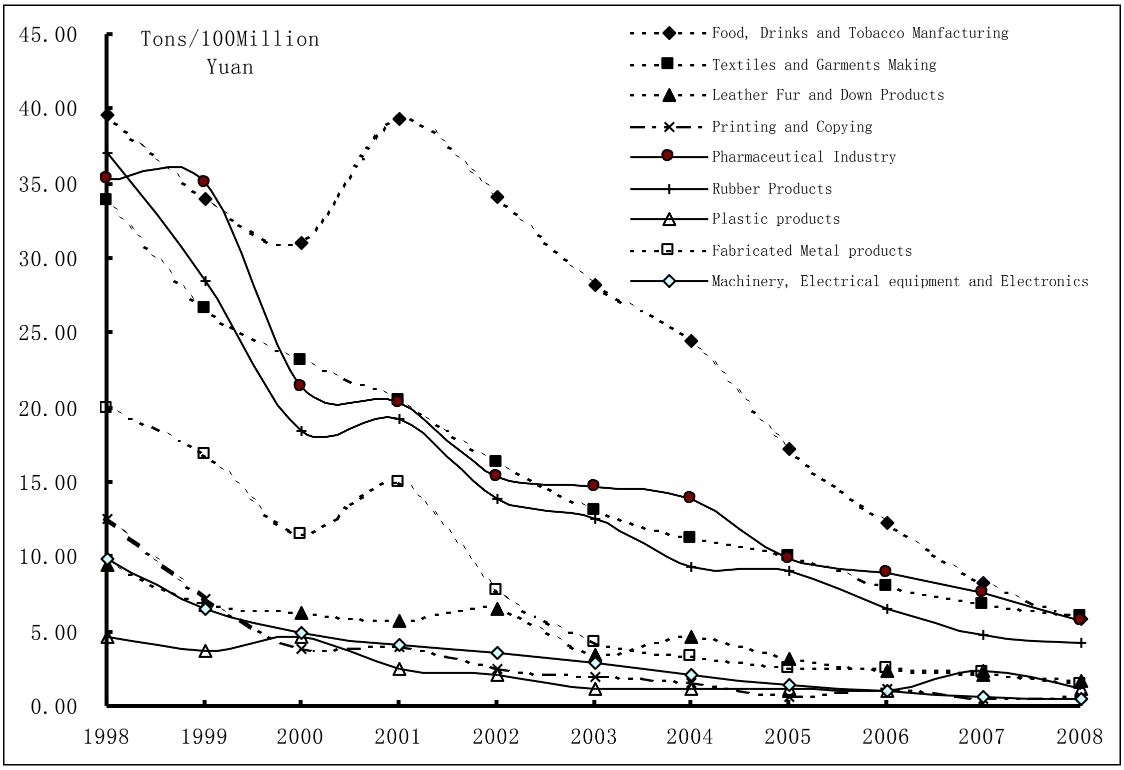


Figure 3 Industrial Dust Intensity Change in High (Top) and Low (Bottom) Pollution Intensive Industries during 1998-2008

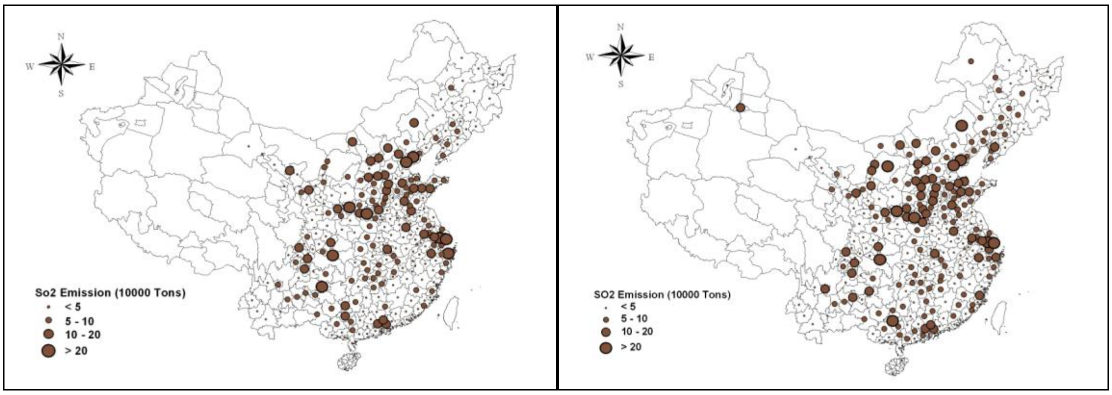


Figure 4 Spatial Distribution of SO2 Emissions in Chinese Cities in 2004(Left) and 2007 (Right)

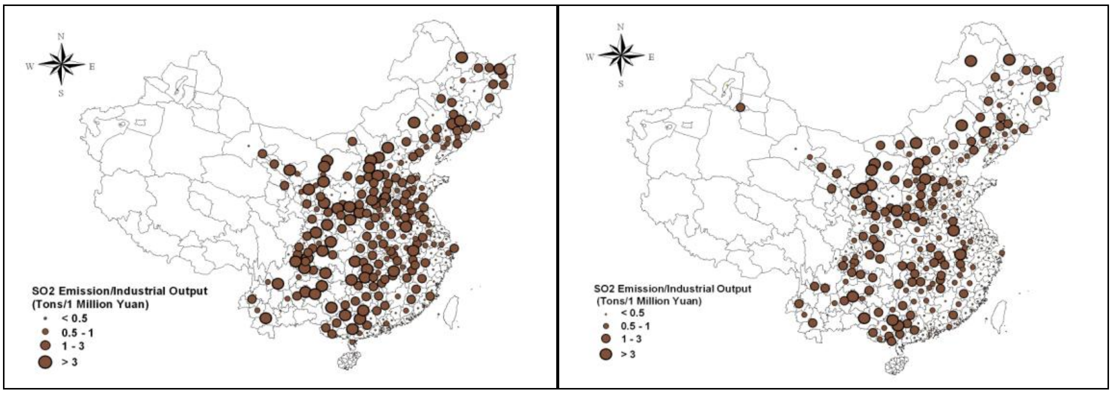


Figure 5 Spatial Distribution of SO2 Emission Intensity in Chinese Cities in 2004 (Left) and 2007 (Right)

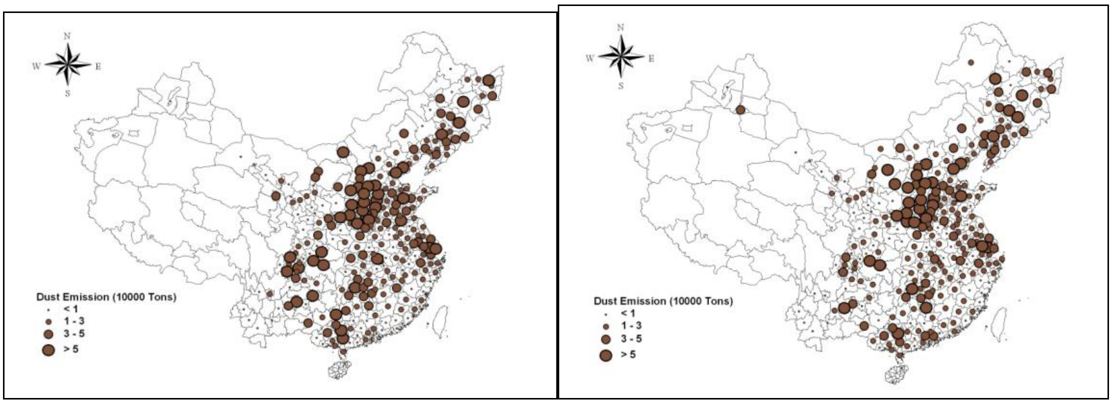


Figure 6 Spatial Distribution of Industrial Dusts in Chinese Cities in 2004(Left) and 2007(Right)

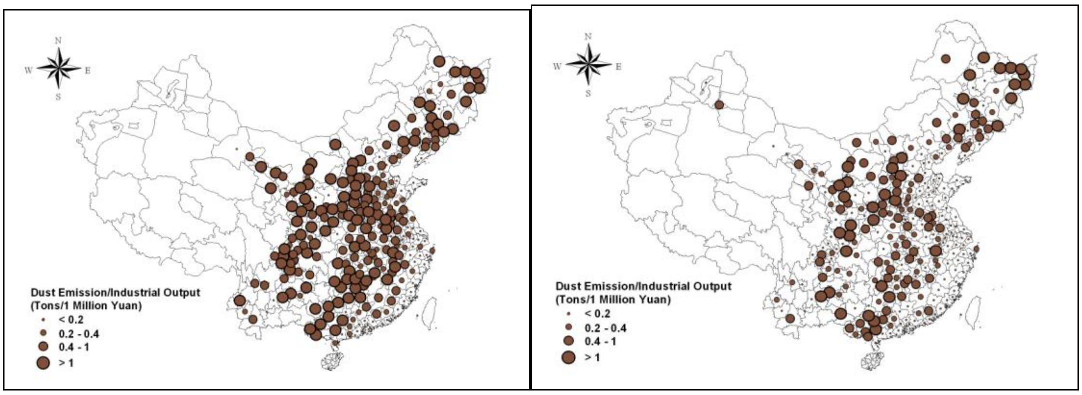


Figure 7 Spatial Distribution of Industrial Dust Intensity in Chinese Cities in 2004 (Left) and 2007 (Right)

Table 1 Industrial SO2 Emissions by Sector (Unit: Tons, Tons/100million Yuan)

Sector	1998		2008		Annual Growth Rate (%)	Emission Intensity	
	Volume	%	Volume	%		1998	2008
Mining	409470	2.58	451975	2.46	0.99	100.47	13.45
Food, Drinks and Tobacco Manufacturing	464426	2.93	411698	2.24	-1.20	60.44	9.72
Textiles and Garments Making	286415	1.81	263827	1.43	-0.82	65.45	12.33
Leather Fur and Down Products	17587	0.11	17347	0.09	-0.14	14.76	2.95
Paper making and paper products	359459	2.27	462959	2.52	2.56	288.96	58.80
Printing and Copying	6953	0.04	3727	0.02	-6.05	12.78	1.39
Petroleum refining and coking	281262	1.77	629183	3.42	8.38	120.74	27.80
Chemical materials and products	940762	5.93	1035423	5.63	0.96	203.28	30.49
Pharmaceutical Industry	80620	0.51	76271	0.41	-0.55	58.73	9.69
Chemical fiber	141916	0.89	117031	0.64	-1.91	171.70	29.48
Rubber Products	64986	0.41	38203	0.21	-5.17	84.88	9.03
Plastic products	14886	0.09	24196	0.13	4.98	9.94	2.44
Non-metal mineral products	2281547	14.38	1680618	9.14	-3.01	711.99	80.25
Ferrous metal smelting and processing	790319	4.98	1607470	8.74	7.36	203.52	35.94
Nonferrous metal smelting and processing	700462	4.42	668786	3.64	-0.46	430.07	31.92
Fabricated Metal products	64382	0.41	42277	0.23	-4.12	29.94	2.81
Machinery, Electrical equipment and Electronics	262635	1.66	138107	0.75	-6.23	14.65	0.91
Power, natural and water production	6967926	43.92	10627957	57.79	4.31	1746.46	327.22
Other industries	1727253	10.89	94725	0.52	-25.20	514.46	3.78
Total	15863266	100	18391780	100	1.49	237.91	36.24

Table 2 Industrial Dusts by Sector (Unit: Tons, Tons/100million Yuan)

Sector	1998		2008		Annual Growth Rate (%)	Intensity	
	Volume	%	Volume	%		1998	2008
Mining	992537	8.52	185388	3.067	-15.45	**243.54**	**5.52**
Food, Drinks and Tobacco Manufacturing	304290	2.61	251282	4.16	-1.90	39.60	5.93
Textiles and Garments Making	148575	1.28	128294	2.12	-1.46	33.95	6.00
Leather Fur and Down Products	11305	0.10	10298	0.17	-0.93	9.48	1.75
Paper making and paper products	259543	2.23	239860	3.97	-0.79	**208.64**	**30.46**
Printing and Copying	6844	0.06	1827	0.03	-12.37	12.58	0.68
Petroleum refining and coking	187479	1.61	255154	4.22	3.13	80.48	11.28
Chemical materials and products	517487	4.44	469443	7.77	-0.97	**111.82**	**13.83**
Pharmaceutical Industry	48536	0.42	45732	0.76	-0.59	35.36	5.81
Chemical fiber	58541	0.50	27070	0.45	-7.42	**70.83**	**6.82**
Rubber Products	28403	0.24	18168	0.30	-4.37	37.10	4.30
Plastic products	7116	0.06	11414	0.19	4.84	4.75	1.15
Non-metal mineral products	2669604	22.92	985294	16.30	-9.49	**833.08**	**47.05**
Ferrous metal smelting and rolling processing	354375	3.04	570353	9.44	4.87	**91.26**	**12.75**
Noferrous metal smelting and rolling processing	145747	1.25	134907	2.23	-0.77	**89.49**	**6.44**
Fabricated Metal products	42778	0.37	23020	0.38	-6.01	19.89	1.53
Machinery, Electrical equipment and Electronics	177597	1.52	88601	1.47	-6.72	9.91	0.58
Power, natural and water production	3419778	29.36	2525716	41.79	-2.99	**857.14**	**77.76**
Other industries	2268428	19.47	72691	1.20	-29.11	675.65	2.90
Total	11648963	100	6044512	100	-6.35	174.71	11.91

Table 3 Definitions of Dependent and Independent Variables

Variable	Definition
TSO2	Total industrial SO2 emissions/gross industrial output
TDUST	Total industrial dust/gross industrial output
PGDP	Per capita GDP
PRIV	Percent of privately-owned enterprises in gross industrial output
COES	Percent of collectively-owned enterprises in gross industrial output
SOES	Percent of state-owned enterprises in gross industrial output
FIES	Percent of foreign invested enterprises in gross industrial output
EXPORT	Percent of exports in GDP
IMPORT	Percent of imports in GDP
LEXRE	Percent of local expenditure in local revenue
VALTAX	Percent of value-added tax in local revenue
INDU	Percent of pollution intensive industries in gross industrial output

Table 4 Panel Regression Results for Pollution Intensity Using the Full Sample

Variable	Industrial SO2 Intensity(LnTSO2)				Industrial Dust Intensity (LnTDUST)			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
LnPGDP	2.9942***	3.1294***	3.1147***	3.0950***	3.3798***	2.7686***	4.7135***	3.6245***
LnPGDP*LnPGDP	-0.1848***	-0.1846***	-0.1867***	-0.1812***	-0.2211***	-0.1739***	-0.2777***	-0.2052***
LnPRIV	-0.0849*			-0.0422	0.0304			0.3733
LnCOES	-0.0105			-0.0127	-0.0107			-0.1852
LnSOES	0.0734**			0.0305	0.1342***			0.4881
LnFIES		-0.1075***		-0.0849**		-0.0873**		-0.0451
LnEXPORT		-0.2862***		-0.2772***		-0.4365***		-0.4321***
LnIMPORT		0.1496*		0.1084		-0.0935		-0.1194
LnLEXRE			0.1661*	0.0789			0.5125***	0.4324***
LnVALTAX			0.2476***	0.2571***			0.1202*	0.1847**
LnINDU1	0.2399***	0.1971***	0.2290***	0.1792***	0.2929***	0.2085***	0.2823***	0.1977***
LnINDU2	-0.1375***	-0.1443***	-0.1510***	-0.1262***	-0.1664***	-0.1564***	-0.1678***	-0.1430***
LnINDU3	-0.0333	-0.0348	-0.0284	-0.0352	0.0104	0.0043	0.0098	0.0086
LnINDU4	0.1258***	0.1089***	0.1193***	0.1178***	0.0854*	0.0657	0.0915**	0.0767*
LnINDU5	-0.1220**	-0.1087**	-0.1324***	-0.1065**	-0.0770	-0.0571	-0.0755	-0.0535
LnINDU6	-0.0971*	-0.1115**	-0.1021*	-0.0788*	0.0032	-0.0015	-0.1364	-0.0015
LnINDU7	0.0826***	0.0729***	0.0865***	0.0752***	0.0747***	0.0636**	0.0823***	0.0688**
LnINDU8	0.1007***	0.0905***	0.1057***	0.0857***	0.0399	0.0320	0.0524*	0.0441
LnINDU9	0.0944**	0.1320***	0.0992**	0.1174***	0.0229	0.0723*	0.0086	0.0401
Time Dummy	Included	Included	Included	Included	Included	Included	Included	Included
# Observations	1144	1144	1144	1144	1144	1144	1144	1144
Adjusted R2	0.3894	0.4056	0.3935	0.4129	0.4680	0.5068	0.4747	0.5153
F-Value	43.87	46.88	47.36	37.54	60.15	70.09	65.55	56.22
Breusch-Pagan $\chi 2$	187.19	119.16	120.22	200.15	134.71	105.21	95.81	131.63

Notes: *, p<0.10; **, p<0.05; ***, p<0.01. Results are corrected with heteroscedasticity.

Table 5 Panel Regression Results for Pollution Intensity in the Coastal Cities

Variable	Industrial SO2 Intensity (LnTSO2)				Industrial Dust Intensity (LnTDUST)			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
LnPGDP	-5.3657***	-6.4792***	-5.4778***	-6.2419***	-5.1718***	-6.7823***	-4.0652**	-6.2375***
LnPGDP*LnPGDP	0.2292***	0.2910***	0.2325***	0.2782***	0.2032**	0.2992***	0.1461	0.2751***
LnPRIV	-0.0063			-0.0198	0.1939**			0.0995
LnCOES	0.1812***			0.1991***	0.1007			0.0962
LnSOES	0.1810***			0.1267**	0.2884***			0.1622***
LnFIES		-0.1232*		-0.1451**		-0.0618		-0.0661
LnEXPORT		-0.3037**		-0.2608**		-0.4766***		-0.4253***
LnIMPORT		0.0933		0.1452		-0.1028		-0.0124
LnLEXRE			-0.0041	0.0064			0.1896	0.2483
LnVALTAX			0.1988	0.2703*			-0.1073	0.0026
LnINDU1	0.2014***	0.1721***	0.2250***	0.1497***	0.1947***	0.1239**	0.2142***	0.1177**
LnINDU2	0.0082	0.0054	-0.0167	0.0102	-0.2015**	-0.2128***	-0.2142***	-0.1774**
LnINDU3	-0.0654*	-0.0577*	-0.0345	-0.0650**	0.0257	0.0242	0.0352	0.0123
LnINDU4	0.2061***	0.1863***	0.2223***	0.1871***	0.1961***	0.1754**	0.2258***	0.1753**
LnINDU5	-0.0443	-0.0294	-0.0659	-0.0369	-0.0009	0.0223	-0.0053	0.0271
LnINDU6	-0.2607***	-0.2291***	-0.2306***	-0.2292***	-0.0892	-0.0716	-0.0681	-0.0807
LnINDU7	0.1603***	0.1729***	0.1900***	0.1414***	0.1894***	0.1916***	0.2157***	0.1709***
LnINDU8	0.0894*	0.0731*	0.0832*	0.0650	0.0819	0.0832	0.1062*	0.0698
LnINDU9	-0.0588	-0.0629	-0.0612	-0.0135	-0.1688**	-0.1285*	-0.1848**	-0.1429*
Time Dummy	Included	Included	Included	Included	Included	Included	Included	Included
# Observations	460	460	460	460	460	460	460	460
Adjusted R2	0.4535	0.4541	0.4377	0.4694	0.5464	0.5626	0.5193	0.5666
F-Value	23.41	23.46	23.33	19.46	33.52	35.73	31.99	28.27

Notes: *, p<0.10; **, p<0.05; ***, p<0.01. Results are corrected with heteroscedasticity.

Table 6 Panel Data Regression Results for Pollution Intensity in the Central Cities

Variable	Industrial SO2 Intensity (LnTSO2)				Industrial Dust Intensity (LnTDUST)			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
LnPGDP	3.9237**	3.1633	1.2810	2.8223	4.3359*	3.9539*	2.9214	3.7155*
LnPGDP*LnPGDP	-0.2118**	-0.1700	-0.0624	-0.1445	-0.2424**	-0.2197*	-0.1514	-0.1894*
LnPRIV	-0.0056			-0.0005	0.0866			0.0577
LnCOES	-0.2039***			-0.2066***	-0.1470***			-0.1597***
LnSOES	0.0342			0.0380	-0.0875*			-0.0709
LnFIES		-0.1074**		-0.0878**		-0.881*		-0.0689
LnEXPORT		0.0941		0.9086		0.2750**		0.2420**
LnIMPORT		0.0028		-0.1819*		-0.3473***		-0.4411***
LnLEXRE			0.3509***	0.2674**			0.6538***	0.5817***
LnVALTAX			0.3445***	0.3312***			0.1846*	0.2269**
LnINDU1	0.2575***	0.2241***	0.2220***	0.2136***	0.2816***	0.2520***	0.2688***	0.2426***
LnINDU2	-0.0217	-0.0536	-0.0372	-0.0022	0.0970	0.1219*	0.1185*	0.1320**
LnINDU3	-0.0200	-0.0296	-0.0360	-0.0509*	0.0528*	0.0439	0.0507	0.0304
LnINDU4	0.0006	0.0033*	0.0286	0.0057	-0.0529	-0.0653	-0.0223	-0.0589
LnINDU5	-0.0697	-0.0815	-0.0520	-0.0468	0.0315	0.0021	0.0418	0.0571
LnINDU6	-0.0377	-0.0451	-0.0008	0.0046	-0.0987	-0.0864	-0.5779	-0.0617
LnINDU7	0.0715***	0.0557**	0.0709***	0.0769***	0.0709**	0.0623**	0.0774***	0.0865***
LnINDU8	0.0725**	0.0554*	0.0771**	0.0908***	-0.0321	-0.0292	-0.0031	0.0188
LnINDU9	0.1809***	0.2333***	0.1635***	0.1459**	0.1729***	0.1808***	0.0904*	0.0971*
Time Dummy	Included	Included	Included	Included	Included	Included	Included	Included
# Observations	440	440	440	440	440	440	440	440
Adjusted R2	0.3681	0.3508	0.3802	0.4013	0.4017	0.4018	0.4311	0.4562
F-Value	16.05	14.96	17.83	14.38	18.34	18.35	21.79	17.74

Notes: *, p<0.10; **, p<0.05; ***, p<0.01. Results are corrected with heteroscedasticity.

Table 7 Panel Data Regression Results for Pollution Intensity in the Western Cities

Variable	Industrial SO2 Intensity (LnTSO2)				Industrial Dust Intensity (LnTDUST)			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
LnPGDP	4.6346***	2.9535**	3.5189**	1.9064	0.9754	0.0161	1.2480	0.4419
LnPGDP*LnPGDP	-0.2658***	-0.1844**	-0.2084***	-0.1480	-0.0809	-0.0340	-0.0891	-0.0610
LnPRIV	-0.2107			-0.1395	-0.0901			-0.0436
LnCOES	0.0387			0.0995	-0.0422			-0.0532
LnSOES	-0.2013***			-0.2365***	-0.1611**			-0.1557*
LnFIES		0.0336		0.0309		0.0395		0.0370
LnEXPORT		0.2181		0.3427		0.0304		0.1180
LnIMPORT		0.7640***		0.5891***		0.5929***		0.5119**
LnLEXRE			-0.2829	-0.3423			0.0562	0.0505
LnVALTAX			0.1986	0.2528			0.1730	0.2473
LnINDU1	0.03870	0.1051**	0.0256	0.0698	0.0749	0.1180**	0.0676	0.0967*
LnINDU2	-0.2737**	-0.1917*	-0.2556**	-0.1618	-0.1368	-0.0611	-0.1254	-0.0890
LnINDU3	-0.0024	0.0378	0.0288	0.0308	0.0145	0.0441	0.0309	0.0371
LnINDU4	0.0731	0.0633	0.0440	0.0120	0.0220	0.0115	0.0124	-0.0047
LnINDU5	-0.1760	-0.1410	-0.1334	-0.0920	-0.0556	-0.0303	-0.0396	-0.0197
LnINDU6	0.1864	0.1780	0.2378*	0.2467**	0.3076**	0.3347**	0.3491**	0.3381***
LnINDU7	0.0442	0.0355	0.0295	0.0488	0.0721	0.0592	0.0589	0.0734
LnINDU8	0.0269	-0.0080	0.0522	-0.0431	0.0379	-0.0262	0.0197	-0.0448
LnINDU9	0.1592**	0.1126	0.1427*	0.1221*	-0.0665	-0.0341	-0.0126	-0.0288
Time Dummy	Included	Included	Included	Included	Included	Included	Included	Included
# Observations	244	244	244	244	244	244	244	244
Adjusted R2	0.1754	0.2100	0.1583	0.2412	0.2958	0.3076	0.2854	0.3124
F-Value	4.04	4.80	3.86	4.51	7.00	7.35	7.07	6.02

Notes: *, $p<0.10$; **, $p<0.05$; ***, $p<0.01$. Results are corrected with heteroscedasticity.