The impact of environmental regulation, shadow economy, and corruption on environmental quality: Theory and empirical evidence from China

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Abstract: Mounting environmental pressures led China to focus on the effectiveness of the environmental regulation to control pollution. Since the shadow economy, or underground economic activities that are not included in official statistics, accounts for an increasing fraction of China's economy, its impacts on environmental quality should be carefully evaluated. In this study, the main research questions are as follows: 1) What is the extent of the effect of environmental regulation on environmental quality? and 2) What are the factors that influence the impact of environmental regulation on environmental pollution? A theoretical model is developed to explain the relationship among the environmental regulation, shadow economy, and environmental quality in China. An empirical analysis is conducted to test the three propositions of the model, thereby examining the explanatory power of the theoretical model. Concretely, using panel data from 30 provinces for the period of 1998-2012, the generalized method of moments (GMM) method is employed to control for potential endogeneity and introduce dynamic effects. The estimation results indicate that stringent environmental regulation and the level of the shadow economy are both positively related to China's environmental pollution; however, the results also indicate that tighter environmental control would help reduce pollution at a given level of the shadow economy. Moreover, an increase in the proportion of corrupt officials may weaken the environmental regulation, which would consequently lead to the increase in illegal production and total pollutant emissions. Besides, many economic and social factors may also affect the environmental quality. For instance, the development of secondary industry contributes toward an increase in pollutant emissions; however, increased research and development (R&D) spending on eco-friendly industrial operations can help to reduce pollution.

Keywords: Environmental regulation; Shadow economy; Corruption; Environmental pollution

1. Introduction

In recent years, China's environmental pollution problems have become increasingly serious; among these problems, haze pollution is particularly prominent. For instance, on November 30, 2015, 37 cities, including Beijing, Tianjin, Hebei, and the surrounding areas, the size of which is nearly that of France, experienced severe haze pollution.[1] Deteriorating environmental quality has attracted wide attention from people of all walks of life. Since environmental pollution control is largely dependent both on the intensity of the environmental regulation and on its supervision and implementation, environmental regulation is considered an important societal concern. According to the world environmental performance rankings, Environmental Performance Index (EPI), which is jointly issued by scientists from the Yale University and the Columbia University, China's EPI score was 65.1 points in 2008, ranking 105th among 149 countries and regions. As of 2014, this score further declined to 43.0 points, and China's ranking slipped to 118th among the 178 countries and regions that were evaluated.[2] To some extent, such EPI scores and rankings reflect the relatively limited effectiveness of China's environmental regulation. In this context, the main research questions in this paper are as follows:

Is China's current environmental regulation effective in reducing environmental pollution?

What are the factors that influence the impact of environmental regulation on environmental pollution?

Studying these issues will not only help in clarifying the effectiveness of environmental regulation in reducing environmental pollution in China but also have important practical significance for the formulation of China's environmental regulation policies.

In view of these important issues, although academia has conducted comparatively deep analysis from various angles, most of the extant literature has not considered the shadow economy when analyzing the factors that influence environmental quality. As Elgin and Öztunali (2014a) revealed the scale of Turkey's shadow economy is massive. Huang (2009) also emphasized that the size of the informal economy that was not accounted for in official statistics might probably be higher than expected in China. According to Schneider's (2005) calculation, China's informal economy accounted for as much as 13% of the gross domestic product (GDP) in 2000. As a result, if the shadow economy contains polluting industries, then, owing to China's relatively weak environmental regulation, the existence of a large-scale shadow economy will cause many environmental problems, such as a surge in pollutant emissions (Mazhar and Elgin, 2013). Therefore, it is necessary and crucial to comprehensively consider the role of the shadow economy when analyzing the impact of environmental regulation on

[1] More information can be found at http://news.xinhuanet.com/english/photo/2015-11/30/c_134870208.htm and http://www.bbc.com/news/world-asia-china-35173709.

[2] The Environmental Performance Index (EPI) is a comprehensive evaluation system for the environmental performance of a given country that focuses on the following two crucial aspects of environmental quality: the protection of human health and the protection of ecosystems. Developed by the Yale Center for Environmental Law & Policy (YCELP) and the Yale Data-Driven Environmental Solutions Group at the Yale University, this index was initially released in 2002 and estimated on a yearly basis. The EPI ranges from 0 to 100, with a higher score indicating better environmental performance. For more information, refer to http://epi.yale.edu/.

environmental pollution (Elgin and Öztunali, 2014b). Given China's unreasonable industrial structure, which relies on the energy- and pollution-intensive secondary industry, particularly heavy industry, the shadow economy may dramatically harm the country's environment (Yu and Gao, 2015). Some of the extant literature has investigated and confirmed that the level of pollutant emissions is closely related to the scale of the shadow economy (e.g., Blackman and Bannister, 1998; Blackman et al., 2006; Baksi and Bose, 2010; Croitoru and Sarraf, 2012).

In addition to serious environmental pollution problems, China also faces a dramatic problem of corruption. According to estimations by the Transparency International, China's corruption perceptions index (CPI) (ranging from 0 to 100, with a higher score indicating less corruption) has been consistently low. For instance, in 2014, China's CPI was 36 points, decreasing from 39 points in 2012, with the ranking decreasing from 80th to 100th globally.[3] Corruption may impactenvironmental pollution by influencing the intensity of environmental regulation. As Welsch (2004) and Cole (2007) stressed, the relationship between corruption and environmental pollution has two dimensions—the direct effect and indirect effect. The direct effect means that corruption reduces the effectiveness of environmental regulation and subsequently affects the quality of the environment. In contrast, the indirect effect of corruption on the environment results from its impact on income levels. Since corruption affects the economic development (e.g., Ehrlich and Lui, 1999; Drury et al., 2005), environmental pollution will, in turn, be affected because of the possible influences of income levels on the environment.[4] Moreover, many studies have confirmed the close relationship between corruption and the shadow economy (e.g., Choi and Thum, 2005; Dreher and Schneider, 2010).

Until now, the research on the relationship among environmental regulation, shadow economy, corruption, and environmental pollution is scarce, and the limited number of extant studies have primarily focused on theoretical analysis. These theoretical research studies have shown that rigorous environmental regulation would encourage the transfer of enterprise production activities from the official economic sector to the shadow economic sector. In other words, although environmental regulation helps to reduce the official statistics on pollution emissions, it might increase the pollution generated from the shadow economy. In China's context, the scale of the shadow economy and the level of corruption are both high, and hence the government has vowed to strengthen the environmental regulation for effectively protecting the environment. Accordingly, it is significant to examine the comprehensive relationship among the environmental regulation, shadow economy, corruption, and environmental

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[3] For more information, one could refer to https://www.transparency.org/research/cpi/overview.

[4] The nexus of environmental quality and economic development has been investigated since the 1990s. In a pioneer research study, Grossman and Krueger (1991) found an inverted-U shaped relationship between the two, by using the data of the three countries in North America. As the economy grows, the environmental pollution will at first increase and subsequently decrease after the peak is reached. They defined this relationship as the Environmental Kuznets Curve (EKC). Many follow-up studies have investigated the existence of EKC, but the empirical results are highly controversial. The detailed discussions on EKC can be found in a series of review papers such as Stern (2004, 2017). Another strand of literature examines the causality between the environmental quality and economic growth (e.g., Ang, 2008; Zhang and Cheng, 2009). A huge and increasing body of literature has indicated that economic development (generally measured by average income) might have an impact on environmental quality despite the disagreement in estimation results until now.

quality in China, and the results of this study can provide helpful references to relevant policymakers.

According to this view, the main contribution of this study is threefold. First, this study comprehensively considers the role of the shadow economy in the analysis of the effectiveness of environmental regulation in reducing environmental pollution in China. In China's context, the ratio of the shadow economy to official GDP statistics is non-trivial. Since the shadow economy is barely regulated and is closely related to energy-intensive industries in China (Yu and Gao, 2015), ignorance of the shadow economy will cause biased estimations in the evaluation of the effectiveness of environmental regulations. Second, a theoretical model is developed to perform an in-depth analysis of the influencing mechanism of the environmental regulation, shadow economy, and corruption on environmental pollution. Constructing a theoretical model contributes toward improving the understanding of the mechanism by which the shadow economy affects environmental quality and lays a solid foundation for empirical analysis. Third, based on the testable propositions of the theoretical analysis, the effectiveness of China's environmental regulation is empirically estimated after fully accounting for the shadow economy. The generalized method of moments (GMM) method, instead of the traditional fixed effects model, is employed to control for potential endogeneity and introduce dynamic effects in this study. Moreover, given the considerable gaps in the economic and social developments across different regions of China, the inland western region and the non-western region are separately analyzed to examine whether the relationship among environmental regulation, shadow economy, and environmental quality may differ at different levels of economic development.

The remainder of the paper is structured as follows. Section 2 briefly reviews the related literature and summarizes the relationship among environmental regulation, shadow economy, corruption, and environmental pollution. Section 3 presents the theoretical model of our research. Section 4 introduces the data source and the empirical analysis method used in this paper. Section 5 reports and discusses the results of the regional empirical analysis, and Section 6 concludes the study and presents suggestions.

2. Literature Review

Until now, there has been a growing amount of literature on the influential factors of environmental pollution. Many relevant studies are based on traditional theories that explain the relationship between environmental quality and economic development, including the environmental Kuznets curve and the pollution haven hypothesis (e.g., Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Torras and Boyce, 1998; Cole et al., 2006).

2.1 Environmental regulation and environmental pollution

Although research on environmental regulation by foreign scholars began earlier, the existing literature is mostly theoretical, not empirical. Overall, these research studies focus on the following two aspects:

(1) Analysis of the impact of environmental regulation on emissions at the enterprise level: For this aspect, using the panel data of 1,759 enterprises from 1988 to

2001, Gamper-Rabindran and Finger (2013) explored the effectiveness of self-regulation in enterprises that joined the “responsible care” alliance. The estimation of the model showed that because of the lack of certification by the third-party agencies, the proportion of toxic substances in the corporate emissions of “responsible care” was higher on average than that of non-responsible care enterprises. Khanna and Kumar (2000) estimated a firm’s specific environmental efficiency through the directional distance equation; they indicated that an economical emission reduction of toxic substances and high-intensity regulation would help enterprises improve their environmental efficiency.

(2) Discussion of the influence of environmental regulation on environmental pollution based on the environmental Kuznets curve (EKC): Through a regression of the random effects model, Hettige et al. (2000) found that there was an EKC curve for the share of manufacturing in the economy. There was a tendency that the sectoral composition may get ‘‘cleaner’’ through middle-income status and then stabilize.

2.2 Shadow economy and environmental pollution

Foreign scholars hold similar views of the relationship between the shadow economy and environmental pollution. They believe that the shadow economy may cause significant harm by aggravating environmental pollution.

By analyzing the survey data on propane in a brick factory, part of the informal brick industry of a city in Mexico, Blackman and Bannister (1998) found that the social pressure played an important role in the utilization of propane. From their point of view, the informal sectors of the developing countries mostly comprise low-technology-intensive and unlicensed small enterprises, which are a major source of pollution and pose a challenge to environmental governance in these countries. Blackman et al. (2006) reached the same conclusion by analyzing the relevant cases of polluting informal sectors in the developing country of Mexico and emphasized the benefits of controlling pollution emissions in the informal economic sectors. Furthermore, Baksi and Bose (2010) built a theoretical framework to examine the effect of environmental regulation at the backdrop of an informal economy. They found that there was a nonlinear relationship between the shadow economy and environmental pollution, depending on the stringency of the regulation and its enforcement. Therefore, stricter environmental regulation can lead to higher or lower environmental pollution. Applying the cost-benefit analysis, Croitoru and Sarraf (2012) estimated the net profit of the illegal brick kilns in Dhaka’s informal economic sectors, when examining the conditions for the implementation of advanced technology. The survey data collected for a period of 5 months in the year 2009 showed the brick kilns were the primary sources of inhalable particulate pollution, whose emissions accounted for 38% of the total emissions. It has been proven that cleaner technologies are morebeneficial for both individuals and societies when compared to traditional techonlogies because the use of cleaning techniques can effectively reduce the premature mortality caused by brick contamination by 45 to 60%. Biswas et al. (2012) established a theoretical model comprising the shadow economy, corruption, and environmental pollution to study both the influence of the shadow economy on environmental pollution for a given level of corruption and the transmission mechanism of how the shadow economy worsens environmental pollution. It appears from the conclusion that the control of corruption contributes toward limiting the impact of the shadow economy on environmental pollution. Elgin and Öztunali (2014) utilized Turkey's annual economic data and analyzed the relationship between several pollution variables and the informal economic scale. They found that, on the one hand, the informal economy on a large- or small-scale is often associated with low- or high pollution levels because informal economic sectors are mostly labor intensive, but less capital intensive, and have a small production scale, which makes informal operations less polluting. On the other hand, they identified that the lack of regulation within informal economic sectors due to their intrinsic factors would lead to environmental deterioration (Schneider, 2014, 2015).

2.3 Environmental regulation, shadow economy, and environmental pollution

For a long time, governments reduced environmental pollution primarily by adopting administrative control measures, such as limiting the amount of sewage, formulating standards for the discharge of pollutants, and taxing pollution practices. However, governmental initiatives to strengthen the intensity of environmental regulation have led enterprises to escape pollution control through the shadow economy; particularly, in developing countries, shadow economic sectors have become the major sources of environmental pollution. This situation has posed enormous challenges in government's efforts to control shadow economic sectors and has resulted in the ineffective implementation of environmental regulation in the official economy.

Until now, only a few studies have been conducted on the relationship between environmental regulation, shadow economy, and environmental pollution. For instance, Chattopadhyay et al. (2010) analyzed the difficulties faced by environmental regulators in pollution control through the establishment of a vertical production model of the official economic sectors and the shadow economy. Similarly, Baksi and Bose (2010) also constructed a two-sector model of the official economy and the shadow economy; the model concludeed that a dependence on the intensity of environmental regulation and its implementation might enable the shadow economy sectors to become a source of environmental pollution leakage. Mazhar and Elgin (2013) conducted an empirical test using the panel data of more than 100 countries between 2007 and 2010 and found that strict environmental regulation could reduce pollution but increase the scale of the shadow economy.

2.4 Corruption and environmental pollution

In general, corruption in economic research refers mainly to political corruption, which means that public officials use public power to seek personal gain. Presently, the study on the relationship between corruption and environmental quality is primarily discussed from the following perspectives:

(1) Considering corruption, income, and environmental pollution in the same research framework. For example, Lopez and Mitra (2000) looked at the impact of corruption on the EKC, and the results showed the existence of the EKC curve as well as an increase in the income levels due to corruption at the inflection point of the EKC.

Cole et al. (2007) also analyzed the direct and indirect effects of corruption on pollution emissions. Through data regression of more than 90 countries from 1987 to 2000, they found that the direct effect was represented by the positive relationship between corruption and pollution, whereas the indirect effect was negatively correlated, and the indirect effect was much greater than the direct effect. Leitao (2010) utilized multinational panel data and the EKC model, which eliminated the nonlinear effects, to analyze how corruption affected income levels at EKC inflection points at different levels of development and corruption. The results indicated that the higher the corruption level was, the higher the income level at the inflection point would be. In addition, the impact of corruption on countries' inflection point and environment will vary because different countries have different income levels (Welsch, 2004).

(2) Emphasizing the impact of corruption on environmental regulation: Fredrikssona and Svensson (2003) studied the relationship among environmental policy, corruption, and political stability using a model of sectional data and environmental policies of 60 countries in 1993. According to their analysis, the relationship between political stability and the stringency of environmental regulation hinged on the level of corruption. Specifically, when the level of corruption is low, political stability has a negative impact on the strength of environmental regulation; however, when the corruption level is high, there is a positive effect of political stability on environmental regulation. Moreover, corruption can weaken the strength of environmental regulation, but the effect will disappear with increased political stability. Pellegrini and Gerlagh (2006) explored the factors that influenced the intensity of environmental regulation in European countries and concluded that the level of corruption was one of the main factors that can be attributed to the variations in environmental policy and that the impact of different levels of corruption was more significant than that of income.

(3) Focusing on the impact of corruption on the environment under open conditions: The development of economic globalization is advancing, and some studies have confirmed the impact of corruption on trade and foreign direct investment (FDI) in various countries. Damaria et al. (2003) studied the relationship among trade policy, corruption, and environmental policy, and analyzed panel data of 30 countries between 1982 and 1992; based on the findings of this analysis, they concluded that trade liberalization could enhance the strength of environmental policy, while corruption had the opposite effects. In addition, the level of corruption can determine the extent of the impact of trade liberalization on environmental policies. Cole et al. (2006) constructed a model of incomplete market competition and analyzed the impact of FDI on environmental regulation. Through an empirical test of seven countries' data, it was found that the level of corruption of governments would affect the relationship between FDI and environmental regulation; particularly, if the level of corruption is high, then the FDI will reduce the intensity of the environmental policy. Rehman and Nasir (2007) empirically analyzed the trade openness, corruption, and environmental quality in the South Asian countries. The results presented that trade openness had a positive impact on environmental quality, but the extent of this impact depended on the level of corruption in each country.

Through the above literature review on four aspects, this study summarized that, like supervision, the shadow economy and corruption are important factors that affect the effectiveness of environmental regulation, and the shadow economy may pose serious harm to environmental pollution. This is because environmental regulation may increase the scale of the shadow economy while controlling official economic pollution, thereby worsening the environment as a whole.

The existing research on the effectiveness of environmental regulation has mainly focused on the choice of various policy tools and the dynamic games between enterprises and government regulation departments, while a systematic analysis of the relationship and the influential mechanism among the environmental regulation, shadow economy, corruption, and environmental pollution is still scarce. Particularly, despite the serious problems concerning both environmental pollution and corruption in China, there are very few studies incorporating these issues in an integrated research framework. To fill the research gap, this study quantitatively investigates the relationship between environmental regulation and environmental pollution by considering the impact of the shadow economy. Additionally, the mechanism of the interaction between them is analyzed and interpreted using a carefully designed theoretical framework. Therefore, this study contributes to the existing literature both theoretically and empirically.

3. Theoretical Model

In this section, a theoretical model is adopted from Biswas et al. (2012) and Yu and Gao (2015) to explain and underscore the relationship between the recent government policy, the shadow economy, and the administrative corruption scenario in China. The main difference between this model and that developed by Biswas et al. (2012) is that this model highlights some important characteristics of environmental regulation and corruption in China, and this model differs from Yu and Gao (2015) by incorporating corruption into the theoretical model. Therefore, the settings of the model enhance the explanatory power of the theoretical framework, thereby enhancing the reasonability and rationality of the empirical results based on the propositions obtained from the theoretical model.

The basic hypothesis of this theoretical model is that, during the production process, the output X of a firm can be produced in both the formal and the informal sectors—$X = x_I + x_F$, where x_F and x_I are the outputs in the formal and the informal sectors, respectively. When producing the same amount of output, the same pollutant is created in both sectors. In the formal sector, the firm may comply with the government policy, which would require the firm to deal with the pollutant, whereas in the informal sector, the firm will illegally drop its waste without any treatment.

In this model, it is assumed that the firm would obtain one unit of revenue if it produced one unit of output, which may also generate one unit of pollutant emissions. According to the government policy, the level of abatement is $e(0 < e \leq 1)$, which indicates that the firm must reduce e units of pollutant emissions when creating one unit of product. In this regard, e measures the strength of the government environmental regulation. For $e = 1$, the firm deals with all the pollution and is not allowed to release any of it; for $e = 0$, the firm can discharge all pollutant emissions without any treatment. $a(e)$ measures the marginal cost of reducing pollution at a given level of e (i.e., the cost of decreasing pollution by one unit). We further assume that $a'(e) > 0$ and $a''(e) > 0$.

The rising cost of handling the pollution under supervision may produce incentives for the firms to transfer part of the productions from the formal sectors to the informal sectors, which may reduce production cost but increase pollutant emissions. To avoid such a situation, the government can assign officials to monitor the suspicious firms and to keep them from discharging pollution illegally. For simplicity, it is assumed that the revenue from the illegal production will be confiscated once detected, and the owners will not receive other penalties such as being jailed or fined.[5] However, there remains the possibility that some illegal production and emissions might not be fully supervised. It is further assumed that the possibility of identifying illegal production is $P(x_I)$ ($P(0) = 0$) with $P' > 0$ and $P'' > 0$. Therefore, the expected value of confiscated revenue is equal to $P(x_I)x_I$.

The firms may attempt to bribe the officials to ensure that officials overlook and not report their illegal production activities, thereby reducing the possibility of the seizure of supervisors for illegal production and emissions. Since it is more difficult for corrupt regulatory officials to conceal the illegal production and pollution, the bribe $T(x_I)$ has to increase along with the scale of informal production. Therefore, T is assumed to be an increasing function ($T' > 0$,$T'' > 0$).

Concerning the regulatory officials, they have two choices when offered bribes—to accept or to refuse. While the corrupt officials accept bribes and discontinue monitoring the informal production activities, the honest officials refuse bribes. In this case, the possibility for the illegal production being detected is $P(x_I)$. Concerning a firm, it would try to bribe regulatory officials only when its net revenue after paying bribes is equal to or higher than zero. Therefore, the amount of the bribe $T(x_I)$ should be lower than the expected value of the confiscated revenue $P(x_I)x_I$, otherwise, it would be impractical for firms to pay a bribe. Mathematically, this implies $P(x_I)x_I - T(x_I) > 0$ and $(P(x_I)x_I - T(x_I))' = P'(x_I)x_I + P(x_I) - T'(x_I) > 0$.

A firm obtains its maximum profit by adjusting the amount of production in the formal and informal sectors. The sales revenue is $x_I + x_F$. Meanwhile, the costs of a firm are as follows:

(1) The firm must deal with a part of the pollutants that accompany the goods produced in the formal sector. The corresponding expense is $a(e)x_F$.

(2) During illegal production, the firm would bribe the supervising officers, among which the proportion of the corrupt ones would be y. Therefore, the expected amount of bribe money would be $T(x_I)y$ for the firm.

(3) Based on (3), the proportion of the honest officers would be $1 - y$, and these officers will rebuff the bribe. Given that the possibility of detecting illegal production

[5] As an anonymous reviewer pointed out, the costs of non-compliance may change significantly if the possibility of being prosecuted and prison sentences are considered. If prison sentences can be imposed on company directors and employees who deliberately contravene environmental regulation, then such violation should also be considered while determining the potential costs of non-compliance. To keep the theoretical model as simple as possible, we ignore this possibility and assume that the costs of non-compliance would only be the revenue generated from the confiscated illegal production. This possibility can be incorporated into the theoretical model to enhance its explanatory power in future studies.

is $P(x_I)$, the expected loss of revenue of informal sectors is $P(x_I)\ El(x_I) = P(x_I)(1-y)x_I$.

(4) The firm also incurs production costs, which are $C(X)$ ($C(x_I, x_F)$) when the total production amount is X. Specifically, following usual practice, we further assume that $C' > 0$ and $C'' > 0$ ($\frac{\partial C}{\partial x_F} > 0$, $\frac{\partial C}{\partial x_I} > 0$, $\frac{\partial^2 C}{\partial x_F{}^2} > 0$, $\frac{\partial^2 C}{\partial x_I{}^2} > 0$).

Following these assumptions, three testable propositions can be derived as follows:

Proposition 1: Tighter environment regulation will cause a decrease in the output of formal production and an increase in the output of informal production. Briefly, it will lead to an increase in the proportion of illegal production to total output. The net impact of tighter environmental regulations on environmental quality would depend on the relative strength of the two opponent effects.[6]

Proposition 2: The impact of an increase in the level of corruption (measured by the proportion of corrupt officials) on environmental pollution is ambiguous. If corruption leads to a looser environmental regulation, then an increase in corruption would lead to an increase in pollution.

Proposition 3: Production in the illegal economic sectors (shadow economy) negatively affects environmental quality owing to an increase in the unmonitored pollution emissions.

Proofs: See the appendix.

In the empirical estimations below, the three aforementioned propositions derived from the theoretical model are tested with actual data from China.

4. Data source and empirical methodology

4.1. Methodology

According to the theoretical model, both direct and indirect effects of environmental regulation on the environmental quality should be investigated. To examine the direct impact, the impact of the shadow economy and official corruption on environmental pollution is considered in the regression equation. To investigate the indirect effects of environmental regulation on environmental pollution through the shadow economy, an interactive term that multiplies the environmental regulation with the shadow economy is also introduced in the regression model. Therefore, the basic econometric model of this study is designed as follows:

$$ep_{it} = \alpha_0 + \eta ep_{it-1} + \alpha_1 er_{it} + \alpha_2 se_{it} + \alpha_3 er_{it} \times se_{it} + \alpha_4 er_{it} \times corr_{it} + \alpha_5 gc_{it} + \theta C_{it} + \varepsilon_{it} \quad (1)$$

where i is the province, t is the time, $\mathrm{ep}_{\mathrm{it}}$ stands for industrial pollution of Province i in Year t. er_{it} stands for the environmental regulation intensity of Province i in

[6] Although the relationship between the stringency of environmental regulation and the scale of informal production may exist in many countries, this study mainly focuses on China. This is because the scale of informal economy in China is considerably large (Huang, 2009), and the negative influence of China's informal economy on environmental quality is quite significant (e.g., Tong et al., 2017). Therefore, the ***Proposition 1*** is mainly applicable to China.

Year t. se_{it} stands for shadow economy scale of Province i in Year t. gc_{it} stands for the official corruption degree of Province i in Year t. $er_{it} \times se_{it}$ is the interactive term of environmental regulation and shadow economy. $er_{it} \times corr_{it}$ is the interactive term of environmental regulation and corruption. C_{it} is a vector that is composed of other control variables that affect environmental pollution, including the real per capita GDP and its square term in each region, trade openness, industrialization, R&D intensity, and educational level and population density. μ_i represents the regional fixed effect variable. v_i represents the time fixed effect variable and ε_{it} represents the random error term.

To obtain the partial effect of environmental regulation on environmental quality, the partial differential of dependent variable *ep* with respect to the environmental regulation *er* is calculated, the result of which is as follows:

$$\frac{\partial(ep)}{\partial(er)} = \alpha_1 + \alpha_3 se \qquad (2)$$

In Eq. (2), α_1 stands for the direct impact of environmental regulation on environmental pollution, and α_3 stands for the indirect impact of environmental regulation on environmental pollution through the shadow economy. If α_3 is estimated to be significant and not equal to zero in magnitude, then the marginal effect of environmental regulation will be dependent on the level of the shadow economy. The introduction of this interactive term examines the indirect effect of shadow economy on the environmental quality through its impact on environmental regulation. Similarly, another interactive term of corruption and environmental regulation can be incorporated to investigate the indirect effect of corruption on environmental quality through its influences on environmental regulation.

Since the current environmental quality is closely related to historical levels, the first-order lag of the dependent variable is introduced as an explanatory variable (Du et al., 2012). However, when using the first-order lag of the dependent variable as an explanatory variable in Eq. (1), the residual term ε might have sequence correlation and be related to the first-order lag term of the dependent variable. Concerning the dynamic panel data, the traditional ordinary least squares (OLS) method may yield biased estimates (Semykina and Wooldridge, 2010). Owing to the potential bilateral causality between environmental pollution, environmental regulation, and the shadow economy, there might be an endogeneity problem; therefore, the conventional OLS estimator is considered inappropriate (Wooldridge, 2016).

One possible method to deal with potential endogeneity problem would be to employ the instrument variables (IV) approach. However, since appropriate instrumental variables, which are vital to the usage of IV method to eliminate endogeneity, are difficult to find in practice, the GMM method originally proposed by Arellano and Bond (1988) is used to estimate the Eq. (1). In essence, GMM is a specific form of the IV method that uses predetermined variables and/or some lag terms for exogenous variables as instrument variables, which verify the rationality of instrument variables through an inspection. Moreover, GMM approach can also allow dynamics.[7] The GMM approach was also used in some recent studies on environmental research such as Halkos and Paizanos (2013) and Liu et al. (2017).

There are two commonly used GMM estimators—the first-difference GMM developed by Anderson and Hsiao (1981) and Arellano and Bond (1991) and the system GMM raised by Arellano and Bover (1995) and Blundell and Bond (1998). The main difference between these two estimators lies in how the instrumental variable is chosen. For the first-difference GMM, the first-order difference is taken first, and the higher-order lags of the dependent and some independent variables are subsequently chosen as instruments for the differenced dependent variable. Contrarily, for the system GMM, the differenced dependent variable and some independent variables of various lags are used as instruments for the dependent variable. Since the system GMM approach can use more information of the data, it is generally more efficient (Huang, 2010). Therefore, the system GMM estimator is used as the benchmark estimation method in this study.

4.2. Variables and data

The variables used in this study are elaborated below:

(1) Environmental pollution (*ep*). To measure the degree of environmental pollution in various regions of China, in this study, three representative indicators (i.e., per capita carbon dioxide emissions, per capita dust emissions, and per capita wastewater discharge) are chosen for the empirical study. These three indicators were also commonly used in previous relevant research studies as the measurements for the degree of environmental pollution (e.g., Auffhammer and Carson, 2008; Song et al., 2008; He and Wang, 2012). Fig. 1 depicts the per capita soot and dust emissions of all 30 provinces under investigation in 2002 and 2014; it is found that most of the soot and dust emissions are congregated in northern regions. The logarithmic form of per capita pollutant emissions is incorporated into the regression equation. The data on per capita pollutant emissions from various regions are derived from the China Environment Statistical Yearbook and the China Entrepreneur Investment Club (CEIC) Database.

[Figure 1 about here.]

(2) Environmental regulation (*er*). Environmental regulation is the core explanatory variable of this study. At present, the relevant data for the variables are difficult to obtain, and the data quality is relatively poor. Considering the data availability and following previous studies on similar topics, such as that of Yin et al. (2015), the proportion of environmental pollution governance investment in GDP is utilized as the indicator of environmental regulation in this study. China's

[7] Another possible method for estimating the dynamic panel data is to employ dynamic panel models with fixed effects (DFE), which was raised by Pesaran and Smith (1995). For DFE, the intercept term (fixed effects) of each province differs, while the long-term coefficients of each explanatory variable are identical. However, despite its ability to deal with dynamics, DFE could not address potential endogeneity. Therefore, DFE is not used in the empirical study of this paper.

environmental governance investment reflects governmental willingness ‘and their efforts and determination in environmental management in the region, thus representing the extent of the actual environmental regulation in the region. Often, with an increase in the stringency of the government's environmental regulation , firms may reduce their monitored production and accordingly increase their illicit production; this would result in an increase in the proportion of illicitly produced products in the total output and higher pollution. According to ***proposition 1***, the direct effect of the environmental regulation on environmental pollution is negative. Therefore, this article expects $\alpha_1 > 0$. The original data for China's environmental regulation are collected from *China Environment Yearbook* and *China Statistical Yearbook* (various years).

To illustrate the spatial correlation of environmental regulation in an intuitive way, the provincial proportion of environmental pollution regulation investment in GDP of all the 30 provinces under investigation in 1998 and 2012 are presented in Fig. 2. There are two main observations from Fig. 2. First, in both years, there are clear differences in the environmental regulation levels across regions. Second, in recent years, environmental regulation has been strengthened in the northwest and part of the northern region with lower environmental carrying capacity.

[Figure 2 about here.]

(3) Shadow economy (*se*). Since shadow economic activities are conducted in a secretive manner, it is difficult to obtain accurate information about these activities. Despite difficulties, some scholars have employed different methods to evaluate the size of the shadow economy. Among them, the Multiple Indicators and Multiple Causes (MIMIC) method integrates the characteristics of the two statistical techniques of factor analysis and regression analysis; since the information coverage is broad, it is theoretically a very robust technique. Compared to the traditional methods used for calculating the informal economy, the MIMIC model has some advantages. For example, the estimations using the MIMIC model are robust to the variables with measurement errors, and the MIMIC model can provide overall model tests and independent parameter tests simultaneously. The basic idea of the MIMIC approach was first proposed by Frey and Weck-Hanneman (1984), who estimated the relative size of the shadow economy by describing the structural relationship between exogenous variables (causal variables of the shadow economy) and endogenous variables (indicator variables containing certain information about the shadow economy). Until now, the MIMIC model has been widely used in the evaluation of the size of the informal economy in many countries and areas (e.g., Bajada and Schneider, 2005; Schneider, 2005; Schneider et al., 2011). In this study, the MIMIC method is also utilized to measure the shadow economy of China's 30 provinces.

Without doubt, the scale of shadow economy in China is hard to come by. It is generally believed that the informal sector is closely related to heavy tax burden, strict environmental regulation, unemployment, inflation, and self-employment conditions (e.g., Bajada and Schneider, 2005; Johnson et al., 1997; Schneider et al., 2010). It is noteworthy that the shadow economy may have both positive and negative impacts on the formal economy. On the one hand, the shadow economy utilizes the resources that should be used in the formal economy, such as labor resources, and therefore it may have a negative effect on the development of the public economy. On the other hand, the underground economic activists may increase the income of the involved people, which would help to boost consumption and the growth of the formal economy sector (Igudia et al., 2016). Essentially, both positive and negative indicators should be utilized to measure the size of the shadow economy. Following Gao (2014), given the data availability and previous relevant studies, in this study, the following seven variables are selected to evaluate the scale of the shadow economy using the MIMIC model: the tax burden, unemployment rate, personal disposable income, level of government control, self-employment rate, real GDP growth rate, and labor participation growth rate.[8] The data for the scale of the shadow economy for Chinese provinces are obtained directly from Gao (2014). Fig. 3 depicts the relative size of the shadow economy when compared to GDP for the entire country and three geographical regions of China (East, West, and Central). As shown in Fig. 3, the changing patterns of different regions are quite similar. In the first half of the sampled period (1998–2005), the scale of the shadow economy increased rapidly; however, after 2005, the relative size of the shadow economy to GDP remained roughly stable. Since the influence of the shadow economy on environmental pollution is expected to be positive, $\alpha_2 > 0$.

[Figure 3 about here.]

[Figure 4 about here.]

As shown in Fig. 4, five provinces in Northern China (i.e., Shanxi, Inner Mongolia, Qinghai, Gansu, and Ningxia) have a relatively larger scale of shadow economy (as a fraction of official GDP). It is interesting to notice that there is some similarity between the spatial distributions of the relative size of the shadow economy (Fig. 4) and the stringency of environmental regulation (Fig. 2). One of the possible reasons for this similarity is a positive correlation between the size of the shadow economy and its environmental impact. Accordingly, the provincial government has to implement a stricter regulation to tackle environmental problems that become more serious due to larger shadow economy..

(4) Government corruption (*corr*). Currently, official corruption involves a wide range of areas, and the corruption that affects environmental regulations may have a more direct impact on environmental quality. It may occur in the formulation or implementation of the environmental policies. For example, officials can use their

[8] For a detailed discussion on the MIMIC method and other competitive approaches as well as the possible causal factors of the shadow economy, one can refer to Schneider (2014). It offers a thorough review of the estimations of shadow economy until date.

licensing authority and supervision for “rent-seeking.” The Corruption Perceptions Index (CPI), issued by the Transparency International, and the international risk guidelines, issued by the World Bank, are the two indicators commonly utilized for measuring the level of corruption in a country. However, it is somewhat difficult to find appropriate and widely accepted indicators for the severity of corruption at the provincial level because of data availability issues. In this study, considering data availability, the number of corrupt officials per 100,000 people who are registered for filing a case is utilized as the indicator of the provincial level of corruption. This indicator has been utilized in previous studies for China, such as Dong and Torgler (2013) and Mei et al. (2014). In Fig. 5, the geographic distribution of corruption in 1998 and 2012 is depicted. It can be seen that, comparatively, the level of corruption was relatively higher in the central and western provinces than it was in the rich and prosperous eastern and coastal provinces.

[Figure 5 about here.]

(5) Control variables. To examine the robustness of the estimated results, this study also incorporates the following control variables:

(i) Real per capita GDP (y). To examine the existence of the Environmental Kuznets Curve (EKC) between environmental pollution and economic development, the logarithmic form of real per capita GDP (1978 prices as constant) (y) and its quadratic component (y2) are introduced to estimate the nonlinear relationship between per capita income and per capita CO_2 emissions (Du et al., 2012; Hao and Wei, 2015).

(ii) Trade openness (open). Theoretically, there are two opposite impacts that trade liberalization may have on environmental quality. On the one hand, a highly advanced eco-friendly technology may be introduced through foreign trade, which will help to reduce pollution; it is defined as the “technique effect” by Grossman and Krueger (1991). On the other hand, since some export goods are produced in energy- and pollution-intensive industries in China, an increase in foreign trade might trigger pollution. In this regard, the net impact of trade openness on environmental pollution is uncertain. Following Du et al. (2012), this study uses the proportion of total imports and exports in GDP (trade intensity) to represent the trade openness.

(iii) The proportion of value added by secondary industry in GDP (second). The industrial structure of the economy may affect pollution, and different industrial structures have different effects on environmental pollution. Following a series of previous studies like Wang et al. (2012), Yin et al. (2015), and Wang et al. (2016), the proportion of value added by secondary industry in GDP is utilized to reflect the impact of the industrial structure on environmental pollution. In general, the higher the proportion of value added by secondary industry in GDP is, the higher the level of pollutant emissions will be. Therefore, the impact of the proportion of value added by secondary industry in GDP on environmental pollution is expected to be positive.

(iv) Population density (pop). The influence of population density on environmental pollution is ambiguous (Lee et al., 2009; Hao et al., 2016). On the one hand, there is an accumulation of population in the industrialized facilities of urban areas, which contributes toward environmental pollution. On the other hand, high population density enables the more efficient and intensive use of energy (e.g., central heating and cooling). Moreover, the increase in population intensity may bring more political pressure on the government to improve environmental quality. Essentially, the net impact of population density on the environment depends on the relative strength of the two opposite effects.

(v) Educational level (edu). Some previous studies have found that a higher education level is conducive to better environmental and health knowledge as well as improved environmental awareness that contributes toward curbing the pollutant emissions (e.g., Hettige et al., 1996; Managi and Jena, 2008; Balaguer and Cantavella, 2018). For instance, Hettige et al. (1996) suggested that poor communities with low levels of education and limited information might contribute to the inappropriately high pollution, either because of lack of awareness about environmental pollution and inability to evaluate its consequences or because they are unable to organize to combat the pollution. In a recent study, Balaguer and Cantavella (2018) also found that the expansion in education rate helped to curb the increase in CO_2 emissions in Australia. However, contrarily, some studies that claimed further education might degrade environmental quality (Gangadharan and Valenzuela, 2001; Hill and Magnani, 2002). Specifically, Hill and Magnani (2002) found evidence that higher education levels might lead to more pollution, which is the case, especially, in the emerging economies where higher educational levels can increase the chances of poor people to be hired in better-paid pollution-intensive industries. In this regard, the total effect of education on the environment is uncertain and deserves further investigations. This study uses the proportion of regional high school and the above cultural-level population to indicate education level.

(vi) R&D strength (rd). Technological progress and technological innovation have an important impact on improving the energy consumption structure of a country and improving energy efficiency. In general, the stronger the R&D capability is, the fewer the resources required to produce the same output will be and the lower the energy consumption per unit of output will be, and therefore lower the corresponding environmental pollution will be, such as CO_2 (Ai et al., 2015; Yin et al., 2015). In this regard, the impact of R&D intensity on environmental pollution is expected to be negative. This study employs R&D expenditures in various regions to indicate the research intensity and development. The real per capita GDP in China, proportion of total imports and exports in GDP, proportion of value added by secondary industry in GDP, population density and proportion of high school, and the above cultural-level population are extracted from the China Statistical Yearbook. The data on internal R&D expenditures in each region are derived from the China Science and Technology Statistical Yearbook and China Statistical Yearbook. The sample data used in this study comprise provincial panel data of 30 provinces in China from 1998 to 2012 (Tibet is excluded because of data unavailability).

[Table 1 about here.]

5. Regression results and analysis

5.1. Estimation results for the entire sample

[Table 2 about here.]

Table 2 reports the system GMM estimation results for the dynamic panel data model. Since there is an evidence of heteroskedasticity, the more appropriate two-step Arellano-Bond procedure is utilized. In the six regression equations, the per capita carbon dioxide emissions, per capita dust emissions, and per capita wastewater discharge are utilized as the dependent variables to measure the level of environmental pollution. As discussed previously, the main explanatory variables include the level of environmental regulation, shadow economy, and the level of corruption. The per capita GDP and the square of the log form of per capita GDP are employed to measure the level of economic development. Since the statistics for the Arellano-Bond tests AR (1) are significant, but those for AR (2) are insignificant, the error term of these models does not have self-correlation problems. Moreover, the statistics of the Hansen test are statistically insignificant, suggesting that the chosen instrumental variables are generally effective.

When only the core explanatory variables are included in the regression in Eq. (1), the estimation results are shown in columns (1), (3), and (5) in Table 1, whereas the estimation results reported in columns (2), (4), and (6) represent the corresponding results obtained after the inclusion of other control variables. From these regression results, the main conclusions can be drawn as follows. (i) In all the specifications, the coefficients of the first-order lag of environmental pollution variables are estimated to be positive, which indicates that the inertia of environmental pollution is high—the current level of pollution is closely related with the level of the last period. (ii) For all models, the estimated coefficients of *er* are significantly positive, suggesting that a large number of stringent environmental regulations are positively related to the levels of the three environmental pollution indicators. From the quantitative relationship point of view, after the inclusion of the control variables, if other conditions remain unchanged, an increase in the fraction of the provincial environmental pollution control investment in GDP by 1% would trigger an increase in the per capita carbon dioxide emissions, per capita smoke emissions, and per capita wastewater discharge by 0.15%, 0.20%, and 0.13%, respectively. The main reason for these results might be that, to some extent, a stricter environmental regulation encourages and stimulates an increase in the illegal and unmonitored production of polluting firms and companies, which might not only compensate for the possible decrease in the pollution generated from legal production but also drive up the total pollution. At the same time, the coefficients of the interactive term of environmental regulation and shadow economy scale ($er \times se$) for the three pollution indicators turn out to be significantly negative, thereby indicating that the environmental regulation indeed reduced pollution after the scale of the shadow economy is controlled for. As a result, these results verify the ***proposition 1*** of the theoretical model and show that the environmental regulations did not function as expected due to the existence of the shadow economy. (iii) The influence of the shadow economy on the three industrial pollution indicators are significantly positive because the coefficients of *se* are statistically significant and nontrivial in magnitude. These results show that the development of the shadow economy would trigger environmental pollution. Therefore, an improvement in the intensity of environmental regulation by the government would lead to a corresponding increase in the scale of the shadow economy(Baksi and Bose, 2010). This confirms the ***proposition 3*** of the theoretical model. (iv) The impact of the proportion of corrupt officials to all government officials on the three pollutant emissions and discharges is positive, and they are statistically significant for soot and wastewater. It is noteworthy that these estimation results are essentially consistent with previous studies like that of Cole (2004), who examined the dual effects of corruption on environmental pollution and found that, for most countries, the negative impact of official corruption on environmental pollution was greater than its positive impact. Intuitively, these results indicate that higher corruption may lead to relaxed environmental regulation, leading to deteriorated environmental quality. The interactive terms of corruption and environmental regulation are negative, and those for soot and wastewater are statistically significant. Again, these results suggest that environmental regulation can be effective in reducing pollutant emissions only when corruption is controlled at a given level. One possible reason that can be attributed to the insignificant estimation results for CO_2 emissions is that the Chinese government did not formulate formal regulations or restrictive policies for CO_2 emissions until very recently (Hao and Wei, 2015); therefore, carbon emissions are not worsened by overly weakened regulations caused by an increase in corruption. In this regard, the ***proposition 2*** of the theoretical model is also confirmed. In summary, all three propositions of the theoretical framework are supported by the actual data, which indicate that the theoretical model developed in the previous section is valid for China.

Some interesting conclusions can also be drawn from the estimation results when the control variables are included. Specifically, there is no consistent evidence for the existence of the conventional inverted U-shaped EKC relationship for the three pollutants. Concerning CO_2 and soot emissions, there seems to be some evidence of the existence of EKC (although not robust or significant), whereas, for wastewater discharges, the nexus might be U-shaped as the estimated coefficients of y and y^2 are negative and positive, respectively. One possible reason for this result might be that the sampled period used in this study ends with 2012, and the emissions and discharges of the three pollutants did not show a clear decreasing trend until then. This result also adds new evidence for long-time critics of the EKC (e.g., Stern, 2004, 2017; Carson, 2010). Previous studies suggested that the estimation results for the EKC depend on the chosen data period and sampled countries or regions. For instance, Musolesi et al. (2010) examined panel data comprising 109 countries between 1959 and 2001 and found that the relationship between CO_2 emissions and per capita GDP was N-shaped only in high-income countries, whereas, in developing countries, emissions increased together with per capita GDP. China, as the largest developing country, has also shown similar characteristics. De Groot et al. (2001) and He and Wang (2012) examined the relationship between various pollutant emissions and GDP per capita in China using provincial- and city-level data, respectively. Their conclusions indicate that the existence of the EKC in China relies on the choice of pollutants and varies at different stages of development. Similarly, in a more recent study using Extreme Bound Analysis (EBA), Yang et al. (2015) reported that the empirical results indicated that the EKC relationship was invalid for all of the seven emission indicators used.

The estimation results indicate that some control variables have a considerable impact on pollutant emissions and discharges. Similar to some previous studies, such as those of Du et al. (2012) and Hao et al. (2015), the secondary industry made a remarkable contribution to environmental pollution, as the proportion of value-added of the secondary industry to GDP was estimated to be significantly positive (although insignificant for wastewater discharge). Such a result reflects that secondary industry in China was energy- and pollution-intensive, and therefore industrial upgrading would be crucial for China's environmental improvement (Cheng et al., 2018). The impact of population density is ambiguous as the coefficients for CO_2 and soot emissions are negative, whereas the coefficient for wastewater discharge is estimated to be positive. These results indicate that, for different types of pollutants, the relative strengths of the positive and negative impacts of population accumulation are different. Partly, since the public awareness and perception of air pollution are relatively strong (Sun et al., 2016), citizens, in general, care more about air pollution because it affects public health directly and significantly (Chen et al., 2017; Lu et al., 2017). Additionally, higher population density tends to decrease air pollutant emissions compared to wastewater discharge. In addition, as expected, the R&D intensity has a negative impact on soot emissions and wastewater discharge (it is statistically significant for the latter), suggesting that innovation and R&D play important roles in improving the environmental quality in China. Moreover, the impact of trade openness on the three pollutants are, in general, positive but insignificant (although for wastewater discharge, it is barely significant), indicating that trade liberalization leads to environmental deterioration in China, at least to an extent. This result implies that the attribution of trade openness to environmental pollution in China might be greater than its inhibitory effect through the introduction of eco-friendly technology. In this regard, similar to Li et al. (2016), this result indicates that the negative "scale effect" and "composition effect" of foreign trade outweigh the positive "technique effect," and thus have led to more pollution in China. Additionally, the effects of education on the environment differ for the three pollutants and are small in magnitude, suggesting that education levels do not play a very important role in changing China's environmental quality during the sampled period

5.2. The estimation results for different geographical regions

[Table 3 about here.]

Given the remarkable differences in the economic and social development across the Chinese regions, the effects of environmental regulation, considering the shadow economy and corruption, might differ for different areas of China. In this regard, the estimations are redone for the two geographical regions of China—the West and the East. According to the practice of the National Bureau of Statistics (NBS), the West of China includes 11 provinces, autonomous regions, and municipalities. We define the East of China as a region that includes all the other 19 provincial administrative units.[9] In Table 3, the estimation results for both regions are presented.

Specifically, columns (1), (3), and (5) of Table 3 present the regression results for the West of China, whereas columns (2), (4), and (6) of Table 3 are for the East. Overall, the estimates for the two subsamples are in line with those for the full sample. All the estimation results indicate that, like the case for the entire nation, the environmental regulations on all three industrial pollutants are ineffective because the corresponding coefficients are significantly positive. Similarly, the coefficients of the interactive term of environmental regulation and the shadow economy on the three environmental pollution indicators are significantly negative, which implies that environmental regulation can contribute toward the improvement of the environmental quality as long as the scale of the shadow economy and the levels of corruption are controlled. For both regions, the effects of the shadow economy on environmental pollution are significant and positive. Similar to the results for the entire nation, the level of corruption is also positively related to pollution in both regions; however, the interactive terms of corruption and environmental regulation are negative, which suggests that the environmental regulation can be effective in reducing pollutant emissions and discharge only when the severity of corruption is controlled at a given level. Moreover, comparatively speaking, the shadow economy affected environmental quality more severely in the West, partly because of the relatively low level of economic development and high level of environmental vulnerability in the West. As a result, for the two subsamples of different geographical regions, the three propositions derived from the theoretical model have also been supported.

6. Conclusions and Policy Suggestions

Environmental deterioration has become a severe problem in many countries. A large underground economy and government corruption may significantly contribute toward

[9] The West of China contains the following six provinces (Sichuan, Guizhou, Yunnan, Shanxi, Gansu, and Qinghai); five ethnic autonomous regions (Xinjiang, Ningxia, Inner Mongolia, Guangxi, and Tibet); and one municipality (Chongqing). Tibet is excluded from the sample because of data unavailability. All the other provincial administrative units are in the East of China. It is noteworthy that under this definition, the East of China comprises the central and eastern regions of the traditional classification.

environmental pollution, especially, in developing countries of Africa, Asia, and Latin America. This study investigates the effectiveness of environmental regulation with full consideration of the shadow economy and corruption in China. A simple theoretical model is built by adopting the pioneering works of Biswas et al. (2012) and Yu and Gao (2015). Subsequently, by using the panel data of 30 provinces in China from 1998 to 2012, three propositions derived from the theoretical model are examined and confirmed by employing the system GMM approach, which can effectively address potential endogeneity and introduce dynamics.

From the analysis of the theoretical framework and corresponding empirical estimations, the following conclusions can be drawn. First, China's environmental regulations during the sampled period were ineffective as the increased investment in environmental protection did not effectively reduce the pollution level as long as the shadow economy and corruption were not well controlled. Second, the existence of the shadow economy reduces the effectiveness of environmental regulations because polluting firms facing such stricter regulations respond by increasing the ratio of illegal, unmonitored productions. Third, the anti-corruption campaign would be beneficial for the environment because increasing anti-corruption efforts would pressurize officials, thereby making them less likely to loosen regulations in return for bribes. Fourth, many economic and social factors may also affect the environmental quality. For instance, the development of secondary industry is closely related to pollutant emissions, but higher R&D expenditure helps in reducing pollution. From the global perspective, this study has shed some light on the mechanism through which the environmental regulation can enhance the environmental quality in the developing countries like India and Brazil that are facing the dual tasks of promoting economic growth and protecting the environment. The theoretical framework and empirical methods used in this study can also be utilized to analyze similar problems in other emerging economies.

Considering these primary conclusions, we provide the following policy recommendations:

(1) Pay more attention to the effectiveness of environmental regulations. It would be more reasonable for the government to formulate the intensity of environmental regulation discriminatively, according to the actual characteristics of each region and industry, and focus on carrying out revisions to adjust environmental regulation promptly to the appropriate level to ensure that it can offer continuous stimulation and avoid being confined to a fixed static standard (Porter and Linde, 1995). Furthermore, the government can also effectively utilize various means of environmental regulation, including environmental taxes, emissions trading systems, recycling systems, green consumption (Stewart, 1993), a sewage charges return mechanism, and a tax subsidy mechanism, to give enterprises the flexibility to adopt more economical methods to satisfy the environmental regulation requirements (Jaffe and Stavins, 1995).

(2) Strengthen the supervision and actively control the size of the shadow economy due to its negative impact on the environment. The government should not only punish the shadow economic behaviors of enterprises through administrative and legal means but also reduce the tax burden on enterprises and create a favorable and fair operating atmosphere for them. This

is because the tax burden of enterprises is an important factor that affects the scale of the shadow economy. Moreover, efforts should be made to cultivate environmental awareness and enhance enterprises' sense of mission and responsibility. The existing environmental regulation policy in China is still limited in terms of effectively curbing the production activities of the shadow economy sectors. Therefore, the government should establish effective pollution reduction incentives and penalties that are also beneficial for the shadow economic sectors.

(3) Make further efforts to punish all types of corruption and strive to strengthen institutional construction. Corruption has a significantly negative impact on the environment; therefore, anti-corruption efforts should be further intensified. In this regard, it is essential to improve government transparency, establish government accountability system, and severely punish governmental corruption, thereby raising the cost of corruption for public officials.

(4) Optimize the industrial structure and accelerate the upgrading of the industrial structure. Although secondary industry has been a key growth engine for China's economy, it has caused serious environmental pollutions. China's ambitious goal of industrial structure adjustment would not only help achieve sustainable development by shifting the development model from the extensive to the intensive style, but also significantly reduce pollution emissions and resource consumption.

(5) Improve energy efficiency and promote the development of green technology. The inefficient use of energy not only wastes resources but also generates pollution and various environmental problems. Therefore, the government should make every effort to establish a market environment that is conducive to enterprise development by selecting appropriate environmental regulation. Besides, it is very important for the governments to promote environmental education and raise the public awareness of environmental protection. Although there is no empirical evidence for the significant impact of general educational level on the environment, environmental education is broadly considered as an important measure to improve environmental quality (Short, 2009).

Although this study for the first time analyzes the impact of environmental regulation on shadow economy and corruption in China, there are still some limitations, which may also be possible research directions for future follow-up studies. First, due to the data unavailability, the monetary indicators are not included in the MIMIC model, and there is still controversy on the scale of shadow economy in China. Second, given the differences in the pollution levels and regulation stringency of various industries, the impact of environmental regulation and shadow economy on the environmental quality can be further investigated at industrial level or even corporation level as long as appropriate data are available. In this way, the policymakers can utilize and refer to the discussed estimation results to formulate and conduct more targeted industrial and environmental policies. Third, the dynamic relationship among environmental regulation, shadow economy and corruption may differ over time. When data with a long time period are accessible, highly advanced techniques like panel smooth transition regression can be used to examine the possible structural change in the relationship in the long run.

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Appendix. The proofs of the three propositions of the theoretical model

The basic assumptions stated in the second paragraph of Section 3 are followed. The theoretical model in the main text of the article shows that since total profit includes profits obtained from the formal and the illegal sectors after cost deduction, the total profit A from production is:

$$A = x_F + x_I - a(e)x_F - T(x_I)y - P(x_I)\ \ El(x_I) - C(X) \quad (1)$$

To maximize its profit, the firm selects its entire output and the proportion of illegal production. For the conditions for the maximum profit, we take the derivative of x_I and x_F and subsequently obtain

$$\frac{\partial A}{\partial x_F} = 1 - a(e) - C'(X) = 0 \quad (2)$$

$$\frac{\partial A}{\partial x_I} = 1 - T'(x_I)y - P'(x_I)(1-y)x_I - P(x_I)(1-y) - C'(X) = 0 \quad (3)$$

Fig. A1 illustrates the production where the output is denoted on the horizontal axis and cost is denoted on the vertical axis. The firm's optimal production X_0 is arrived when $C'(X)$ is equal to the net benefit of the formal sector (MBF=1- $a(e)$) and the net benefit of the illegal sector (MBI=1-$T'(x_I)y$ -$P'(x_I)(1-y)x_I - P(x_I)(1-y)$.

Combining (2) and (3) yields

$$a(e) = T'(x_I)y + P'(x_I)(1-y)x_I + P(x_I)(1-y) \quad (4)$$

Considering the government policy, the derivations for implicit functions in Eqs. (2) and (4) are calculated as follows: (y in Eq. (6) is fixed, suggesting that the proportion of corrupt officers is stable.)

$$\frac{\partial X}{\partial e} = \frac{-a'(e)}{C''(X_0)} < 0 \quad (5)$$

$$\frac{\partial x_I}{\partial e} = \frac{a'(e)}{T''(x_I)y + P''(x_I)(1-y)x_I + 2P'(x_I)(1-y)} > 0 \quad (6)$$

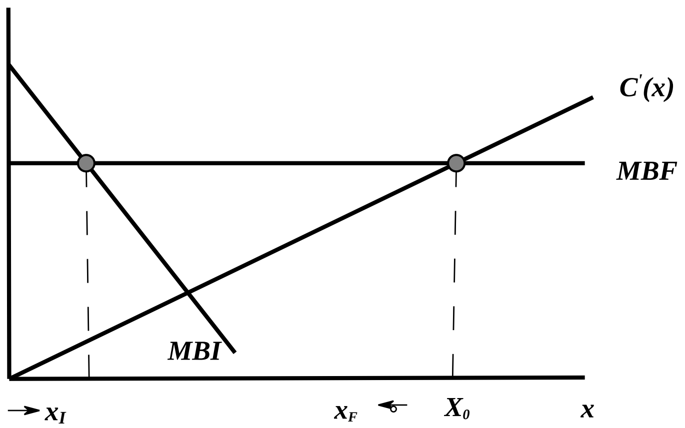

Fig. A1. Profit-maximizing production in formal and informal sectors

From $a'(e) > 0$, $C''(X_0) > 0$ and $T''(x_I)y + P''(x_I)(1-y)x_I +$

$2P'(x_I)(1-y) > 0$ in the basic assumptions, we get Eqs. (5) and (6). Eqs. (5) and (6) indicate that as environmental regulation becomes stricter, which means that a firm must reduce more of the pollutant when producing one unit of output, the total output will fall and the output of the informal sector will increase.

To gauge the effectiveness of environmental regulation for enhancing environmental quality, the partial derivation of total pollutant emissions E with respect to the level of environmental regulation e is calculated. Specifically,

$$E = x_I + (1-e)x_F = x_I + (1-e)(X - x_I) = (1-e)X + ex_I \quad (7)$$

$$\frac{\partial E}{\partial e} = \frac{\partial x_I}{\partial e} + (1-e)\frac{\partial x_F}{\partial e} - x_F \quad (8)$$

According to Eq. (8), an increase in the strength of regulatory policy will lead to a decrease in the entire output and an increase in the output of the informal sectors. Therefore, $\frac{\partial x_I}{\partial e} > 0$, $\frac{\partial x_F}{\partial e} < 0$. However, since the accurate relationship between the output of the formal sector and the velocity of change in the amount of formal and informal sectors are not clear, the sign of Eq. (8) is ambiguous.

Eq. (2) explains that the marginal legal net profit $1 - a(e)$ should be equal to the marginal production cost $C'(X)$. Eq. (4) shows that the maximum profit is achieved when the cost for reducing pollutants in legal sector $a(e)$ is equal to the sum of the marginal cost of bribery $T'(x_I)y$ and the marginal cost of penalty $P'(x_I)(1-y)x_I + P(x_I)(1-y)$ by honest officers.

Until now, the ***Proposition 1*** is proved.

To account for the influence of the proportion of corrupt officers on production, we take the derivate of y for implicit functions in Eq. (3):

$$\frac{\partial x_I}{\partial y} = \frac{-T'(x_I) + P'(x_I)x_I + P(x_I)}{yT''(x_I) + (1-y)(2P'(x_I) + P''(x_I)x_I) + \frac{\partial^2 C}{\partial {x_I}^2}} > 0 \quad (9)$$

In Eq. (9), since, in the basic assumption, $T''(x_I) > 0$, $P'(x_I) > 0$, $P''(x_I) > 0$ and $\frac{\partial^2 C}{\partial {x_I}^2} > 0$, the denominator of the right term is evidently according to the conditions above. There is a stipulation in the basic assumption that bribe money $T(x_I)$ should be less than the value of the expectation for confiscated money $P(x_I)x_I$; based on this requirement, the numerator of the right term $-T'(x_I) + P'(x_I)x_I + P(x_I)$ is greater than 0. Therefore, $\frac{\partial x_I}{\partial y} > 0$.

Studying the impact of an increase in the proportion of corrupt officers on government policy, we take the derivate of y for implicit functions in Eq. (4):

$$\frac{\partial e}{\partial y} = \frac{\left(yT''(x_I) + (1-y)\left(2P'(x_I) + P''(x_I)x_I\right)\right)\frac{\partial x_I}{\partial y} + (T'(x_I) - P'(x_I)x_I - P(x_I))}{a'(e)} \quad (10)$$

A firm will defer to the principle of not taking a loss when supplying the following bribe: $T'(x_I) - P'(x_I)x_I - P(x_I) < 0$.

By considering the relationship between the proportion of corrupt officers and the entire amount of production pollutant E, we take the derivate of y in Eq. (7):

$$E = x_I + (1-e)x_F = (1-e)X + ex_I$$

$$\frac{\partial E}{\partial \mathrm{y}} = (1-e)\frac{\partial X}{\partial \mathrm{y}} + e\frac{\partial \mathrm{x_I}}{\partial \mathrm{y}} \quad (11)$$

Subsequently, the derivate differentiation of X with respect to y in Eq. (2) is calculated to obtain the implicit function,

$$\frac{\partial X}{\partial \mathrm{y}} = -\frac{a'(e)}{C''(X)}\frac{\partial e}{\partial y} = -\frac{\partial e}{\partial y}\frac{\left(yT''(x_I)+(1-y)\left(2P'(x_I)+P''(x_I)x_I\right)\right)\frac{\partial x_I}{\partial y}+(T'(x_I)-P'(x_I)x_I-P(x_I))}{C''(X)} \quad (12)$$

$$\frac{\partial E}{\partial y} = (1-e)(-\frac{\partial e}{\partial y}\frac{\left(yT''(x_I)+(1-y)\left(2P'(x_I)+P''(x_I)x_I\right)-\frac{eC''(X)}{(1-e)\frac{\partial e}{\partial y}}\right)\frac{\partial x_I}{\partial y}+(T'(x_I)-P'(x_I)x_I-P(x_I))}{C''(X)}) \quad (13)$$

The main conclusion from Eqs. (12) and (13) is as follows: if an increase in the proportion of corrupt officers leads to a decrease in the strength of environmental regulation, then both the total output and the illegal output from the shadow economy will increase. If this holds, then the amount of pollutants will increase. However, if higher corruption (reflected by an increase in the proportion of corrupt officers) is accompanied by more stringent environmental regulation, then changing the direction of the total level of pollution will be ambiguous because the first term of the numerator in the right term of Eq. (13) will be greater or smaller than 0, and therefore the sign of $\frac{\partial E}{\partial y}$ will remain undetermined.

On the one hand, an increase in corruption would mean that the possibility of detecting the informal sector will be smaller; therefore, firms and companies will have a greater incentive to bribe officials to obtain a higher output in the informal economic sectors. On the other hand, as environmental regulation becomes stricter, firms may save costs by reducing the scale of the shadow economy rather than by paying more bribes. The net impact on the environment depends on the effect that dominates.

In Eq. (10), the denominator of the right term $a'(e)$ is greater than 0; in the numerator, the former term is greater than 0, and the latter is less than 0. If $\frac{\partial x_I}{\partial y} > 0$, then there will be an increase illegal production when there is an increase in the proportion of corrupt officers . An increase in informal production will, in turn, lead to tighter government supervision.

Therefore, ***Proposition 2*** of the theoretical model is obtained.

By considering the relationship between the shadow economy and the entire amount of the pollution, we take the derivate of x_I in Eq. (7):

$$\frac{\partial E}{\partial x_I} = 1 + (1-e)\frac{\partial x_F}{\partial x_I} \quad (14)$$

From the formal explanation of the total output X obtained during the production process, we obtained its definition:

$$X = x_I + x_F \tag{15}$$

With Eq. (10) and Eq. (11), we could obtain the following:

$$\frac{\partial E}{\partial x_I} = 1 + (1-e)\frac{\partial x_F}{\partial x_I} = (1-e)\frac{\partial X}{\partial x_I} + e = 1 > 0 \tag{16}$$

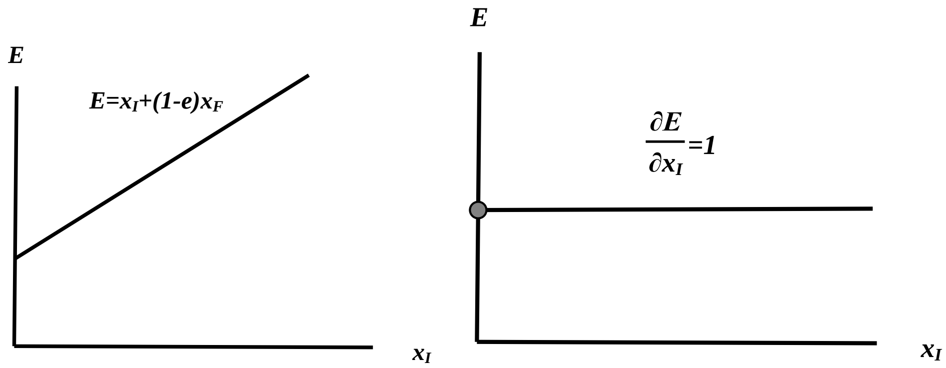

Fig. A2. Relationship between pollution E and illegal production x_I

Fig. A2 illustrates that when the legal production x_F is stable, the relationship between pollution E and illegal production x_I is directly proportional (left panel), and the proportion is always equal to 1 (right panel).

Eq. (12) indicates that an increase in the quantity of illegal output will lead to an increase in pollution without proper treatment during the same process.

Therefore, the ***Proposition 3*** is proved.

Tables and Figures

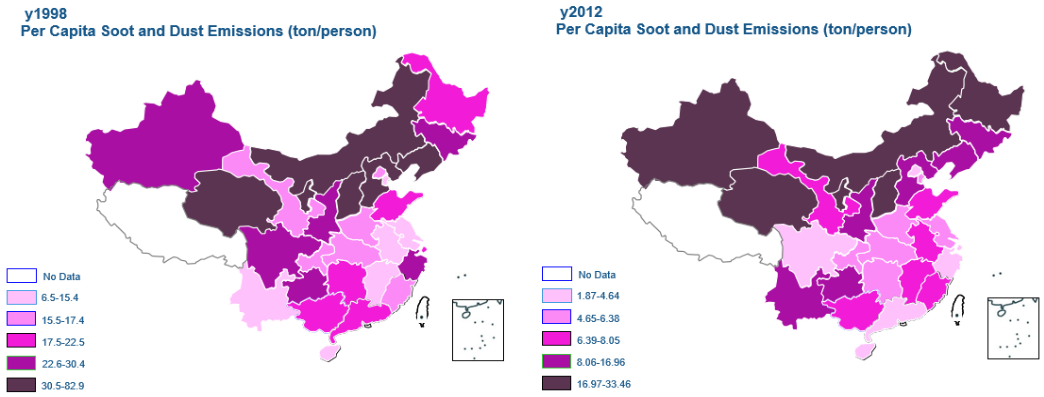

Fig. 1. Provincial per capita soot and dust emissions in 1998 (left panels) and 2012 (right panels).

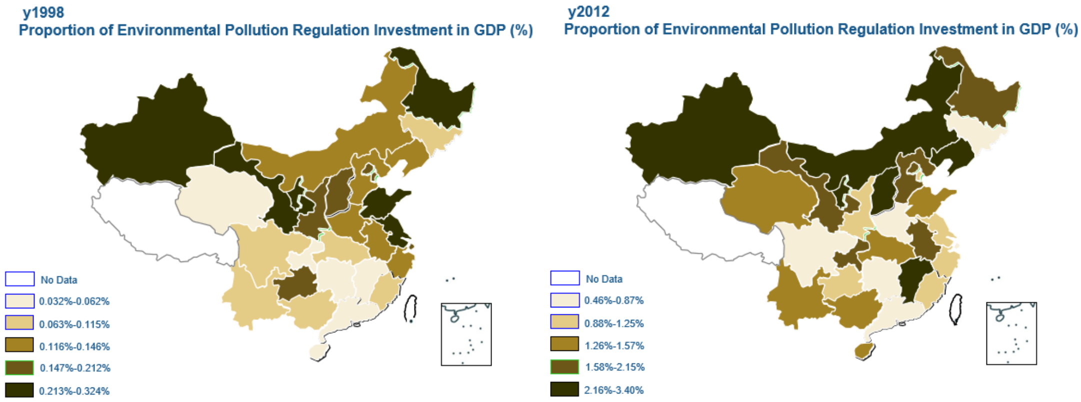

Fig. 2. Provincial proportion of environmental pollution regulation investment in GDP in 1998 (left panel) and 2012 (right panel).

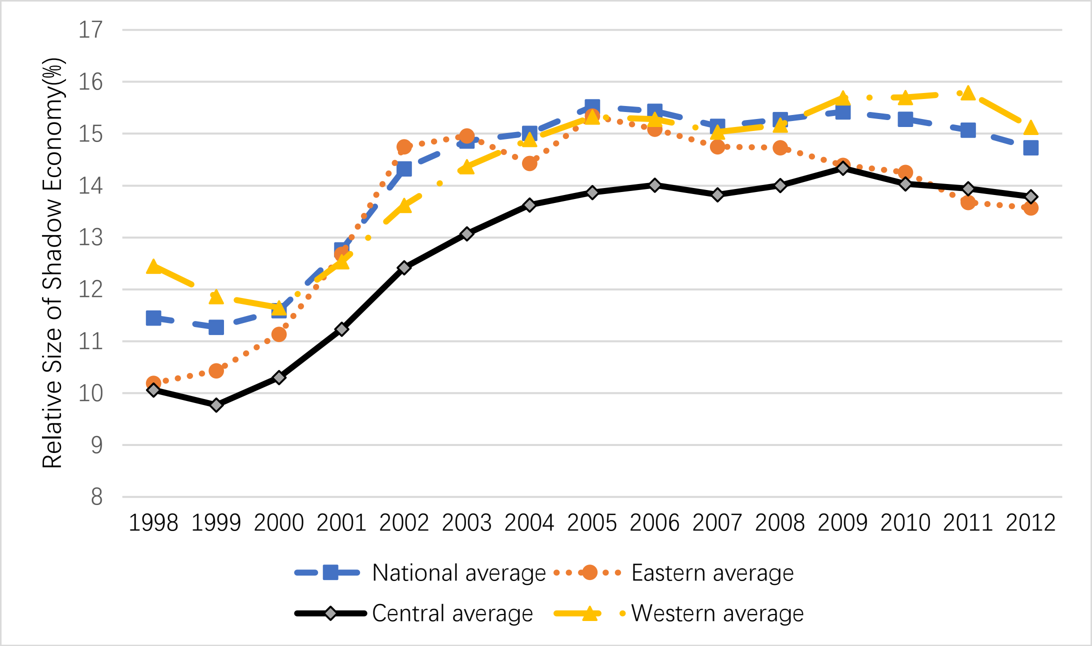

Fig. 3. The relative sizes of the shadow economy compared with GDP for the entire nation and three geographical regions, 1998-2012

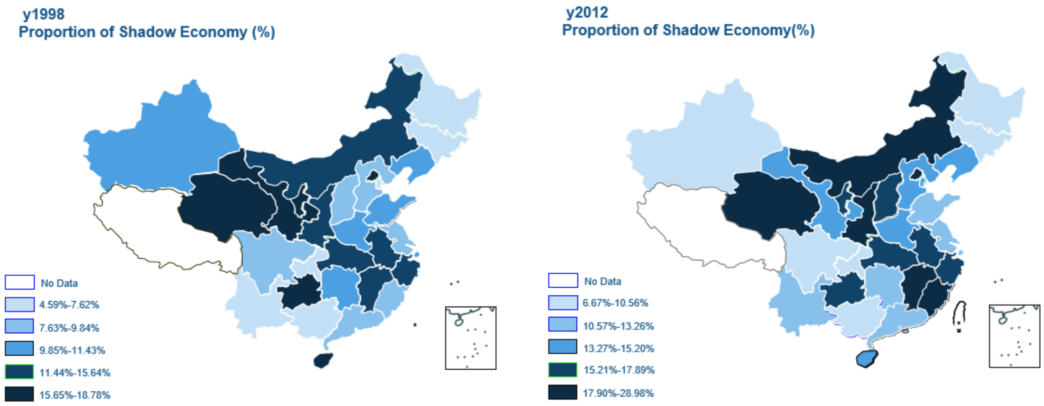

Fig. 4. Provincial proportion of the shadow economy in 1998 (left panel) and 2012 (right panel).

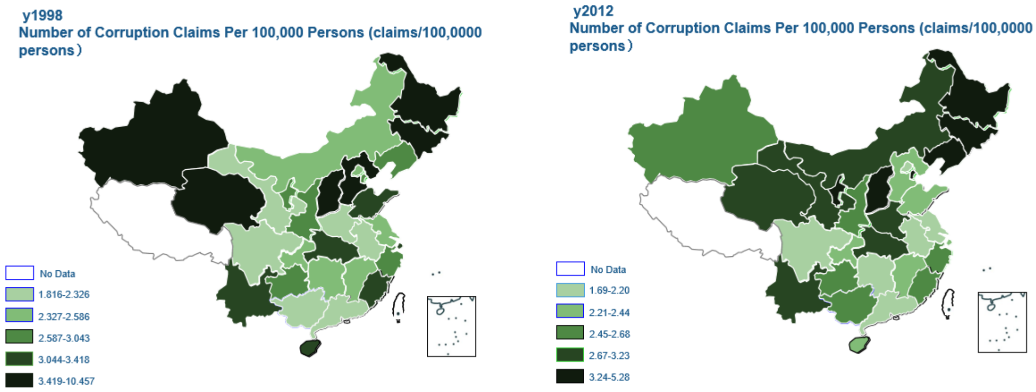

Fig. 5. Provincial number of corruption claims per 100,000 persons in 1998 (left panel) and 2012 (right panel).

Table 1. Descriptive statistics of each variable in the model.

Variable	Definition	Unit	Average	Maximum	Minimum	Std. dev.	Obs.
CO_2perc	Per capita carbon dioxide emissions in provinces	t/person	5.17	26.29	1.14	3.46	450
Sootperc	Per capita soot and dust emissions	t/person	0.02	0.08	0.002	0.01	450
Wastewaterpec	Per capita wastewater emissions	t/person	40.90	142.11	13.88	20.48	450
er	Proportion of environmental pollution regulation investment in GDP	%	1.09	4.16	0.03	0.68	450
se	Relative size of the shadow economy compared to GDP	%	14.21	30.5	4.59	4.82	450
corr	Number of corruption claims per 100,000 persons	Claims/100,0000 persons	3.01	16.03	1.43	1.12	450
y	Real per capita GDP (at 2000 constant price)	Yuan/person	15991.98	69596.92	2341.61	12432.11	450
open	Proportion of total imports and exports in GDP	%	31.52	172.15	3.20	40.13	450
second	Proportion of value added of secondary industry	%	0.45	0.59	0.20	0.08	450
edu	Proportion of population with a high school degree	%	21.36	59.60	6.14	9.11	450
rd	Per capita R&D expenditure in provinces	Yuan/person	322.27	5138.76	3.32	616.91	450
pop	The number of people per kilometer	People/km^2	408.21	3778.46	6.96	558.21	450

Table 2. Estimation results for the entire sample

Independent Variables	(1) ln CO_2per	(2) ln CO_2per	(3) ln sootper	(4) ln sootper	(5) ln wastewater	(6) ln wastewater
ep(-1)	0.905***	0.958***	0.901***	0.755***	0.913***	0.640***
	(0.060)	(0.089)	(0.032)	(0.104)	(0.028)	(0.118)
se	3.327**	1.442*	1.485*	3.789**	0.690**	2.624***
	(1.258)	(0.667)	(0.739)	(1.289)	(0.247)	(0.725)
er	0.339*	0.238**	0.382***	0.639***	0.202***	0.364***
	(0.135)	(0.089)	(0.073)	(0.175)	(0.046)	(0.054)
er×se	-0.010*	-0.010*	-0.008	-0.023**	-0.003*	-0.011***
	(0.005)	(0.004)	(0.004)	(0.008)	(0.001)	(0.003)
corr	0.270	0.171	0.578***	0.802***	0.148*	0.290**
	(0.242)	(0.176)	(0.081)	(0.210)	(0.072)	(0.109)
corr×er	-0.152	-0.074	-0.238***	-0.259*	-0.134**	-0.196***
	(0.137)	(0.099)	(0.047)	(0.107)	(0.050)	(0.051)
y	2.996**	1.280	1.823**	2.184**	-0.015	-0.165
	(1.080)	(0.681)	(0.602)	(0.843)	(0.195)	(0.576)
y^2	-0.151**	-0.07*	-0.094**	-0.092*	0.002	0.0123
	(0.053)	(0.031)	(0.031)	(0.038)	(0.010)	(0.026)
open		0.037		0.159		0.104**
		(0.044)		(0.129)		(0.039)
pop		-0.031		-0.043		-0.019
		(0.044)		(0.059)		(0.023)
rd		0.013		-0.320**		0.010
		(0.037)		(0.120)		(0.074)
edu		-0.002		0.014*		0.003*
		(0.003)		(0.007)		(0.002)
second		-0.001		0.007*		0.004
		(0.001)		(0.003)		(0.003)
_cons	-15.36**	-6.349	-10.11***	-13.76**	0.023	0.870
	(5.705)	(3.438)	(2.984)	(4.645)	(0.953)	(2.985)
obs	420	420	420	420	420	420
Hansen Test	1	1	0.869	0.971	0.952	1
AR(1)	0.001	0.003	0	0	0.001	0.001
AR(2)	0.407	0.706	0.406	0.646	0.258	0.460

Notes: The meanings and definitions of the variables are given in Table 1. The numbers in the parentheses beneath the estimated coefficients are standard errors. For the Hansen test and Arellano-Bond tests, the statistics are reported. *, **, and *** denote statistically significance at the 10%, 5%, and 1% levels , respectively.

Table 3. Estimation results for different regions of China

Independent Variables	(1) ln co2per East	(2) ln co2per West	(3) ln sootper East	(4) ln sootper West	(5) ln wastewater East	(6) ln wastewater West
ep(-1)	0.955***	0.943***	0.964***	0.907***	0.614***	0.947***
	(0.029)	(0.034)	(0.028)	(0.039)	(0.186)	(0.036)
se	1.536***	0.975**	0.625**	2.072***	2.989*	0.327**
	(0.485)	(0.478)	(0.878)	(0.759)	(4.045)	(0.604)
er	1.462**	-0.028*	0.171***	0.344**	0.806**	0.283**
	(0.274)	(0.091)	(0.116)	(0.131)	(0.447)	(0.096)
er×se	-0.006**	-0.006**	-0.007**	-0.013*	-0.039*	-0.001**
	(0.003)	(0.003)	(0.006)	(0.006)	(0.021)	(0.004)
corr	0.0363*	0.162***	0.007**	0.240**	0.417*	0.300**
	(0.072)	(0.109)	(0.129)	(0.144)	(0.317)	(0.108)
corr×er	-0.244**	-0.311**	-0.017*	-0.102**	-0.213*	-0.224**
	(0.117)	(0.121)	(0.080)	(0.107)	(0.202)	(0.070)
y	2.500*	1.019	0.893	0.645	0.118	0.547*
	(0.528)	(0.523)	(0.913)	(0.800)	(0.206)	(0.539)
y^2	-0.124*	-0.052	-0.045	-0.037	-0.005	-0.028*
	(0.026)	(0.028)	(0.045)	(0.043)	(0.014)	(0.029)
_cons	-12.57	-4.797	-4.870	-3.814	-4.644	-2.816
	(2.688)	(2.464)	(4.638)	(3.739)	(3.125)	(2.492)
obs	154	266	154	266	154	266
Hansen Test	0.559	0.520	0.559	0.331	1	0.957
AR(1)	0	0	0.001	0	0	0
AR(2)	0.226	0.520	0.891	0.557	0.667	0.405

Notes: ln(x) represents taking the logarithm of the corresponding variable x. T is the time trend. The meanings of the variables are given in Table 1. The numbers in the parentheses beneath the estimated coefficients are standard errors. *, **, and *** denote being statistically significant at the levels of 10%, 5% and 1%, respectively.