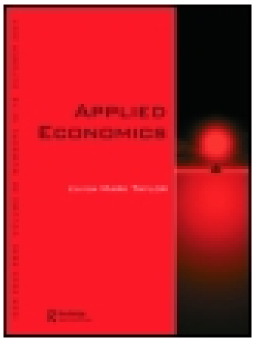

Applied Economics

ISSN: 0003-6846 (Print) 1466-4283 (Online) Journal homepage: http://www.tandfonline.com/loi/raec20

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To cite this article: Spyridon Stavropoulos, Ronald Wall & Yuanze Xu (2017): Environmental regulations and industrial competitiveness: evidence from China, Applied Economics, DOI: 10.1080/00036846.2017.1363858

To link to this article: http://dx.doi.org/10.1080/00036846.2017.1363858

Published online: 11 Aug 2017.

APPLIED ECONOMICS, 2017
https://doi.org/10.1080/00036846.2017.1363858

Environmental regulations and industrial competitiveness: evidence from China

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ABSTRACT

Economic activities are closely related to real-world environmental issues. Currently, more attention is paid to the association between environmental regulations and industrial competitiveness (IC) because of pressures on economic development and environmental protection. In this study, we identify and explain the association between environmental regulations and IC in China. As the largest developing country in the world, China has the unavoidable responsibility of protecting the environment and promoting global economic development. We analyse the mechanisms behind environmental regulations and industrial competiveness at the provincial level and conclude that the impact of environmental regulations upon IC is not a simple linear one, but a U-shaped relationship. It is argued that the crucial intervention to activate the U-shaped relationship, or Porter's Hypothesis, is innovation, which can be triggered by stringent regulations and well-designed policies.

KEYWORDS
Environmental regulations; industrial competitiveness; Porter's Hypothesis

JEL CLASSIFICATION
Q50; R11

I. Introduction

Economic activities are closely linked to real-world environmental issues. Economic activities can improve or damage environmental quality, which in turn may facilitate or impede economic operations. Currently, environmental protection and sustainable development have permeated every aspect of human social and economic activities.

Environmental problems are usually caused by the negative externalities of economic activities, which means that economic actors add external costs to society through pollution without paying the corresponding social costs. In the absence of regulation, individuals tend to overexploit the environment at their own advantage. Therefore, environmental problems cannot be solved by simple market mechanisms: most countries implement environmental regulations. Thus, strengthening environmental protection and reinforcing environmental regulations have become key issues, especially in developed countries (Vogel 2009).

Developing countries, whose economic development and technological levels are relatively low, are facing a dilemma. On the one hand, due to the significant role of industrialization in promoting economic growth, these countries urgently need to develop new industry. However, because they are limited by their technological level, capital strength and human capital, 'pollution-intensive' industries are their first choice, with the consequence of huge costs to the environment. When facing the choice between economic development and environmental protection, the former gets preference due to the 'common view' that firms have already made an optimum choice in real economic activity, where the implementation of environmental regulations will increase the cost of production, thus impeding competitiveness and economic development (Denison 1979; Gollop and Roberts 1983). Furthermore, developing countries assume that their 'pollution-intensive' industries will be negatively affected by an increase of stringent environmental regulations. Besides this, environmental regulations in developed countries always tend to be more stringent than those in developing countries, which leads

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public opinion to be sensitive to the potentially negative effects of environmental policy on international trade and industrial competitiveness (IC). In this light, academics and policymakers pay significant attention to questions pertaining the adoption of stringent environmental regulations and whether this will hinder industrial and national competitiveness (Wallace 1995).

China has achieved remarkable economic progress during the past 30 years. Many factors have contributed to this success, particularly industrialization. Even so, China is still experiencing a late-middle period of industrialization (Cai 2009; Li 2009; Zhang 2012), in which China's development has been extensive, and where the nation has consumed a huge amount of resources with low efficiency and high pollution. The government's unilateral pursuit of rapid economic growth has subsequently led to deterioration of the environment. According to the OECD report, *Environmental Performance Review (2007)*, air pollution in Chinese cities is among the worst in the world, and almost one-third of China's rivers are severely polluted. The *Chinese Green National Economy Accounting Study Report*, issued by SEPA and NBS, shows that the economic losses caused by environmental pollution are 511.8 billion yuan (approximately 62.5 billion dollars), which accounted for 3.05% of the country's GDP that year. Thus, China's environmental situation is quite severe. Nonetheless, the Chinese government has taken recognition of this dilemma and has begun to take stringent actions. However, concerns about the negative effect of environmental regulations on economic competitiveness and development have not disappeared, and such concerns remain influential to the formulation and implementation of environmental regulations, especially by local governments, which often fail to achieve their goals to protect the environment (Li 2012).

The purpose of this study is to identify and explain the relationship between environmental regulations and IC. First, we adopt indices to measure both the degree of environmental regulation stringency and IC. We then explore and identify the effects of environmental regulations on IC in China. The research is conducted at the provincial level such that industries in the secondary sector are treated as an aggregate, while taking into account their spatial effects.

II. Literature review

Environmental regulations

In general, environmental problems derive from market failure (Pigou 1920; Coase 1960). Because of negative externalities, natural resources are overused and environmental problems increase. There is a severe discontinuity between the optimal outputs determined by the maximization of individual profit and the maximization of social welfare, and the costs of environmental pollution are mostly not accounted for by polluters, which obliges other stakeholders to share these costs. In other words, the costs to polluters are much lower than those impinged on society. Therefore, it is imperative that governments take actions to correct market failure, constrain environmental externalities and pursue environmental equity by means of environmental regulations (Stewart 1991).

Despite this urgent need, no clear, structured, effective definition of environmental regulations exists. However, some initial conceptualizations can be found:

> Regulations are general rules or specific actions imposed by administrative agencies that interfere directly with the market allocation mechanism or indirectly by altering consumer and firm demand and supply decisions. (Spulber 1989, p37)

In this context, our study aims to define environmental regulations by reference to regulatory economics: environmental regulations are the general rules and specific actions enforced by administrative agencies so as to control pollution and manage natural resources with the purpose of protecting the environment and internalizing externalities, including direct and indirect interventions.

In the 1990s, the conceptual boundaries of environmental regulations were extended. In addition to the environmental regulations imposed by administrative agencies, voluntary regulations made by firms and industrial associations were also included into environmental regulations (Zhao, Zhu, and He 2009).

At present, environmental regulations maintain three policy instruments, or a hybrid of these: (1) instruments to conduct, (2) price instruments and (3) quantity instruments (Wiener 1999). This research groups these into two categories, i.e.

command-and-control instruments and market-based instruments. Command-and-control instruments are conduct-oriented regulations. In this, administrative agencies can mandate practices and technologies to protect the environment (Wiener 1999). Usually, this concerns a series of standards designed by regulators to be followed by polluters, or to direct a certain industry to adopt particular technologies in accordance to defined rules and regulations. Administrative agencies can impose sanctions on violators and reward compliers. For example, in the case of pollutant discharge in China's coking chemical industry,[1] new ways of discharging have been clearly set by administrative agencies, which require that firms adopt certain technologies so as to control the emission of SO_2.[2] Moreover, these agencies have even set output ceilings so as to control the negative externalities generated by producers, like in the Chinese paper-making industry, whose output ceiling was 116 million tons in 2015.[3]

Command-and-control instruments can also be simple and direct. Standards and rules set by administrative agencies usually reflect the willingness of society to control and reduce pollution. It is the most widely adopted approach today (Wiener 1999). However, due to the different levels of economic development and technology, the stringency of these environmental regulations differs. Generally, developed countries adopt stringent regulations, while developing countries often implement lax regulations (Copeland and Taylor 1994).

However, in light of the existence of previous government failure, the formulation and implementation of these environmental standards may not achieve the optimal result in reality, by for instance increasing the government's financial burden or the costs to society in general (Zhao, Zhu, and He 2009; Wang 2012; Li 2013).

On the other hand, market-based instruments use market signals to control pollution and internalize externalities, mainly including price and quantitative instruments. In terms of price instruments, Emission Tax/Pigouvian tax is representative measure. For quantity instruments, emission permit trading is a widely used measure. In addition, this also includes subsidy systems, deposit refund systems and voluntary environmental agreements (Stavins 2000; Segerson and Miceli 1998). Price instruments always direct polluters to pay for the social costs of their activities and hereby internalize environmental costs. These instruments can be imposed *ex post* or ex ante. *Ex post* instruments are based on the strict liability of sources of pollution that have damaged the environment. With respect to ex ante instruments, administrative agencies impose tax on polluters for the estimated external costs of their emissions beforehand (Wiener 1999). Quantity instruments first set upper limits on the amount of resource usage and pollution discharge. Administrative agencies then partition this quantity to different parties by granting licences or permits. These licences and permits can be traded in the market, through negotiation between different participants. Compared to price instruments, quantity instruments use trading between polluters to internalize externalities and implement regulations, which eases the financial burden upon the government and reduces the total social cost. However, its defects are also obvious. With the total amount of pollutants unchanged, these tend to concentrate in particular areas. Moreover, the premise of emission permit trading is sometimes hard to achieve completely, especially in terms of zero-transaction cost. Even so, it is still an innovation in governmental policy and indeed has positive effects on environmental protection (Wiener 1999; Zheng 2005).

III. Industrial competitiveness

Competition is fundamental to the market economy and especially the efficient allocation of resources. In this context, academics and organizations strongly debate national competitiveness – where in fact, IC, national competitiveness and enterprise competitiveness are strongly linked. Similarly, the improvement of IC is based on the improvement of enterprise competitiveness within the industry, which consequently improves national competitiveness (Porter 1990).

[1]Referring to the Chinese national standard, *Emission standard of pollutants for coking chemical industry (GB16171-2012)* issued by MEP and GAQSIQ of China.
[2]In 2002, MEP and MT of China promulgated a policy, *named Pollution Control Technology Policy of Sulphur Dioxide Emissions in Coal Industry*, which mandated certain technologies to control Sulphur Dioxide Emissions.
[3]Referring to *China's twelfth five-year plan for paper-making industry* issued by NDRC in 2011. It is a supporting plan of *the Twelfth Five-year Plan of National Economy and Social Development*.

As for the definition of IC, no consensus exists. In 1985, World Economic Forum (WEF) first put forward the concept of international competitiveness: the ability that firms in one country provide products and services that are of a better quality and have lower costs than those of foreign competitors. In 1991, IMD and WEF jointly defined international competitiveness as follows: the ability that firms in one country design, produce and sell products and services at a global scale, with more attractive price and non-price characteristics than those of its competitors (IMD. 1991). In 1994, WEF and IMD redefined international competitiveness as the ability of a nation or firm to produce more sustainable wealth than global competitors (IMD. 1994).

Michael Porter (1990), one of the first academics to engage with IC, argued that simply defining competitiveness at the national level is not appropriate. Instead, he stressed that the focus should be on specific industries and industrial segments – through which national competitiveness can be explained. He defined IC as follows: the superior productivity, either in terms of lower costs than competitors, or the ability to offer superior products, justified by a premium price (Porter and Van De Linde 1995). The famous Chinese economist Jin (1996) used a similar definition i.e. that IC is the productivity reflected by sales performance within international markets.

In this study, IC is similarly defined as (1) superior productivity to occupy markets and gain profits, and (2) the capacity reflected in international markets to achieve a product's value, meet the consumers' demands and realize sustainable development.

IV. The association between environmental regulations and IC

Currently, there are three key theoretical perspectives regarding the effect of environmental regulations upon IC. First, regulations are regarded as being helpful to competitiveness, while second, they are perceived to have a negative effect, due to increased costs. Third, it is said to insignificantly impact IC.

V. Traditional hypotheses

Traditional hypotheses maintain that the implementation of environmental regulations will negatively affect IC because of increasing costs, decreasing profits and losses in productivity. Two common suppositions are the 'race-to-the-bottom hypothesis' and the 'pollution haven hypothesis'.

The race-to-the-bottom hypothesis emerged in the United States between the late nineteenth and early twentieth centuries. It stresses that environmental regulations will increase costs in certain industries and that each country anticipates that other countries will adopt less stringent environmental standards so as to avoid cost increases that result from relatively high environmental standards. Hence, all countries will ultimately race to lower their standards so as to make themselves more attractive to outside financial investment (Schram 2000), which in turn leads to globally relaxed regulations and ultimately to the deterioration of the global environment. This hypothesis illustrates a contradiction between individual and collective rationality. Although the hypothesis is derived from the case of the United States, it tends to contradict reality today, because global environmental regulations have proven to be more stringent than expected, where even the recent financial crisis has not altered this trend.

The pollution haven hypothesis may be one of the most controversial premises in international economics. It can be explained by the H–O theory, in which environmental factors are regarded as inputs of production – in which countries that have abundant environmental factors hold a comparative advantage. In this light, the cost of environmental factors is determined by the stringency of environmental regulations (SER). Therefore, countries with less stringent regulations are said to have comparative environmental advantages. Next, as a consequence of trade, pollution-intensive industries relocate to these countries, which are almost always in the developing world. Thus, pollution havens are unintentionally formed due to the agglomeration of these pollution-intensive firms and industries (Siebert 1977; McGuire 1982). Furthermore, many policymakers and academics argue that stringent environmental regulations will hollow out industry, leading to a decline in exports and an increase in imports. A reduction in the competitiveness of these industries is therefore inevitable (Jaffe et al. 1995).

Scholars have conducted several empirical studies to test this hypothesis. Gray and Shadbegian (1995) use data on the paper, oil and steel industries (1979–

1990) to test this and found that abatement costs have a significant, negative relationship with total factor productivity. Specifically, $1 spent in abatement will cost the equivalent of $1.74 in productivity loss in the paper industry, $1.35 in the oil industry and $3.28 in the steel industry. However, other environmental regulation measures, e.g. control of emissions and enforcement and compliance, do not show an obvious association with total factor productivity. Picazo-Tadeo, Reig-Martinez and Hernandez-Sancho (2005) used the directional distance function to test the influence of environmental regulations on the Spanish ceramic pavement industry. Their results show that firms with the potential to improve their desired output will be significantly affected by environmental regulations that prevent waste disposal. They found that if the disposal of industrial water is free, then the amount of products will increase by 7%. Conversely, when the disposal of waste water is charged, the potential increase in goods will decrease to 2.2%. This illustrates that environmental regulations are causal to decreased growth.

VI. Revisionist hypotheses

Unlike the previous hypotheses, revisionist hypotheses argue that environmental regulations generate win–win situations, where the environment improves and IC is enhanced at the same time. The Porter Hypothesis, coupled with the Pollution Halo Hypothesis and the race-to-the-top Hypothesis, represents such a view.

The Porter Hypothesis was developed in the article, *Toward a New Conception of the Environment-competitiveness Association*, by Porter & Van der Linder (1995), and suggested that innovation can be triggered by properly designed environmental standards through which the competitiveness of a particular industry is enhanced over time. Benefits can be derived from (1) innovation offset; and (2) the early mover advantage. Innovation is said to offset the costs of obeying regulations, and where more stringent regulations can also generate greater innovation. In addition, firms can gain early mover competitive advantages within the international market, once domestic environmental standards are consistent with international ones (Porter and Van De Linde 1995). Thus, the Porter Hypothesis provides a win–win situation between environmental regulations and IC, instead of a trade-off.

Zarsky (1999) proposed the Pollution Halo Hypothesis, which asserts that FDI can aid the diffusion of cleaner technologies, better environmental management systems and best practices throughout the world, because MNCs maintain the same environmental standards and procedures across countries. Thus, FDI can promote the transfer of superior technologies from developed to developing economies. Although this hypothesis concerns the impact of FDI on the environment, FDI is closely related to competitiveness (Dunning 1992). The hypothesis indicates that with an increase in competitiveness, the SER will also increase such that they have a positive association.

The race-to-the-top hypothesis is based on the famous 'California effect' proposed by Vogel (1997). It maintains that stringent environmental regulations can push regulatory standards upwards. From the 1970s to the 1990s, California enacted stricter automobile emission standards than other states. Instead of states with lax regulations undermining the California's automobile industry, this helped to push the whole country's auto emission standard upwards. The effect even spilled over to Europe, as manufacturers had to comply to stricter regulations so as to ensure market access and avoid the huge expenditures of complying to different standards. Furthermore, Vogel concluded that market competition caused by trade liberalization facilitates the spillover of environmental standards from greener to less green nations (Vogel, 1997). Because the degree of liberalization and trade openness is a vital factor in improving competitiveness and can be reflected by FDI, one can also conclude that environmental regulations have a positive association with competitiveness.

Some studies adopt an econometric model to overcome the limitations of Porter's Hypothesis, which lacks quantitative analysis. Hamamoto (2006) applied an econometric model to Japanese manufacturing industries and found evidence to support Porter's Hypothesis. The author used pollution control expenditures to measure environmental regulations and showed that environmental regulations have a positive effect on R&D activity. Further, R&D investment has a significant, positive influence on total factor productivity and stimulates a high rate of return. Boyd, Tolley and Pang (2002) used the Malmquist–Leunberger Index, which provides a link between the rate of diffusion of technology and productivity growth and the directional distance function, to test the association between environmental regulations (measured by emissions of NO_x). This is tested on the productivity of the glass container industry with data ranging from 1987 to 1990. The results show that the potential output of a win–win situation exceeds the output loss caused by environmental regulations in all years except 1988, as well as the change in technology contributed to productivity growth and environmental protection. These conclusions support Porter's Hypothesis.

Bommer (1999) supports the revisionist hypothesis from an alternative perspective. The author builds a political-support maximum model based on the assumption that the information between the regulator and the regulated is asymmetric. The results show that an entrepreneur may rearrange capital and relocate production for purely strategic reasons instead of reduced competitiveness. Relocation is a way of indirect rent seeking to convince a regulator of the enterprises' inability to accept further tightening of environmental regulations (Bommer 1999). Thus, Bommer's research denies the traditional hypothesis. Dong, Gong and Zhao (2012) study the association between FDI and environmental standards and applies a north–south market model based on the assumption that pollution is trans-boundary. The authors find that if the market sizes of two countries are small, FDI can trigger a 'race-to-the-top' in emission standards, but if the market sizes are sufficiently large, FDI will not change the environmental standards. The authors deny the traditional hypothesis to some extent, although they do not demonstrate a 'race-to-the-top' under the circumstances of a large-size market.

VII. Comprehensive 'theory'

Debates between promoters of the traditional and revisionist hypotheses are vigorous, which impels some researchers to reexamine the association between the two. Some think that environmental regulations alone cannot influence IC but have a combined effect with other factors. Others do not regard environmental regulations as having a decisive impact on competitiveness. Although there has been no well-formulated theory to this point, many academics have built economic models or conducted empirical research to support their views.

For example, Sinclair-Desgagné (1999) summarized innovation into three types: (1) incremental, (2) risk reducing and (3) radical. The author argues that the Porter Hypothesis is partially acceptable. Generating a win–win situation depends on the type of innovation firms pursue – incremental, risk reducing or radical – and on the measures taken by regulators to facilitate the innovation. Another study by Sartzetakis and Constantatos (1995) notes that the effect of environmental regulations is related to the instruments the government chooses. For example, in a Cournot–Nash equilibrium, regulations implemented through emission permit trading can contribute to the efficient allocation of an abatement effect and an increase in the total market share of firms, which command and control instruments may fail to achieve (Sartzetakis and Constantatos 1995).

The research conducted by Xepapadeas and De Zeeuw (1999) is also important. The authors develop a mathematical model in which firms invest in machines at different ages, whereby the newer machines have high productivity and are cleaner but are also more expensive compared to the older machines. They find that more stringent environmental regulations have two effects: (1) a productivity effect and (2) a profit-emission effect. The former refers to a situation in which the downsizing of capital stock and the modernization of machines arising from strict regulations leads to an average increase in productivity. However, the profit-emission effect implies that profits and emissions will decline at the same time. Although the decreasing speed of profits will be lowered by the modernization of machines, a profit decline is inevitable. The authors do not evaluate the effect of environmental regulations on IC directly but focus on productivity and profit, which are two important aspects of competitiveness. However, their performance related to environmental regulations differs.

Jaffe et al. (1995) conclude that sometimes the effect of environmental regulations on IC may be so small that it is hard to detect. They find that with existing data, there is a limited ability to measure the degree of stringency that compliance costs are a small proportion of the total costs of production, that there are gaps between the environmental requirements in some nations and that firms are unwilling to relocate to technologically inferior nations or to developing countries with greater-than-expected pollution controls. Based on a review of empirical studies, the authors conclude further that little consistent empirical evidence can be found to support either the traditional hypothesis or the revisionist hypothesis. Therefore, Jaffe et al. (1995) consider that the truth lies somewhere between the two extreme situations.

VIII. Materials and methods

The purpose of this study is to explore the impact of environmental regulations on IC. Specifically, this study aims to investigate the influence of different stringent environmental regulations on IC and their underlying mechanisms, in the context of China. Therefore, IC forms our dependent variable, while the SER serves as the independent variable. The research is conducted at the provincial level. Due to data unavailability, different industries in the secondary sector were aggregated. Panel data for secondary sectors in each province were collected.

Superior productivity was used to define IC, based on the definition proposed by Porter (1990), meaning that high productivity leads to high competitiveness. In microeconomics, the traditional production function is determined by labour, capital, land and entrepreneurship. Later, Cobb and Douglas improved the production function by adding the technology factor (Cobb and Douglas 1928). Therefore, this research also measured superior productivity using the above aspects. Considering the unavailability of data and drawing on previous experience in related research, we did not include land data, and we used the innovation factor to represent entrepreneurship and technology factors. Thus, the productivity function is as follows:

$$Productivity = f(Labour, Capital, Innovation) \tag{1}$$

Additionally, according to the competitiveness theory proposed by WEF and IMD,[4] these factors of production, namely labour, capital and innovation, only reflect competitive assets. The ability to integrate these factors is also important, which to some extent indicates the competitive process and entrepreneurship.

Thus, the evaluation of IC was conducted based on four aspects: labour, capital, innovation and integrative ability. Hence, the formula for the IC function is as follows:

$$\begin{aligned} &Industrial\ Competitiveness \\ &\quad = g(Labour, Capital, Innovation, Ability) \end{aligned} \tag{2}$$

This formula measures IC from the perspective of production. It refers to the built-in mechanism that can improve productivity and further improve competitiveness (Schumpeter 1934; Corden 1994; Preibisch 2007; Wang 2012).

In terms of defining our independent variable SER, existing instruments include command-and-control, price and quantity instruments. The Chinese government mixes instruments and the proportion of different instruments changes over time (Jiang 2010). Hence, measuring SER based on the instruments themselves is difficult.

Following Claire and Levinson (2016), we provide the following four challenges, quoting:

(1) *multidimensionality* – environmental regulations cannot easily be captured by a single measure of 'stringency';
(2) *simultaneity* – regulations are meant to affect emission levels, but emissions levels can also be a factor in determining the stringency of a regulation, because, for example, jurisdictions with the most serious pollution problems may impose the strongest regulations;
(3) *industrial composition* – in places where the mix of industries is more pollution intensive, the average business automatically faces more stringent regulations and
(4) *capital vintage* – regulatory standards are typically stricter for new sources of pollution, which may result in firms keeping older plants in operation longer, thus affecting the environment, the economy and measures of regulatory stringency.

[4]Quote from a secondary source: Wang, Y., 2000. The International Competitiveness of the Chinese Economy. Jiangxi People's Publishing House, Nanchang, pp 43.

Therefore, this research uses environmental regulatory instruments to define and measure stringency. Many academics have adopted a similar method (De Vries and Withagen 2005; David Popp 2006; Greenstone, List, and Syverson 2012). For example, Olsthoorn et al. (2001) use SO_2, NO_X and COD emissions to operationalize environmental performance. The diversity of industries in our study represents different types of pollution, e.g. waste water, SO_2 (representing waste gas) and solid waste were used to measure the achievement and effectiveness of environmental regulations. Notably, SO_2 data have been used to represent waste gas because SO_2 is the typical coal-smoke pollution that is consistent with the current Chinese energy structure.

Operationalization of other control variables: The association between the environment and competitiveness has been researched for quite some time, but no conclusive results have been obtained. One reason is that prior research has not accounted for important moderating factors or control variables (Wagner, 2001). To study the association between SER and IC, other exogenous variables that may influence the association must therefore be controlled for. Wagner (2002) proposes that the scale of firms, the different characteristics of countries, the different operating processes used and varying industrial market structures can all have a significant influence on the model. In addition to such factors, Li (2013) argued that pollution intensity is also important and may influence the association.

Considering the scope and aim of this research and the availability of data, the scale of industry, pollution intensity and number of firms within industries were added to the model, with certain location characteristic factors. Specifically, the scale of an industry could determine the ability of the industry to comply with environmental regulations and control pollution. The pollution intensity of an industry may reveal the difference in the processes and techniques of production and the difficulties faced in controlling pollution. The number of firms within the industry reflects the industry's market structure to some extent such that an industry with more firms tends to have a lower degree of monopoly and vice versa.

Location variables can depict the basic characteristics of each province, which can influence the association between SER and IC (Wagner, 2001). These variables include population, which indicates the size of the local labour market, GDP per capita, which reflects the level of economic development, infrastructure level, education level and FDI, which reflects the openness of the economy. These variables are adopted in many empirical studies on regional competitiveness, including the Global Competitiveness Report issued by the WEF and the Hungary competitiveness report by Lengyel (2004).

Data sources included statistical yearbooks related to environment, science, technology and the industrial economy, the yearbook of China concerning each province, and the China Economy Information Net Statistics Database, which were issued by national and provincial governments. The data range from 2001 to 2010 for 30 provinces; data were unavailable for Tibet, Taiwan, Hong Kong and Macao.

Before proceeding with the analysis and modelling, data and variables were processed. Due to the nature of the data, variables related to price and output i.e. *SI*, *GDP_PC* and *FDI* were divided by inflation rate, and the price data were weighted by the price level of the base year, 2000. Additionally, because FDI were originally reported in US dollars, it was converted into Chinese Yuan according to the average exchange rate in that year, so as to maintain data consistency. *SER*, *PI*, *IC* and *INF* were composite variables that needed to be calculated. To simplify the calculation, all sub-variables were given the same weight. Within each sub-variable, the indicators also had the same weight. Before summing up the different indicators of *SER*, *IC* and *PI*, the indicators were standardized from 0 to 1 to eliminate the effect of index dimension. The min–max method was applied as the following formula 3 shows:

$$I_{kt} = \frac{V_{kt} - \min(V_k)}{\max(V_k) - \min(V_k)} \qquad (3)$$

where I_{kt} is the normalized value of indicator k in time t. V_{kt} is the original value of indicator k in time t. $\min(V_k)$ and $\max(V_k)$ are the respective minimum and maximum values of indicator k during the studied period.

After that, all the indicators were aggregated into *SER*, *PI*, *IC* and *INF* indexes, respectively. Descriptive statistics of all variables included in the model and their correlations can been found in Tables 1 and 2, respectively.

Table 1. Descriptive statistics.

	Mean	SD(overall)	SD (between)	SD (within)	Min	Max
IC	0.320	0.094	0.068	0.066	0.064	0.596
SER	0.662	0.181	0.139	0.119	0.127	0.953
PI	0.197	0.156	0.132	0.087	0.002	0.735
SI	9427.588	13,389.470	11,133.650	7684.463	194.160	82,918.450
MS	10,158.040	12,958.940	11,827.260	5679.849	388.000	65,495.000
GDP_PC	1.666	1.348	1.182	0.680	0.298	7.248
POP	4313.570	2611.130	2647.251	144.936	523.100	10,440.960
FDI	226.339	304.922	287.505	113.167	1.256	1568.854
INF	0.206	0.167	0.161	0.053	0.003	0.892
EDU	7.185	4.979	4.696	1.845	1.828	31.499

Table 2. Correlation table.

	SER	*SER*^{2}	*PI*	d(*SI*)	*MS*	d(*GDP_PC*)	d(*POP*)	d(*FDI*)	*INF*	*EDU*
SER	1.00									
SER^2	–	1.00								
PI	−0.58	−0.58	1.00							
d(*SI*)	0.40	0.41	−0.52	1.00						
MS	0.41	0.42	−0.50	0.88	1.00					
d(*GDP_PC*)	0.47	0.49	−0.62	0.47	0.43	1.00				
d(*POP*)	0.14	0.15	−0.28	0.46	0.44	0.28	1.00			
d(*FDI*)	0.19	0.18	−0.21	0.26	0.19	0.21	0.07	1.00		
INF	0.51	0.52	−0.51	0.29	0.27	0.69	0.26	0.14	1.00	
EDU	0.26	0.29	−0.45	0.09	0.07	0.68	0.23	0.10	0.79	1.00

In the environmental discipline, a famous curve exists namely the Environmental Kuznets Curve, which describes the U-relationship between economic development level and environmental quality. It demonstrates that environmental degradation worsens as economy develops until the average income reaches a certain threshold (Shafik 1994). To some extent, this theory can also be used in the analysis on environmental regulation and IC. IC would expectedly worsen as environmental regulations are strengthened, until the SER reaches a turning point. In case of the non-linear association between IC and SER like the Environmental Kuznets Curve, the square term of SER was included in the model, and the cubic term of SER was also tried out during modelling.

To reflect the spatial association between neighbouring provinces, a spatial regression model was applied. Panel data for the whole secondary industry of different provinces were modelled using either the spatial autoregression model (SAR), the spatial error model (SEM) or the spatial Durbin model (SDM). Before modelling, the spatial weight matrix was set according to geographic situation, and Moran's *I* index was also calculated to test the existence and properties of spatial association.

Two basic models in spatial econometrics are the SAR model and the SEM. In 2009, LeSage and Pace proposed a more general model, the SDM, which nests both spatial lagged dependent variables and independent variables, and is more general. When $\theta = 0$, it is the SAR; when $\theta + \rho\beta = 0$, it is the SEM model.

The following formulas are potential models:

$$IC = \alpha + \alpha_i + \boldsymbol{\rho WIC} + \boldsymbol{X}\beta + \varepsilon \quad \varepsilon \sim \boldsymbol{NID}(0, \sigma^2 \boldsymbol{I}) \tag{4}$$

$$\boldsymbol{IC} = \alpha + \alpha_i + \boldsymbol{X}\beta + \varepsilon, \varepsilon = \lambda \boldsymbol{W}\varepsilon + \mu \quad \mu \sim \boldsymbol{NID}(0, \sigma^2 \boldsymbol{I}) \tag{5}$$

$$\boldsymbol{IC} = \alpha + \alpha_i + \rho \boldsymbol{WIC} + \boldsymbol{X}\beta + \boldsymbol{WX}\theta + \varepsilon \quad \varepsilon \sim \boldsymbol{NID}(0, \sigma^2 \boldsymbol{I}) \tag{6}$$

where $\boldsymbol{X}$ is the vector of control variables, ρ and λ are the autoregression coefficient, $\boldsymbol{W}$ is the spatial weight matrix, ε is the error term, α is the common intercept and α_i is individual effect. The selection of the model was based on a series of statistical tests, including Lagrange Multiplier (LM) tests and its robustness tests, Likelihood Ratio (LR) tests and Wald tests. (See appendix for detailed results)

IX. Results

Elhorst (2010) proposed a series of test procedures to determine which model is the most appropriate to explain the data. First, we applied OLS, the LM test and the robust LM test to test whether the SAR or

SEM model is more appropriate to describe the data. Conducting the OLS and spatial lag models allowed us to assess whether the SDM statistically outperforms the other models, particularly the spatial lag model. In the case that the OLS model is rejected, then the SDM model would be estimated by maximum likelihood. Subsequently, the LR test could be used to test the hypotheses $H_0: \theta = 0$ and $H_0: \theta + \rho\beta = 0$. In the case that the hypotheses are rejected at the same time, the SDM model would be most appropriate. However, if $H_0: \theta = 0$ cannot be rejected and the (robust) LM test is also in favour of SAR, the SAR model can best describe the data. If $H_0: \theta + \rho\beta = 0$ cannot be rejected and the (robust) LM test also points to the SEM model, then the SER model describes the data best. If one of these conditions is not satisfied, i.e. the (robust) LM test and the LR test point to different models, then the SDM model is still best because it generalizes the SAR and SEM models. The (robust) LM tests mentioned above were developed by Anselin (1988). These tests are based on the results of the OLS estimation. Two types of LM tests were applied, one-directional test and one robustness test.

First, a pooled regression model is estimated without considering spatial effects. Based on these estimations, the LM tests were conducted to perform the first-round selection. The results of the LM tests are listed below. Due to lack of space, the estimation results of the pooled regression model are not listed.

Table 3 shows that spatial effects exist, and therefore, the OLS estimation is rejected. Because China's industrial economy has not experienced a structural transformation since 2001 (Cai 2009; Li 2009; Zhang 2012), the spatial model also only considers the individual effect model and neglects the time effect. The Hausman test that is shown in Table 4 rejects the random effect. Therefore, the following estimations only consider the individual fixed effects. The estimation includes the squared term of SER. The estimation results for SDM are as follows:

Table 3. Results of tests for spatial dependence.

Statistics	Value	Prob.
LM error	77.931	0.000*
LM lag	24.324	0.000*
Robust LM error	55.176	0.000*
Robust LM lag	1.569	0.210

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 4. Estimation results for SDM.

Variable	Coefficient (SE)	Variable	Coefficient (SE)
SER	−0.2147** (0.0972)	*W × SER*	−0.3950** (0.1736)
SER^2	0.1447* (0.0774)	$W \times SER^2$	0.2409* (0.1382)
PI	−0.1418*** (0.0428)	*W × PI*	−0.2007** (0.0763)
d(*SI*)	5.05×10^{-6}* (2.37×10^{-6})	*W ×* d(*SI*)	3.76×10^{-6} (2.84×10^{-6})
MS	-9.34×10^{-8} (5.38×10^{-7})	*W × MS*	-6.29×10^{-7} (6.66×10^{-7})
d(*GDP_PC*)	0.0926** (0.0289)	*W ×* d(*GDP_PC*)	−0.0180 (0.0448)
d(*POP*)	4.49×10^{-5} (3.61×10^{-5})	*W ×* d(*POP*)	-1.127×10^{-4} (6.58×10^{-5})
d(*FDI*)	1.76×10^{-5} (3.37×10^{-5})	*W ×* d(*FDI*)	4.56×10^{-5} (4.87×10^{-5})
INF	0.0375 (0.0733)	*W × INF*	0.0235 (0.1145)
EDU	0.0028* (0.0017)	*W × EDU*	0.0036 (0.0031)
Rho	0.2479** (0.07624)		
LR($H_0: \theta = 0$)	16.24***	LR($H_0: \theta + \rho\beta = 0$)	34.87***
Hausman test	68.93***	*R* squared	0.7621

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The two LR tests reject the null hypotheses. Therefore, the SDM model is an appropriate model according to the rules of Elhorst.

However, the coefficients above do not explain the spillover effect and marginal effect of the variables as in an ordinary model because the point estimates of spatial regression models do not consider complex interactions correctly and lead to erroneous conclusions (LeSage and Pace 2009). LeSage and Pace (2009) therefore propose a partial derivate method to interpret the impact of changes to the variables. They divide the impact into three effects, namely the direct effect, indirect effect and total effect. The direct effect shows the effect from the change in an explanatory variable in a local unit, the indirect effect measures the impact on other dependent variables in other units and the total effect is the sum of the direct effect and the indirect effect. The three effects are listed below.

IC and SER are in U-shaped relationship, which means that the traditional hypothesis explains the first part, while Porter's Hypothesis explains the second part. Additionally, IC is not only influenced by SER in the local unit but is also influenced by SER in neighbouring units and even in non-neighbouring units.

The turning point can be calculated according to Table 5. For the direct effect, the turning point is approximately 0.74, which means that SER has a

Table 5. Direct effect, indirect effect and total effect of explanatory variables.

Variable	Direct effect	Indirect effect	Total effect
SER	−0.2434**	−0.5512**	−0.7946**
	(0.0812)	(0.2303)	(0.2521)
SER^2	0.1640**	0.3318*	0.4959**
	(0.0687)	(0.1800)	(0.1897)
PI	−0.1535***	−0.3036***	−0.4570***
	(0.0468)	(0.0811)	(0.0968)
d(*SI*)	5.32×10^{-6}**	5.5×10^{-6}	1.08×10^{-5}**
	(2.26×10^{-6})	(3.35×10^{-6})	(4.14×10^{-6})
MS	4.1×10^{-8}	4.1×10^{-7}	9.99×10^{-7}
	(5.45×10^{-7})	(7.35×10^{-7})	(9.42×10^{-7})
d(*GDP_PC*)	0.0980***	−0.0020	0.0959
	(0.0292)	(0.0592)	(0.0655)
d(*POP*)	3.87×10^{-5}	-1.31×10^{-4}	9.2×10^{-5}
	(3.77×10^{-5})	(8.4810^{-5})	(9.27×10^{-5})
d(*FDI*)	2.01×10^{-5}	7.31×10^{-5}	9.32×10^{-5}
	(3.42×10^{-5})	(5.81×10^{-5})	(7.41×10^{-5})
INF	0.0343	0.0490	0.0833
	(0.0655)	(0.1219)	(0.1269)
EDU	0.0030*	0.0056	0.0086**
	(0.0016)	(0.0037)	(0.0038)

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

negative impact on local IC until it reaches 0.74. For the indirect effect, the turning point is at approximately 0.83, which shows that SER has a positive influence on the IC concerning other units after reaching 0.83. The indirect impact is not only at the neighbouring unit but also on the non-neighbouring unit because of the spatial interaction between neighbouring units and non-neighbouring units. For the total effect, the turning point is approximately 0.80. The total effect shows the aggregated impact of the SER of a local unit on the global scale. Therefore, after the SER of one unit arrives at 0.80, it can generate a positive influence as a whole, namely it has a positive impact on China.

For the other variables, pollution intensity (*PI*), the increment of GDP per capita (d(*GDP_PC*)), the increment of industry scale (d(*SI*)) and the percentage of people with higher education (*EDU*) also impact the local IC. *PI* also influences other units. Globally, *PI*, d(*SI*) and *EDU* on the whole influence IC. Although the influence of d(*SI*) and *EDU* on other units is not significant, they generate indelible impacts on the local IC and globally produce significant impacts. Moreover, competitiveness in neighbouring units also has a positive impact on local IC.

The signs of all of the other significant variables conform to theory. Pollution intensity has negative influences on three levels because higher pollution would impel people and even capital to flee. The increment of the scale of industry is positive because a scale effect can be activated by the augment of the scale. GDP per capita is also positive because it indicates that the economic level of a province, and the development of economy and industry are always mutually promoted. *EDU* has good effects on IC, both locally and globally because higher education can transform human resources into human capital. More people receiving higher education can increase human capital and then raise labour productivity. As for the competitiveness of neighbouring units, the positive sign means positive agglomeration, which is consistent with Moran's *I* test.

X. Discussion

The above analysis suggests that IC and SER have a U-shaped relationship. The turning point is 0.74 for local, 0.83 for other provinces and 0.80 for the whole country. It is obvious that SER firstly has a negative impact on the industry and then a positive impact, which means that the traditional hypothesis fits the first part and then Porter's Hypothesis kicks in. What is the mechanism behind the U-shaped relationship? The U-shaped relationship means that when environmental regulations are lax, there is a trade-off; when they are stringent, there is a positive impact. The explanation follows.

Assuming all else is equal, when regulations are lax, most firms in society cannot obtain an innovation offset due to reasons mentioned by Porter. Thus, the trade-off system functions. This trade-off will continue until the stringency reaches a turning point and innovation is triggered because the production possible frontier does not move outward, and more factors are used to address environmental regulations during that period. Because of a fear of a continuous decrease in competitiveness, the government would likely stop enforcing the more stringent regulations. It is a vicious circle.

When regulations are stringent to some extent, they will trigger innovation for some firms, provided that other conditions are successfully being met. The whole process is similar to the procedure shown in Figure 1. When environmental regulations are strengthened to some extent, firms are gradually divided into two categories. Those firms that can move their bounded-rational frontier outward and trigger innovation offset will enjoy increased IC, while those that cannot will be eliminated because

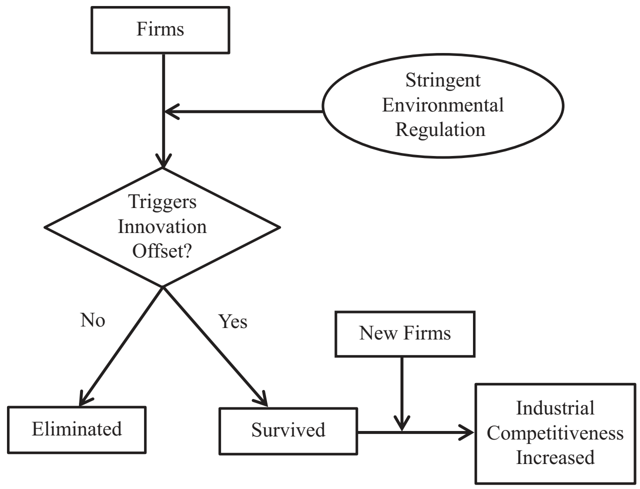

Figure 1. Influences of stringent environmental regulations.

they fall behind the competition and cannot keep pace with the times. It takes some time to trigger innovation and eliminate the laggard firms, so there could be trade-off at first. But after that, the surviving firms will improve the IC of the whole society. Meanwhile, many new firms that conform to the time trend will join the competition, which can also improve competitiveness. Thus, positive impacts occur.

In consideration of the above two points, the U-shaped relationship is generated when the SER ranges from a low level to a high level.

XI. Conclusions

Currently, more attention is paid to the association between environmental regulations and IC due to increasing pressures on economic development and environmental protection. As for China, little research has been conducted on this topic, although the country plays a significant role in the world's economic development and environmental protection. Therefore, this study aims to build an appropriate framework to explain the impact of environmental regulations on IC and to explore the mechanisms behind the association based on data for China. Our conclusions are as follows.

There is a U-shaped relationship between environmental regulations and IC, and not a simple linear relationship. Such an association means that there is a turning point before which environmental regulations will not have a positive impact on IC. This conclusion also demonstrates that the traditional hypothesis fits the situation first when regulations are lax; later, after the turning point, Porter's Hypothesis works.

Within this framework, the traditional hypothesis and Porter's Hypothesis do not contradict each other because the former is based on the rational-economic man assumption, while the latter is based on the bounded rationality assumption. The traditional hypothesis stresses that the response path to more stringent regulations moves along with the production possibility frontier, while Porter's Hypothesis states that the response path moves from the point within the frontier curve to the point approaching the frontier curve. Innovation can move the frontier curve outward. If innovation offset is triggered successfully, Porter's Hypothesis works, and then, a U-shaped relationship can exist. Then, in the long run, environmental regulations have positive impacts on IC. If innovation offset fails to be triggered, a trade-off association between environmental regulation and IC works and continues.

Stringent regulations can force firms to pay attention to more fundamental solutions rather than end-of-pipe or secondary treatment solutions (Porter and Van De Linde 1995), which is demonstrated by the econometric model, where stringent environmental regulations could have positive impacts, while lax regulations would have a negative influence.

The idea that a well-designed policy and better education can trigger innovation originated from bounded rationality. A well-designed policy can reduce the cost of information collection and provide useful information. Education can also improve one's cognitive and processing ability. Both can improve people's rationality level and further trigger innovation.

Although China is in a good position to generate positive impacts of environmental regulations on IC as a whole, its development is still unbalanced. Most provinces in middle, west and northeast China still do not enjoy a positive association between the two variables. Thus, there is much room for improvement. The government can do something to turn the situation around in the following ways.

Currently, the main regulation instruments are still the command-and-control. Although such instruments are effective in reducing pollutant emissions, they sometimes do not reflect market demand and are economically inefficient due to government failure. Therefore, this kind of policy often drains the production factor, which can distort the output arrangement between firms and the government and make the optimal combination impossible.

This study recommends that the Chinese government adopts market-based instruments. These instruments signal market demand and market trends, thus reducing the possibility of government failure and providing more useful and correct information for rational decision-making. Market-based instruments are better designed than command-and-control instruments because of their ability to self-adjust according to market signals and require less human intervention.

Porter and Van De Linde (1995) stressed that stringent regulations can focus greater company attention on fundamental solutions, rather than end-of-pipe or secondary treatment solutions. Therefore, stringent regulations can trigger innovation better and faster.

In this study, the U-shaped relationship between environmental regulations and competitiveness has been demonstrated. Only stringent regulations that pass the turning point can generate a positive effect on IC. Although there may be a trade-off at first, the government should not be too concerned. The long-term impact is positive as long as the regulations are well designed. Thus, the government should set its sights to implementing stringent environmental regulations.

To close, two limitations will be discussed that can lead to future research opportunities. First, due to data unavailability, different industries in the secondary sector had to be aggregated to the provincial level. This restriction needs to be overcome, considering that impacts on competitiveness are likely to be sector specific. Hence, an industry-specific study needs to be conducted in future. Second, another limitation of our study is that it treats Chinese provinces as unrelated systems, hereby not accommodating the possibility that policy might lead to emission leakage, for instance that the output of energy-intensive industries could relocate from provinces with emission commitments to provinces without.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

Specification of Spatial Weight Matrix

The spatial weight matrix $\boldsymbol{W}$ is the key of spatial analysis because it expresses the spatial association between units. How to set an appropriate spatial weight matrix is controversial and difficult (Bavaud, 1998). Usually, $\boldsymbol{W}$ is set by dichotomy based on the Rook criterion of contiguity. The rule defines $w_{ij} = 1$ for regions that share a common side with the region of interest; $w_{ij} = 0$ for non-neighbouring regions and elements of the principal diagonal. The general form of matrix $\boldsymbol{W}$ is as follows:

$$\boldsymbol{W} = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1N} \\ w_{21} & w_{22} & \cdots & w_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ w_{N1} & w_{N2} & \cdots & w_{NN} \end{bmatrix} \tag{7}$$

Table A1 shows information about the neighbouring provinces of each province, except for Tibet, Taiwan, Hong Kong and Macao. It is worth noting that Hainan province is an island located to the south of Guangdong Province. It was once a part of Guangdong in the history. Therefore, the research set Guangdong as the neighbouring province of Hainan.

Such a spatial weight matrix based on the Rook criterion is reasonable in this research. For regional characteristics variables, neighbouring provinces often has more association with each other than non-neighbouring provinces in economy and culture. As for environmental regulations, the weight is also rational. Here is the deduction. Assume that industrial competitiveness IC_{it} is a function of pollutants (P_{it}) and other characteristic variables ($\boldsymbol{Z_{it}}$), the competitiveness is as follows:

Table A1. Description of indicators.

Category	Variable	Sub-variable	Indicator	Units
Y	Industrial competitiveness (*IC*)	Labour	Labour productivity (output per employment)	10k yuan per capita
			Growth of employment	%
		Capital	Capital productivity (output per capital)	
			Growth of fixed asset	%
		Innovation	Ratio of new products to revenue from principal business	%
			Numbers of patent per unit of firms	
		Ability	ratio of profits to cost	%
			Product sale rate	%
X	Stringency of environmental regulation (*SER*)		Treatment rate of waste water	%
			Treatment rate of SO_2	%
			Treatment rate of solid waste	%
	Pollution intensity (*PI*)		Emission of waste water per unit of output	ton/10k yuan
			Emission of SO_2 per unit of output	ton/10k yuan
			Emission of solid waste per unit of output	ton/10k yuan
	Scale of industry (*SI*)		Output of industry	10k yuan
	Market structure (*MS*)		Numbers of firms within the industry	
	Population (*POP*)		Population of the province	10k
	Economic development situation (*GDP_PC*)		GDP per capita of the province	10k yuan per capita
	Infrastructure (*INF*)		Density of road network	km/km^2
			Density of railway	km/km^2
			Density of post road	km/km^2
	Education level (*EDU*)		Proportion of residents with higher education	%
	Foreign capital (*FDI*)		Foreign direct investment	100m yuan

$$IC_{it} = f(P_{it}, \boldsymbol{Z_{it}}) \tag{8}$$

Then, assume pollutants can spill over to other provinces through wind and water flow, biologic chain etc. and can only have significant impacts on neighbouring provinces because of the distance limitation. Another important assumption is that emission of pollutants is decided by the degree of stringency of environmental regulations (SER_{it}). Therefore, the amount of pollutants in a province is as follows:

$$P_{it} = g\left(SER_{it}, \sum_{j \neq i} SER_{it}\right) \tag{9}$$

where SER_{it} represents pollutants produced by the local province; $\sum_{j \neq i} SER_{it}$ represents pollutants from neighbouring provinces which indicates the spillover effect of pollutants. Combining formula 6 with formula 7, the SER in the local provinces together with the SER in the neighbouring provinces can have an influence on the local industrial competitiveness as follows:

$$IC_{it} = h\left(SER_{it}, \sum_{j \neq i} SER_{it}, \boldsymbol{Z_{it}}\right) \tag{10}$$

Therefore, the spatial weight matrix based on the Rook criterion is also reasonable to interpret the functions of neighbouring environmental regulations.

Before using the spatial weight matrix $\boldsymbol{W}$, $\boldsymbol{W}$ should be normalized in the row, namely every matrix element w_{ij} is divided by the sum of elements of each row element, which uses formula 9. The purpose of normalization is to make the sum of spatial effects of neighbouring units on each unit equal to 1 and to eliminate the external influence of the inter-region. After that, $\boldsymbol{W}$ is set.

$$w_{ij}^* = \frac{w_{ij}}{\sum_{j=1}^{N} w_{ij}} \tag{11}$$

$$\boldsymbol{W_E} = \begin{bmatrix} w_{11}^* & w_{12}^* & \cdots & w_{1N}^* \\ w_{21}^* & w_{22}^* & \cdots & w_{2N}^* \\ \vdots & \vdots & \ddots & \vdots \\ w_{N1}^* & w_{N2}^* & \cdots & w_{NN}^* \end{bmatrix} \tag{12}$$

Test for spatial association

Before modelling, the spatial association should be tested to decide whether to adopt the spatial model or not. Moran (1950) proposes Moran's I test to detect the global spatial association. The null hypothesis is that a spatial association does not exist. The formula is as follows:

$$I = \frac{n}{\sum_i^n \sum_j^n w_{ij}} \times \frac{\sum_i^n \sum_j^n w_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\sum_i^n (y_i - \bar{y})^2} \tag{13}$$

where w_{ij} is the spatial weighted matrix, y_{ij} and $\bar{y}$ are the variable in the ith location and the mean of the variable and n is the number of observations.

The statistic value of Moran's I ranges from −1 to 1. If the value is significantly larger than 0, the spatial units that have similar attributes agglomerate. If it is significantly smaller than 0, the spatial units are negatively related which means that units with different attributes are clustered. If the value equals 0 approximately, spatial effects do not exist. Moreover, the Z test will be used to test the significance of Moran's I. The formula is as follows:

$$Z = \frac{I - E(I)}{\sqrt{\mathrm{Var}(I)}} \tag{14}$$

where $E(I)$ is the expect value of Moran I, Var(I) is the variance of Moran I and their calculation is based on the random distribution assumption. Under the null hypothesis, the Z statistic follows asymptotic normal distribution.

The table below shows the Moran's I test of IC and SER from 2001 to 2010.

As is shown in Table A2, it is apparent that the Moran's I of IC and SER are all positive and significant at least on 5% level from 2001 to 2010, which means that

Table A2. Neighbouring information of each provinces.

Code	Name of provinces	Neighbouring provinces	Code	Name of provinces	Neighbouring provinces
1	Beijing	2, 3	16	Henan	3, 4, 12, 15, 17, 26
2	Tianjin	1, 3, 15	17	Hubei	12, 14, 16, 18, 22, 26
3	Hebei	1, 2, 4, 5, 6, 15, 16	18	Hunan	14, 17, 19, 20, 22, 24
4	Shanxi	3, 5, 16, 26	19	Guangdong	13, 14, 18, 20, 21
5	Inner Mongolia	3, 4, 6, 7, 8, 26, 27, 29	20	Guangxi	18, 19, 24, 25
6	Liaoning	3, 5, 7	21	Hainan	19
7	Jilin	5, 6, 8	22	Chongqing	17, 18, 23, 24, 26
8	Heilongjiang	5, 7	23	Sichuan	22, 24, 25, 26, 27, 28
9	Shanghai	10, 11	24	Guizhou	18, 20, 22, 23, 25
10	Jiangsu	9, 11, 12, 15	25	Yunnan	20, 23, 24,
11	Zhejiang	9, 10, 12, 13, 14	26	Shaanxi	4, 5, 16, 17, 22, 23, 27, 29
12	Anhui	10, 11, 14, 15, 16, 17	27	Gansu	5, 23, 26, 28, 29, 30
13	Fujian	11, 14, 19	28	Qinghai	23, 27, 30
14	Jiangxi	11, 12, 13, 17, 18, 19	29	Ningxia	5, 26, 27
15	Shandong	2, 3, 10, 12, 16	30	Xinjiang	27, 28

(Source: *Map of People's Republic of China* issued by SinoMaps Press in 2013)

Table A3. Moran's *I* of IC and SER (2001–2010).

	IC		SER	
Year	Moran's *I*	*p*-Value	Moran's *I*	*p*-Value
2001	0.2362	0.014*	0.3768	0.003**
2002	0.3674	0.015*	0.4492	0.002**
2003	0.3530	0.001**	0.3595	0.002**
2004	0.2393	0.017*	0.4470	0.002**
2005	0.2633	0.014*	0.3651	0.004**
2006	0.2650	0.015*	0.4244	0.001**
2007	0.2728	0.011*	0.4584	0.001**
2008	0.3329	0.004**	0.4562	0.001**
2009	0.3051	0.006**	0.4514	0.002**
2010	0.3215	0.003**	0.4638	0.001**

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

dependence between phenomena at different locations that means observation at one unit is determined partially by what happens elsewhere in the system. Therefore, the econometric models presented above are appropriate for the analyses (see formulas 4–6).

spatial units agglomerate positively in terms of environmental regulations and industrial competitiveness in China and the distribution is not random. The spatial association cannot be ignored.

Model specification: Since the spatial association has been detected, the spatial model is the better choice. For spatial dependence, Anselin (1988) summarizes two reasons to explain the situation. The first is the by-product of measurement errors for observation in neighbouring spatial units. In practice, data are obtained at an aggregate level. So, there may be no correspondence between the spatial scope of the phenomenon under the research and the delineation of the spatial units of observations. Therefore, measurement error is likely to exist. And, it tends to spill over across the boundaries, which means that measurement errors for observation i are likely to be related to neighbouring spatial units. The second reason is spatial interaction and diffuse process leading to the