The effect of strategic synergy between local and neighborhood environmental regulations on green innovation efficiency: The perspective of industrial transfer

Abstract

Considering the environmental governance dilemma caused by environmental decentralization, this study aims to explore whether the strategic synergy between local and neighborhood environmental regulations can be an essential tool to improve green innovation efficiency and achieve sustainable development. Using the data of industrial firms from 2005 to 2019, and employing network slack-based measure and Tobit regression, this study provides empirical evidence that (1) the green innovation efficiency shows an upward trend in fluctuations but still has great room for improvement; (2) the direct impact of local environmental regulation on green innovation is positive, but the indirect impact through forcing firms to transfer into the neighborhood with loose regulation is negative, that is, the industrial transfer plays a suppression effect; (3) the strategic synergy of environmental regulations has U-shaped and direct effect on green innovation and also has a positive indirect effect through inhibiting the firm's behavior transferring into the neighborhood. This study reveals the influence mechanism of the strategic synergy of local-neighborhood environmental regulations and offers empirical evidence to explain the reason why synergistic environmental governance can effectively promote green innovation, which provides the theoretical guidance for government to formulate environmental policies and construct an environmental governance system.

Keywords: Green innovation, environmental regulations, industrial transfer, strategic synergy.

1. Introduction

With the increasingly serious pollution problems, environmental regulation is regarded as an essential tool to promote the firm’s green innovation and achieve sustainable development (Wu et al., 2020). However, in countries with environmental decentralization, environmental regulation (ER) might not achieve the desired effect as its significant regional differences, results in the environmental governance dilemma at the national level. The most typical examples are developing countries such as China, India (Du et al., 2020), and Brazil (Jabbour et al., 2020; Lipscomb and Mobarak, 2017). Taking India as a case, with the continuous economic development of southern regions, local governments pay more attention to balancing the relationship between the economy and the environment and formulating stricter ER to achieve sustainable development (Lovo, 2018). Consequently, industrial firms are gradually transferring from southern regions into northern regions with the easy ER and the policies to attract outside investment, which also causes the pollution problem in these regions (Kattumuri and Lovo, 2018). For industrial firms with higher pollution, such policy differences among local governments endow them with the second choice excepting green innovation facing ER, that is, relocating to other regions with easy ER, which triggers pollution transfer (Yilanci et al., 2020). In this case, the phenomenon of industrial transfer and even pollution transfer emanating from regional policy differences is not conducive to the central government to stimulate firms to green innovation (Li et al., 2021; Zhang et al., 2017), but also causes the environmental governance dilemmas (Besley and Coate, 2003). Therefore, how does solve the environmental governance dilemma caused by regional differences have been become a burning question for policymakers and policy researchers.

The strategic synergy of local-neighborhood environmental regulations (SSER) provides an interesting view for the central government to tackle the dilemma by restricting the transfer behavior of industrial firms and promoting green innovation (Ge et al., 2020). The SSER can be described as a political behavior initiated by the governments in different regions to realize common environmental benefits by setting pollution governance goals and developing action plans jointly (Wang and Zhao, 2021). A typical case is the *Air Pollution Prevention and Control Action Plan* formulated by the government of China, which aims to establish a collaborative environmental governance system between the governments of the Beijing-Tianjin-Hebei region (The capital economy circle) and the Yangtze River Delta region (Li et al., 2019c). In this case, the environmental regulations of local and neighborhood regions are gradually reaching unanimity, which greatly limits the industrial firm's transfer behavior that aims to avoid additional pollution control costs (Zhang et al., 2020; Zhao et al., 2020). For industrial firms, the behavior of transferring to other regions is no longer conducive to achieving their goals for reducing costs facing the gradual convergence of local-neighborhood regulations (Li et al., 2019b), and green innovation and environmental practices have become the only strategic choice to meet the requirement of local ER (Awan et al., 2018; Shao et al., 2020).

Despite the strategic synergy of local-neighborhood environmental regulations is expected to become an efficient tool to solve environmental governance dilemmas and promote the firm's green innovation, little empirical evidence supports this view. On the one hand, most prior literature focuses on the influence of local ER on the firm's green innovation, such as the studies of Song et al. (2020a), Liu et al. (2020), and Du et al. (2021). These studies mainly explore whether ER formulated by local government is conducive to promoting the firm's green innovation based on the Porter hypothesis. On the other hand, some studies start from the spatial spillover effect to analyze the direct effect of local ER and the indirect effect of neighborhood ER on the firm's green innovation. The typical representatives are the studies of Li et al. (2019d), Peng et al. (2021), and Li and Du (2021). Although these studies are innovative compared with prior studies, they are still based on the Porter hypothesis and emphasize the role of local ER, and ignore how to solve environmental governance dilemmas through the way of strategic synergy under the context of significant regional policy differences. A few studies have constructed the combination framework of the Porter hypothesis and Pollution haven hypothesis to analyze the strategic interaction types of local-neighborhood ER, such as Peng (2020), Song et al. (2021), and Wu et al. (2021), but such studies not further explored the heterogeneous impact of different interaction types on the firm's green activities.

To sum up, it is still a worthy topic that explores the influence mechanism of strategic synergy between local-neighborhood environmental regulations on green innovation efficiency. Thus, this study aims to explore these research questions as follows:

(1) Can strategic synergy of local-neighborhood environmental regulations

influence green innovation efficiency?

(2) How does the strategic synergy of local-neighborhood environmental regulations influence green innovation efficiency by inhibiting the industrial transfer behavior of firms?

To answer the above questions, taking industrial firms of China as a typical research object, this study utilizes the network slack-based measure (SBM) method to assess the industrial firm's green innovation efficiency based on the provincial panel data from 2005 to 2019; Then, the panel Tobit regression model is employed to explore the influence mechanism of the strategic synergy of local-neighborhood ERs on green innovation efficiency and explores whether strategic synergy of regulations is an effective solution for improve innovation efficiency and realize sustainable development or not.

This study has several contributions as follows. First, this study clears the relationship between the strategic synergy of local-neighborhood environmental regulations and green innovation efficiency based on the hybrid perspective of the Porter hypothesis and the Pollution haven hypothesis, which enriches the existing research on innovation management and environmental policy. Second, this study reveals the mediating role of industrial transfer on the relationship between strategic synergy and green innovation efficiency, which uncovers the influence channel of ER and provides empirical evidence to explain the reason why the SSER is an efficient tool to overcome the environmental governance dilemma. Also, this finding provides theoretical guidance for central government and local governments to formulate environmental policies and construct an environmental governance system.

2. Literature review and research hypotheses

2.1 Literature review

With the increasingly serious pollution problems, improving green innovation efficiency is regarded to break the link between economic development and environmental pollution (Du et al., 2021; Ikram et al., 2022). For firms, green innovation reflects their efforts to reduce pollution emissions and energy consumption in business activities through developing green products and technologies and improving production processes (Awan and Sroufe, 2022; Zhu et al., 2021). From the perspective of input-output analysis, green innovation efficiency represents a firm capability to utilize innovation resources, that is, an indicator to measure whether a firm can achieve its green innovation goals with minimum cost (Zeng et al., 2021).

In early studies, firms are considered to lack the motivation to implement innovation activities and improve innovation efficiency because of the dual externalities of green innovation (Wang and Yu, 2021). For firms, the positive externality refers that their green innovation activities might bring knowledge spillover effect which makes other firms can acquire this innovation achievement through imitation and learning (Zhang et al., 2021); and the negative externality reflects that their innovation cost might be much higher than the cost to directly release pollutant when environmental policy is loose (Dwivedi et al., 2022; Liu et al., 2020). In this context, policy researcher suggests that environmental regulation (ER) is an effective tool to tackle dual externalities of green innovation and force firms to implement green innovation and improve innovation efficiency.

Existing studies mainly discuss the relationship between ER and green innovation efficiency based on the Porter hypothesis and pollution haven hypothesis. ER is a series of laws and regulations formulated by the government to restrain the firm's pollution behavior and realize sustainable development (Xie et al., 2017). From the Porter hypothesis, ER can emanate a compensatory effect for the firm to offset its innovation cost, thus forcing the firm to implement green innovation and improve innovation efficiency (Liu et al., 2020; Pan et al., 2019). Specifically, firms not only achieve competitive advantage and superior performance through implementing green innovation and improving innovation efficiency but also obtain innovation subsidies from the government (Liu et al., 2020). However, some researchers disagreed above view, and argue that the effect of ER on green innovation efficiency may not be linear (Zhang et al., 2022). In the short term, ER might emanate compliance costs for firms by forcing them to control terminal pollution emission, which greatly enhances their economic burden and reduce green innovation efficiency (Ouyang et al., 2020); in the long term, ER also generates the compensation effect for firms and improve their innovation efficiency (Wang et al., 2022). From the Pollution haven hypothesis, some scholars pointed out that ER also has obvious shortcomings because of its significant regional differences (Wang et al., 2019). Facing strict local ER, firms might choose to transfer to the neighboring regions with loose ER to avoid environmental governance costs, thus causing these neighboring regions to become the pollution haven (Yin et al., 2015). Extent studies have analyzed the impact of such local-neighborhood ERs differences on the firm's green innovation efficiency from the perspective of the selection effect and argued that the firms that remain in the local region are those with strong strength and high green innovation efficiency, and the firms transferring into neighboring regions are those with higher pollution and inefficient.

For the central government, however, the phenomenon of industrial transfer caused by regional differences in ER is a challenge to its environmental protection policy and causes its environmental governance dilemma (Dong et al., 2020). To solve this dilemma, a few studies suggest that regional governments should form a strategic alliance to jointly formulate environmental policies to limit pollution transfer caused by industrial transfer, and improve the green innovation efficiency of the firm in all regions. Such as, Deng et al. (2019) analyzed the optimal green innovation strategy of the firm under different strategic interaction modes between different regional governments based on the game theory. Their research shows that firm's innovation output is much higher when the regional governments jointly make decisions than when the regional governments make decisions in a decentralized manner. Peng (2020) empirically analyzed whether local-neighborhood governments have reached strategic alliances, and explored the impact of local-neighborhood ERs on green innovation efficiency.

Through the review of prior literature, it can be found that existing studies have not analyzed how to solve the environment governance dilemma caused by regional differences in ER based on the strategic synergy between local-neighbor governments. Although a few studies have preliminarily analyzed the strategic synergy modes between local-neighborhood ERs, such studies are not enough to fill this knowledge gap. These studies either analyzed the performance of the firm's green innovation under different strategic synergy modes based on game theory or only empirically analyzed the types of strategic synergy modes of local-neighbor governments, without further exploring the impact of different modes on the firm's green innovation efficiency.

Therefore, to fill the above knowledge gap, this study constructs the research framework based on the Porter hypothesis and the Pollution haven hypothesis. According to this research framework, this study aims to empirically explore whether the strategic synergy of local-neighborhood environmental regulations (SSER) can improve the firm's green innovation efficiency by inhibiting the firm's behavior that transferring into other regions with loose ER.

2.2 Research hypotheses

2.2.1 Local environmental regulation and green innovation efficiency

As a policy tool, environmental regulation (ER) is often employed by the government to force firms to change their original production processes, products, and technologies to reduce their pollutant emission through mandatory means such as laws and regulations (Qiu et al., 2021). For industrial firms, to gain legitimacy for survival and development and meet the requirement of ER, it is necessary to make the change and take their products, technologies, and production processes greener (Li et al., 2019a). In this case, ER is a positive factor in promoting green innovation activities of industrial firms.

The relationship between ER and green innovation efficiency can be discussed based on the compliance cost effect and compensatory effect. The compliance cost reflects an environmental governance fee for firms to reduce pollution emissions, mainly terminal pollution when facing ER. Many studies pointed out this compliance cost will crowd out the investment in green innovation and is not conducive to enhancing innovation efficiency, such as Rexhäuser and Rammer (2014) and Tang et al., (2020). However, this view is criticized by many scholars, who believe that the compliance cost is a relatively short-run concept and present their arguments from the compensation effect. As Liu et al. (2020) pointed out, green innovation will help firms to obtain long-term competitive advantages and incentive subsidies, that is compensation effect, which in turn greatly improves the green innovation efficiency. Further, Qiu et al. (2021) believed that the impact of ER is nonlinear, in the short term ER has a negative influence on green innovation efficiency through compliance cost, but in the long term, ER will encourage firms to continuously improve innovation efficiency to offset this compliance cost. Moreover, other scholars analyzed the positive role of ER on green innovation efficiency from the selection effect. Specifically, facing strict ER, firm may withdraw from this market (delisting or industrial transfer) due to the high environmental governance cost (Combes et al., 2012). In this case, the overall innovation efficiency of the firm in a certain region has been greatly improved because firms with low innovation efficiency were eliminated (Zhang and Li, 2022). Overall, the impact of ER on the green innovation efficiency of industrial firms in a certain region is still positive. Thereby, this study proposes Hypothesis 1 as follows.

H1: The local environmental regulations have a positive effect on the green innovation efficiency of industrial firms.

2.2.2 Strategic synergy of local-neighborhood environmental regulations and green innovation efficiency

In the context of Chinese style decentralization, ER shows significant regional differences. In fact, the policy fragmentation easily triggers the firms to avoid additional environmental governance costs by transferring to regions with lower regulation, which is called the “pollution haven effect” (Yilanci et al., 2020). That is, a loose policy environment maybe attracts a large of firms to agglomerate in this region, which results in this region becoming a pollution haven (Liu et al., 2017). Some researchers pointed out that this phenomenon mainly exists in “footloose” and pollution-intensity industries, that is, these firms prefer choosing industrial transfer when facing strict local ER (Dou and Han, 2019).

The strategic synergy of local-neighborhood environmental regulations (SSER) is expected to become an efficient tool to solve the environmental governance dilemma. As Galinato and Chouinard (2018) noted, the state of congruence between local-neighborhood ERs may greatly affect the effectiveness of the environmental governance of government. In this view, previous studies distinguished three strategic interaction types of local-neighborhood regulations, which include “race to the bottom”, “race to the top”, and “differentiation strategy”, such to Dong et al. (2020). Further, Song et al. (2021) explored the effect of neighborhood ER on industrial structure adjustment after confirming the interaction types of local-neighborhood ERs. Moreover, other scholars have done similar research, such as Ge et al. (2020) and Peng (2020).

However, these studies only identified the strategic interaction types of ERs but did not further provide empirical evidence to explain whether strategic synergy or interaction of local-neighborhood ERs can effectively improve green innovation efficiency and to what extent.

According to the above discussion, the SSER can improve green innovation efficiency theoretically despite the lack of empirical evidence. However, this relationship between strategic synergy and innovation efficiency may be non-linear. Specifically, SSER is to force firms to implement green innovation and improve innovation efficiency by restraining their transfer behavior. In this case, thus, ER cannot generate the selection effect to improve innovation efficiency in the short term by forcing firms to withdraw from local markets. In other words, the negative effect resulting from the compliance cost effect of ER cannot be masked by the selection effect in the short term. However, the negative effect will eventually be offset by the compensation effect in the long term, which in turn leads to the overall effect of ER on innovation efficiency being negative first and then positive. Therefore, this study defines Hypothesis 2 as follows.

H2: The strategic synergy of local-neighborhood environmental regulations has a U-shaped effect on green innovation efficiency.

2.2.3 The mediation role of industrial transfer between local environmental regulation and green innovation efficiency

In the view of the Pollution haven hypothesis, the pressure of ER maybe forces firms to transfer from a region with high regulation intensive to a region with low regulation intensive (Levinson, 2016). Many researchers described this phenomenon as the result of environmental decentralization and suggested that this often occurs in heavy pollution industries (Fu et al., 2021). Moreover, some scholars pointed out that firms will weigh the cost and benefit resulting from transfer behavior before choosing industrial transfer, that is, ER only is one of the decision factors of firm behaviors (D'Amato et al., 2018; Espínola-Arredondo and Muñoz-García, 2013).

From the perspective of innovation, the industrial transfer behaviors of the firm are not conducive to firms implementing green innovation (Cai and Ye, 2021). Conversely, for the region that undertaking industrial transfer, the transfer-into behavior of firms from other regions to this region will lead to a large number of firms agglomerating in this region, which stimulates economic development and green innovation (Zhang and Wang, 2021). Considering the knowledge spillover effect, industrial agglomeration can reduce the innovation cost of firms by promoting knowledge dissemination and exchange (Zeng et al., 2021). In the process of green innovation, knowledge is a crucial and scarce resource, and the sharing and exchange of knowledge be a major determinants of green innovation success. Specifically, industrial agglomeration can help firms to form an innovation network structure, that is, promote the exchanging of talents, resources, and knowledge, thus improving green innovation efficiency (Tseng et al., 2016). Therefore, Hypothesis 3 can be concluded as follows:

H3: The industrial transfer of industrial firms plays a mediation role in the relationship between local environmental regulation and green innovation efficiency.

2.2.4 The mediation role of industrial transfer between strategic synergy of local-neighborhood environmental regulations and green innovation efficiency

As above discussed, the regional difference in ER is the main reason forcing firms to transfer to other regions thus affecting green innovation efficiency. This may change, however, as the local ER aligns with the neighborhood ER gradually (Cui and Moschini, 2020). The strategic synergy of local-neighborhood ERs limits the scope for firms to transfer to other regions to reduce their environmental cost (Song et al., 2021). For firms, industrial transfer not only requires an allocation cost but also cannot achieve its goal of avoiding strict ER. In this view, the strategic synergy of local-neighborhood ERs has a positive influence to limit the firm's transfer behavior.

In addition, considering the role of industrial transfer of firms on green innovation, this study proposes Hypothesis 4 as follows.

H4. The industrial transfer of industrial firms plays a mediation role in the relationship between the strategic synergy of local-neighborhood environmental regulations and green innovation efficiency.

Integrating the above hypotheses proposed, this study constructs the hypothesis framework as follows (see Figure 1).

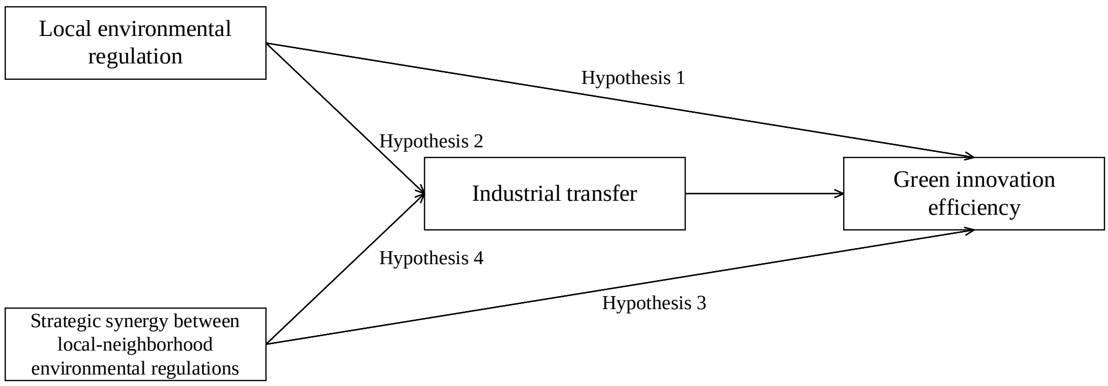

Figure 1. The hypothesis framework of this study

3. Methodology

3.1 Data collection

The data samples of this study are panel data of industrial firms in 30 provinces in China from 2005 to 2019. Considering the availability of data, the research objects of this study do not include Xizang Province and Taiwan Province. Specifically, the data on green innovation efficiency are derived from *China Industrial Statistical Yearbook* and *China Science and Technology Statistical Yearbook* from 2006 to 2020; the data on environmental regulations are derived from *China Environmental Yearbook*, *China Environmental Statistical Yearbook*, *China City Statistical Yearbook* from 2006 to 2020; The data of control variables are derived from *China Statistical Yearbook* and *Statistical Yearbook* of each provincial statistical office. Descriptive statistics of each variable are shown in Table 1 and Table 2.

3.2 Variables selection

3.2.1 Measurement indexes of green innovation efficiency

According to the innovation value chain theory provided by Hansen and

Birkinshaw (2007), green innovation is a complex process, including the green R&D stage that transforms R&D resources into technical achievements, and the green achievement transformation stage that transforms these achievements into economic and environmental benefits. The green innovation process is shown in Figure 2.

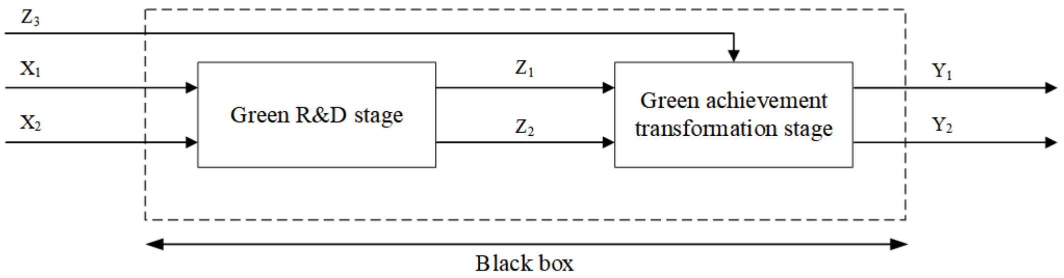

Figure 2. The green innovation process of industrial firms

Therefore, the multistage characteristics of green innovation are needed to consider when evaluating efficiency. Based on this, this study constructs an indicator system for evaluating the overall and staged efficiency of green innovation. The details are as follows.

(1) Green R&D stage

The green R&D stage requires inputting a large number of R&D capital and R&D personnel, to obtain technical achievements such as new green technologies or productions (Zhu et al., 2021). Therefore, the input variables in this stage mainly contain R&D capital and R&D personnel, and this study takes the full-time equivalent of R&D personnel and the internal R&D expenditure of industrial firms as proxy variables (Jiang et al., 2021); the output variables in this stage mainly include technical achievements such as new technologies or products, and this research takes the number of patent applications and the number of valid invention patents of industrial firms as proxy variables.

(2) The green achievement transformation stage

In the green achievement transformation stage, the R&D achievements are expected to transform into economic and environmental performances through a series of production practices (Tang et al., 2020). Therefore, the inputs in this stage mainly include two parts: R&D achievement obtained in the upper stage and energy consumption in the production practices (Tian and Lin, 2018). This research takes the number of patent applications, the number of valid invention patents, and the energy consumption of industrial firms as proxy variables. Moreover, the output variables in this stage can be divided into economic and environmental benefits. The economic benefit is considered as desirable output, taking the sales revenue of new products as proxy variable. To reflect the environment-friendly characteristics and pollution control role of green innovation, this study takes comprehensive index of environmental pollution as evaluation index. Specifically, this index is measured by the entropy method based on the pollution emission indicators (industrial waste water discharge amount, industry SO_2 emissions quantity, and the quantity of industrial solid waste generation)

The descriptive statistics in the efficiency evaluation model are shown in Table 1.

Table 1. Descriptive statistics in the evaluation model

Variable	Units	Mean	S. D.	Min.	Max.
R&D personnel	People	64960	98290.93	85	642490
Internal R&D expenditure	10 thousand	2345785	3649055	1356	23148566
Number of patent applications	Item	15474	30743.68	5	272616
Number of valid invention patents	Item	13828	36019	7	375515
Energy consumption	10 thousand Ton	13339	8422.19	822	41390
The sales revenue of new products	10 thousand Yuan	37489270	59469617	85659	4.3E+08
Environmental pollution comprehensive index	Non-dimensional	151647	107745	2462	473402

3.2.2 Variable selection in the regression model

(1) Explained variable

In the Tobit regression model, the overall and staged efficiency of green innovation evaluated by the Network SBM method is taken as the explained variables.

(2) Explanatory variable

i. Local environmental regulation

In this research, environmental regulation (ER) is considered an explanatory variable. The ER mainly restricts pollution emission and diffusion in the production process of firms through mandatory means such as pollution emission standards (Guo and Yuan, 2020). According to the research of Song et al. (2020b) and Wu et al. (2020), this study uses three indicators of the treatment rate of industrial waste water, industry SO_2 removal rate, and comprehensive utilization rate of industrial solid waste to construct the comprehensive evaluation indicator of ER. The process of calculation is just as follows.

First, three indicators are standardized, respectively.

$$Pt_{i,j}^{s} = \frac{Pt_{i,j}}{\frac{1}{n}\sum_{i} Pt_{i,j}} \qquad \text{(Formula 1)}$$

Where, $Pt_{i,j}$ represents the *j* indicator in the *i* province (*i=1,2, 3, …,30; j=1,2,3*). The higher the value of $Pt_{i,j}^{s}$, the higher the treatment capacity of *j* environmental pollutant in the *i* province.

Secondly, this research adopts the weighted average to calculate the intensity of ER at the province level based on the standardized treatment capacity of the aforementioned pollutants. A higher value refers to the stronger intensity of ER. The details are as follows.

$$ER_i = \frac{1}{3}\sum_{j=1}^{3} Pt_{i,j}^{s} \qquad \text{(Formula 2)}$$

ii. Neighborhood environmental regulation

Before the measure strategic synergy of local-neighborhood ERs, it is the precondition of evaluating the intensity of neighborhood ER. Referring to the method of Li et al. (2011), this study uses the spatial weight matrix combining geographic and economic distance to evaluate the intensity of neighborhood ER. The expression of this matrix is shown as follows:

$$W = W_d \times W_e = \begin{pmatrix} 0 & \frac{1}{d_{1,2}} & \cdots & \frac{1}{d_{1,n}} \\ \frac{1}{d_{2,1}} & 0 & \cdots & \frac{1}{d_{2,n}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{d_{n,1}} & \frac{1}{d_{n,2}} & \cdots & 0 \end{pmatrix} \times diag\left(\frac{\overline{Y_1}}{\bar{Y}}, \frac{\overline{Y_2}}{\bar{Y}}, \ldots, \frac{\overline{Y_n}}{\bar{Y}}\right) \qquad \text{(Formula 3)}$$

where, W_d is geographic distance spatial weight matrix. The element of W_d is w_{hi}, and $w_{hi} = 1/d_{hi}$. d_{hi} is the straight-line distance between province *h* and province *i*. is the economic distance spatial weight matrix. $\overline{Y_\iota}$ is the average value of per capita GDP of province *i* in the sample period, and $\bar{Y} = 1/(t_1 - t_0 + 1)\sum_{i=1}^{n}\sum_{t_0}^{t_1} Y_{i,t}$ is the average of the per capita GDP in the sample period.

Based on the above, the neighborhood ER can be measured as $NER_{it} = W \times ER_{it}$.

iii. Strategic synergy of local-neighborhood environmental regulation

To measure the strategic synergy of local-neighborhood environmental regulations (SSER), this study adopts the profile-deviation model from the view of strategic synergy. Conceptually, the strategic synergy reflects the state of consistency between local and neighborhood ERs, the higher the degree of consistency, the higher the degree of strategic synergy. The profile-deviation model is used to estimate the consistency of ERs. That is,

$$SSER_{it} = 1 - \sqrt{(ER_{it}^{s} - NER_{it}^{s})^2} \quad \text{(Formula 4)}$$

where, the superscript s of ER_{it}^{s} and NER_{it}^{s} implies that the variables have been standardized.

(3) Mediator

Generally, the measurement indicator of industrial transfer can be distinguished as absolute and relative (Zhang et al., 2020). Considering the data availability, this research adopts the relative indicator to represent the degree of industrial transfer in a region. The industrial transfer behavior of firms will increase the number of firms in transfer-taking regions and decrease the number of firms in transfer-out regions (Song et al., 2020a). Therefore, this research adopts the proportion of the number of firms of industrial firms in each province in the number of firms of national industrial firms to measure the industrial transfer behavior of industrial firms. The detail is as follows.

$$\mathrm{IT}_{i,t} = \frac{The\ number\ of\ firms_{i,t}}{\sum_{i=1}^{30} The\ number\ of\ firms_{i,t}} \quad \text{(Formula 5)}$$

The decrease of $\mathrm{IT}_{i,t}$ means that industrial firms of province *i* transfer to other regions in the year of *t*.

(4) Control variable

This study comprehensively considers the factors that possibly affect green innovation, and uses the following variables to assure the explanatory power of the regression mode. *Education level* (EL): this study uses the ratio of the number of people with a high school degree to the total population to measure the education level (Deng et al., 2012); *Freight volume (FV)*: The logarithm of total freight volume of railway, highway, and waterway is used to measure the freight volume (Wu et al., 2021); *Trade openness (TO):* this study uses the logarithm of the import and export volume to measure the openness level (Cai et al., 2016); *Economy development level* (EDL): the logarithm of GDP per capita is used to measure the economic development level (Peng, 2020); *Urbanization rate* (UR): the rate of urban population to total population is employed to evaluate the urbanization rate (Song et al., 2021).

The descriptive statistics in the regression model are shown in Table 2.

Table 2. Descriptive statistics in the regression model

Variable	Abbr.	Obs.	Mean	S. D.	Min	Max
Green innovation efficiency	GIE	450	0.425	0.207	0.073	1
Green R&D efficiency	GRDE	450	0.478	0.245	0.089	1
Green achievement transformation efficiency	GATE	450	0.434	0.313	0.018	1
Local environmental regulation	ER	450	1	0.194	0.243	1.474
Neighborhood environmental regulation	NER	450	0.001	0.001	0.001	0.003
Strategic synergy of environmental regulations	SSER	450	0.647	0.195	0.102	1
Industrial transfer	IT	450	0.033	0.037	0.001	0.154
Education level	EL	450	0.001	0.001	0	0.003
Freight volume	FV	450	11.367	0.862	8.827	12.981
Trade openness	TP	450	6.209	1.446	2.079	9.880
Economy development level	EDL	450	10.461	0.654	8.528	12.009
Urbanization rate	UR	450	0.540	0.139	0.269	0.896

3.3 Methods

3.3.1 Network Slack-based measure model

The traditional DEA method considers the green innovation activity as an unobservable black box. When measuring innovation efficiency, it does not regard the inner structure of innovation activities, nor the innovation resource allocation in two stages, so it cannot reflect the actual situation of innovation activities (Zhang et al., 2021). In fact, innovation activities are a complex system composed of many interconnected sub-decision-making units (Sub-DMUs) (Färe et al., 2007). In addition, the most of traditional DEA models are radial-based models, which assume the inputs and output change in the same proportion. It does not accommodate the slack inputs and outputs (slack means input excesses or output shortages), thus, these methods do not provide an accurate efficiency evaluation (Keskin, 2021).

To solve the above problems of the traditional DEA, according to the study of Tone and Tsutsui (2010), this study sets the Network Slack-based measure (SBM) considering the undesirable outputs to evaluate the overall efficiency and staged efficiency of green innovation of industrial firms. Unlike the traditional DEA model, this method considers the relationship between Sub-DMUs and introduces the intermediate inputs that cannot be dealt with by the traditional DEA method when evaluating innovation efficiency. Moreover, as a non-radial model, the Network SBM provides means to evaluate the efficiency together with the slack value of each input and output (Zhang et al., 2021). To sum up, compare with traditional DEA, the network SBM solves the slack problem that cannot be dealt with by the traditional method and has more discriminatory power to evaluate the efficiency of DMUs.

Suppose there are J DMUs ($J=1, 2, 3, ..., j$), with each having two Sub-DMUs. Each DMU has five factors: A inputs (A=1, 2, 3, …, a), M intermediate outputs (M=1, 2, 3, …, m), B intermediate inputs (B=1, 2, 3, …, b), N desirable outputs (N=1, 2, 3, …, n), and Q undesirable outputs (Q=1, 2, 3, …, q).

The overall efficiency of DMU can be evaluated as follows:

$$\rho = min \frac{w^1\left[1-\frac{1}{A}(\sum_{a=1}^{A}\frac{s_a^-}{x_{ao}^1})\right]+w^2\left[1-\frac{1}{B}(\sum_{b=1}^{B}\frac{s_b^-}{x_{bo}^2})\right]}{w^1\left[1+\frac{1}{M}(\sum_{m=1}^{M}\frac{s_m^+}{y_{mo}^1})\right]+w^2\left[1+\frac{1}{N+Q}(\sum_{n=1}^{N}\frac{s_n^+}{y_{no}^2}+\sum_{q=1}^{Q}\frac{s_q^-}{y_{qo}^2})\right]} \quad \text{(Formula 6)}$$

s. t.

$$\sum_{a=1}^{A} \lambda_j^1 \times x_{aj} + s_a^- = x_{ao}$$

$$\sum_{m=1}^{M} \lambda_j^1 \times y_{mj} - s_m^+ = y_{mo}$$

$$\sum_{b=1}^{B} \lambda_j^2 \times x_{bj} + s_b^- = x_{bo}$$

$$\sum_{n=1}^{N} \lambda_j^2 \times y_{nj} - s_n^+ = y_{no}$$

$$\sum_{q=1}^{Q} \lambda_j^2 \times y_{qj} + s_q^- = y_{qo}$$

$$\lambda_j^1 \geq 0, \lambda_j^2 \geq 0, j = 1,2, \dots, J$$

$$s_a^- \geq 0, a = 1,2, \dots, A$$

$$s_m^+ \geq 0, m = 1,2, \dots, M$$

$$s_b^- \geq 0, b = 1,2, \dots, B$$

$$s_n^+ \geq 0, n = 1,2, \dots, N$$

$$s_q^- \geq 0, q = 1,2, \dots, Q$$

where, x_a^1 and x_b^2 are input and intermediate input; y_m^1 is intermediate output, y_n^2 is desirable output, y_q^2 is undesirable output; w^1 and w^2 are the weight for each Sub-DMU, and $w^1 + w^2 = 1$; λ_j represents the weight for inputs and outputs in each Sub-DMUs; s_a^- , s_m^+, s_b^- , s_n^+ , s_q^- are slacks denoting input excess, intermediate output shortfall, intermediate input excess, desirable output shortfall, and undesirable output excess.

The efficiency of Sub-DMU can be evaluated by ρ^1 and ρ^2, calculated as Formula 2 and Formula 3.

$$\rho^1 = min\frac{1-\frac{1}{A}\sum_{a=1}^{A}\frac{s_a^-}{x_{ao}^1}}{1+\frac{1}{M}\sum_{m=1}^{M}\frac{s_m^+}{y_{mo}^1}} \quad \text{(Formula 7)}$$

$$\rho^2 = min\frac{1-\frac{1}{B}\sum_{b=1}^{B}\frac{s_b^-}{x_{bo}^2}}{1+\frac{1}{N+Q}(\sum_{n=1}^{N}\frac{s_n^+}{y_{no}^2}+\sum_{q=1}^{Q}\frac{s_q^-}{y_{qo}^2})} \quad \text{(Formula 8)}$$

3.3.2 Tobit regression model

(1) Basic regression model

This research adopts the Tobit regression model to examine the roles of local environmental regulation (ER) and strategic synergy of local-neighborhood environmental regulations (SSER), considering it has the advantage when the explained variable is restricted. The particularity of this method is consistent with characteristics of green innovation efficiency between 0 and 1, as evaluated by the SBM method. The basic regression model is constructed as follows:

$$GIE_{i,t} = \beta_0 + \beta_1 ER_{i,t} + \beta_2 X_{i,t} + \varepsilon_{i,t} \quad \text{(Formula 9)}$$

In this model, $GIE_{i,t}$ reflects the green innovation efficiency of industrial firms in province *i* in the year of *t*. $ER_{i,t}$ refers to ER in province *i* in the year of *t*. *X* represents the control variables. $\varepsilon_{i,t}$ is the random error.

Moreover, this study constructs a non-linear model to examine the influence of SSER on green innovation efficiency. The Formula is shown in Formula 10.

$$GIE_{i,t} = \beta_0 + \beta_1 SSER_{i,t} + \beta_2 SSER_{i,t}^2 + \beta_3 X_{i,t} + \varepsilon_{i,t} \quad \text{(Formula 10)}$$

(2) The test of mediation effect

To further verify the influence mechanism of local ER and SSER on green innovation efficiency from the Porter hypothesis and pollution haven hypothesis, this study takes industrial transfer (IT) as a mediator and adopts the causal step approach to test the mediation effect. The test models are shown in following

Formulas (11), (12), and (13) are used to analyze the mediation effect of industrial transfer between local ER and green innovation efficiency. According to the causal step approach, Formula (11) aims to test the total effect of the explanatory variable on the explained variable, if the β_1 is significant, the total effect of the explanatory variable also significant; Formula (12) mainly examines the significance of α_1, if significant, go to the next step; Formula (13) aims to analyze the significance of γ_1 and γ_2. γ_2 significant means that the mediation effect exists. The significance of γ_1 determines the type of mediating effect, if significant, the mediation variable plays a partial mediation role and the proportion of mediation effect is $\frac{\alpha_1 \times \gamma_2}{\beta_1}$, if not significant, the mediation variable plays a full mediation role.

There is also a special case where the sign of $\alpha_1 \times \gamma_2$ and β_1 is opposite, meaning that the mediating variable plays a suppression effect on the relationship between explanatory and explained variables (MacKinnon et al., 2000), and the proportion of suppression effect is $\left|\frac{\alpha_1 \times \gamma_2}{\beta_1}\right|$.

$$GIE_{i,t} = \beta_0 + \beta_1 ER_{i,t} + \beta_2 X_{i,t} + \varepsilon_{i,t} \qquad \text{(Formula 11)}$$

$$IT_{i,t} = \alpha_0 + \alpha_1 ER_{i,t} + \alpha_2 X_{i,t} + \varepsilon_{i,t} \qquad \text{(Formula 12)}$$

$$GIE_{i,t} = \gamma_0 + \gamma_1 ER_{i,t} + \gamma_2 IT_{i,t} + \gamma_3 X_{i,t} + \varepsilon_{i,t} \qquad \text{(Formula 13)}$$

Formulas (14), (15), and (16) are used to analyze the mediation effect of industrial transfer between SSER and green innovation efficiency. Considering the non-linear effect of SSER, the test approach mediation effect is slightly different from Formula

(11) to Formula (13) (Hayes and Preacher, 2010). Formula (14) aims to test the significance of β_2, if significant, the non-linear total effect of explanatory variable also significant; Formula (15) examine the significant of α_1; Formula (16) mainly tests the significance of γ_2 and γ_3, if γ_3 is significant, the mediation effect exists. The significance of γ_2 also determines the type of mediating effect. If partial mediation effect, the proportion is $\frac{\alpha_1 \times \gamma_2}{\beta_1 + \beta_2 SSER}$, it can be seen from this that if the total effect is nonlinear, the proportion of the mediation effect is not a constant, but a variable that changes with the change of the explanatory variable.

Also, if the mediator plays a suppression role, the proportion is $\left|\frac{\alpha_1 \times \gamma_2}{\beta_1 + \beta_2 SSER}\right|$.

$$GIE_{i,t} = \beta_0 + \beta_1 SSER_{i,t} + \beta_2 SSER_{i,t}^2 + \beta_3 X_{i,t} + \varepsilon_{i,t} \quad \text{(Formula 14)}$$

$$IT_{i,t} = \alpha_0 + \alpha_1 SSER_{i,t} + \alpha_2 X_{i,t} + \varepsilon_{i,t} \quad \text{(Formula 15)}$$

$$GIE_{i,t} = \gamma_0 + \gamma_1 SSER_{i,t} + \gamma_2 SSER_{i,t}^2 + \gamma_3 IT_{i,t} + \gamma_4 X_{i,t} + \varepsilon_{i,t} \quad \text{(Formula 16)}$$

4. Results

4.1 Evaluation results of green innovation efficiency of industrial firms

Based on the constructed network SBM model, this study used Lingo 17.0 software to evaluate the overall and staged efficiency of green innovation in China's industrial firms from 2005 to 2019. The evaluation results are shown in Figure 3 and Table A1 (in the Appendix section). Besides, to comprehensively reflect the regional difference in innovation efficiency, this study divided the samples into three regions of eastern, central, and western regions. The green innovation efficiency of these regions is presented in Figure 4.

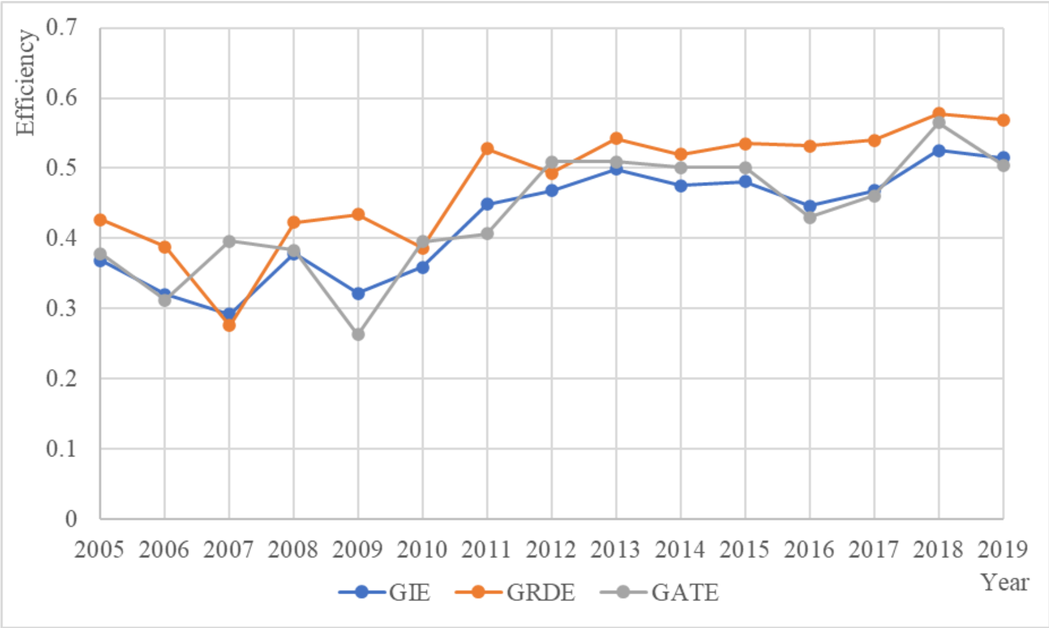

Figure 3. The overall and staged efficiency of green innovation of industrial firms

On the whole, the overall and staged efficiency of green innovation show an upward trend in fluctuations in the sample period. According to the changing trend of efficiency, this study divided the sample period into two stages, that is, 2005-2011 and 2012-2019. First, from 2005 to 2011, the overall and staged efficiency show greatly fluctuated, and the GIE and GRDE reach the lowest value in 2007 (0.292 and 0.276, respectively); Secondly, starting from 2012, the overall and staged efficiency begin to gradually increase, and reach the highest value in 2018 (0.525, 0.578 and 0.565, respectively). Although the overall and staged efficiency of green innovation activities show an upward trend in recent years, it still has great potential for improvement, especially, in green achievement transformation efficiency.

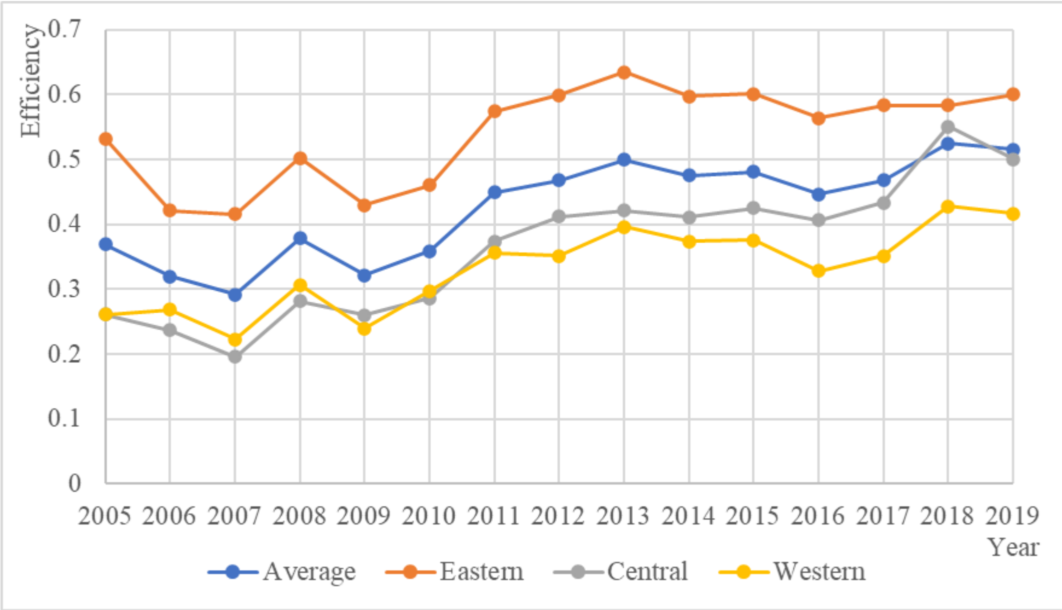

Figure 4. The GIE of industrial firms in different regions

Moreover, the green innovation efficiency reflects a significant regional difference, as shown in Figure 4. Specifically, the innovation efficiency of different regions shows the "the east > the center > the west" trend. This finding certainly agrees with reality. The possible reason is that the provinces in the central and western regions lag far behind the provinces in the eastern region in terms of economic development, infrastructure construction, human capital level, and good innovation policy, which cannot attract skilled talent and qualified firms, lead to lower innovation efficiency. Also, it can be seen that the innovation efficiency of each region has an overall increasing trend, but still has huge room for improvement.

4.2 Regression results

4.2.1 The results of the basic regression model

To examine the influence of local environmental regulation (ER) and strategic synergy of local-neighborhood environmental regulations (SSER) on the green innovation efficiency of industrial firms, this study utilized the Tobit regression model to empirically analyze. The Stata 16.0 software is used in this process. The regression results are reported in Table 3. It can be seen that the LR $\chi2$ of all models is significant at 99%, implying that these models meet the requirement of the significance test.

Table 3. The analysis results of the Tobit regression model

Variable	GIE	GRDE	GATE	GIE	GRDE	GATE
ER	0.10185** (2.25)	0.16000** (2.24)	0.02639 (0.32)	-	-	-
SSER	-	-	-	-0.56573*** (-3.12)	-0.52625* (-1.80)	-0.86697*** (-2.62)
$SSER^2$	-	-	-	0.37213** (2.65)	0.31312 (1.39)	0.61424** (2.37)
Cons_	1.32444*** (3.23)	1.81211*** (2.74)	0.35363 (0.38)	1.32222*** (3.23)	1.88559*** (2.82)	0.50587 (0.64)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
LR χ^2	321.84***	157.08***	160.39***	333.71***	157.16***	169.55***
Likelihood	334.93	92.06	22.94	338.68	92.46	26.61

*Note: *, **, and *** represent the 10%, 5%, and 1% significance levels, respectively.*

As the Table 3, the local ER has a significant and positive influence on green innovation ($\beta = 0.10185$, $p < 0.05$), which supports Hypothesis 1. Specifically, the efficiency of green R&D stage also affected by local ER ($\beta = 0.16000$, $p < 0.05$), but the efficiency of green achievement transformation stage not ($\beta = 0.02639$, $p > 0.10$).

In addition, the SSER has a U-shaped effect on green innovation, which supports Hypothesis 2. Specifically, the impact of SSER on the efficiency of the green R&D stage is negative linear and the efficiency of the green achievement transformation stage is U-shaped.

4.2.2 Robustness analysis

To ensure the robustness of the research results, this study replaced the panel Tobit regression model with OLS regression to re-estimate Formula 9 and Formula 10. The estimation results are reported in Table 4. It can be found from re-regression results by the OLS method, the coefficients of the main explanatory variables are similar to estimation results analyzed by the panel Tobit regression model, except for the slight difference in the size and significance of coefficients. It implies that the re-estimation results are strong robustness.

Table 4. The results of the robustness analysis

Variable	GIE	GRDE	GATE	GIE	GRDE	GATE
ER	0.11281*** (2.56)	0.14970** (2.32)	0.02643 (0.37)	-	-	-
SSER	-	-	-	-0.60053*** (-3.31)	-0.54851*** (-2.06)	-0.78022*** (-2.69)
$SSER^2$	-	-	-	0.39257*** (2.78)	.33537 (1.62)	0.54469*** (2.42)
Cons_	1.35077*** (3.38)	1.78865*** (3.00)	0.24043 (0.37)	1.34113*** (3.38)	1.90866 (3.21)	0.27968 (0.43)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Within R^2	0.408	0.293	0.245	0.447	0.284	0.261

*Note: *, **, and *** represent the 10%, 5%, and 1% significance levels, respectively.*

4.3 Analysis of influence mechanism

Although the above estimation results show that local environmental regulation (ER) can greatly improve the green innovation efficiency of industrial firms, the pollution haven hypothesis reveals another possible choice for the firm facing strict ER, that is, transferring into other regions with a loose policy environment. Thus, this study took the industrial transfer as the mediator to examine the impact mechanism of local

ER on green innovation activities of industrial firms. Further, as an efficient tool to promote green innovation under the context of Chinese-style decentralization, the SSER is also discussed as the influence channel for enhancing innovation efficiency in this section. The regression results are shown in Table 5.

Table 5. Analysis of impact mechanism: The mediating role of industrial transfer

	IT	GIE		GRDE		GATE	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ER	-0.00471* (-1.74)	0.10185** (2.25)	0.10740** (2.38)	0.16000** (2.24)	0.16873** (2.37)	0.02639 (0.32)	0.02605 (0.32)
IT	-	-	1.02851* (1.79)	-	1.94531** (1.99)	-	-0.06373 (-0.06)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LR χ^2	184.46***	321.84***	328.57***	157.08***	162.27***	160.39***	160.37***
Log Likelihood	1590.94	334.93	336.54	92.06	94.08	22.94	22.94
	IT	GIE		GRDE		GATE	
	(8)	(9)	(10)	(11)	(12)	(13)	(14)
SSER	0.00442* (1.79)	-0.56573*** (-3.12)	-0.60745*** (-3.34)	-0.52625* (-1.80)	-0.58677** (-1.99)	-0.86697*** (-2.62)	-0.87548*** (-2.63)
$SSER^2$	-	0.37213** (2.65)	0.39684*** (2.83)	0.31312 (1.39)	0.34901 (1.55)	0.61424** (2.37)	0.61918** (2.39)
IT	-	-	1.21732** (2.16)	-	2.05967** (2.17)	-	0.28475 (0.26)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LR χ^2	184.78***	333.71***	343.48***	157.16***	163.41***	169.55***	169.74***
Log Likelihood	1591.03	338.68	341.01	92.46	94.83	26.61	26.65

It can be clearly seen from Column (1) in Table 5, the local ER has a significant and negative influence on industrial transfer (into other regions). In other words, facing strict local regulation, many firms may choose to transfer to other regions to avoid more environmental governance costs. Column (2) in Table 5 reflects the total effect of local ER on green innovation efficiency. Column (3) in Table 5 shows the positive influence of local ER and industrial transfer (transfer into local).

Integrating of results shown in Columns (1) to (3) in Table 5, it can be found that the industrial transfer plays a partial mediation role in the local ER and green innovation efficiency, and the proportion of mediation effect on total effect is 4.76%. It supports Hypothesis 3. That is, the influence of local ER can be divided into two aspects, on the one hand, the local ER can exert direct pressure on the firm to improve its innovation, on the other hand, it can also indirectly inhibit efficiency improvement by promoting industrial transfer (into the neighborhood) of local firms. The case (direct influence is positive but indirect influence is negative) is also known as the suppressing effect. This finding verifies that the Porter effect and pollution haven effect co-exist in China market.

Moreover, Column (8) in Table 5 reflects the positive role of the strategic synergy of local-neighborhood environmental regulations (SSER) on industrial transfer (into the neighborhood). Column (9) in Table 5 reflects that the total effect of SSER on green innovation efficiency is U-shaped, which verifies Hypothesis 2. Column (10) in Table 5 shows the positive impact of industrial transfer and the U-shaped impact of strategic synergy on green innovation efficiency.

Integrating the results shown in Column (8) to (10) in Table 5, it can be clearly found that the SSER not only directly improves the green innovation efficiency but also indirectly enhance efficiency by inhibiting the firm's behavior transferring into other areas with loose ER. This finding confirms Hypothesis 4, indicating that when local and neighboring ERs tend to be consistent, firms will not choose to transfer into the neighborhood to avoid local ER. In addition, due to the total effect of SSER being non-linear, the proportion of the mediation effect of the industrial transfer is not constant but varies with the degree of strategic synergy.

In addition, Columns (1), (4), and (5) in Table 5 show the mediation role of industrial transfer between local ER and green R&D efficiency but are not hypothesized. According to Columns (1), (6), and (7) in Table 5, the mediator of industrial transfer between local regulation and green achievement transformation efficiency is not significant. From Columns (8), (11), and (12) in Table 5, this study finds that the total and direct effect of SSER on green R&D efficiency is linear and negative, but the indirect effect is positive. Finally, Columns (8), (13), and (14) in Table 5 reflect that the indirect effect of strategic synergy on green achievement transformation efficiency is not significant, but the direct effect.

5. Discussion

5.1 Green innovation efficiency of industrial firms

According to innovation chain theory, this study divided the firm's green innovation activities into the green R&D stage and green achievement transformation stage and used the data of Chinese industrial firms from 2015 to 2019 to evaluate the efficiency of whole innovation activities and sub-stage. In this process, the network slack-based measure method considering undesirable output is used to evaluate efficiency. This study found some interesting and thought-provoking results.

First, this study found that although the green innovation efficiency of industrial firms shows an upward trend in fluctuations in the sample period, it still has great room for enhancement. This result is also supported by the study of Zhu et al. (2021). This finding reflects that the development modes of industrial firms are gradually being transformed into sustainable development (Gupta et al., 2021; Ogbeibu et al., 2022). For industrial firms, fulfilling environmental responsibilities and promoting green innovation are the key path to obtaining sustainable advantages in this era of serious environmental problems (Jabbour et al., 2015).

Second, industrial firms show weak achievement transformation capability, that is, the green achievement transformation efficiency is always low than the green R&D efficiency. This finding indicates that the low efficiency of the achievement transformation stage is the key factor in weakening the overall efficiency of green innovation activities. Moreover, this finding is different from (Wang et al., 2016) and (Wang et al., 2021). One possible reason is that the market maturity of new technologies and products is too low, and difficult to meet the practice demands of industrial firms. For industrial firms, pursuing economic benefit is a primary task in business activities, which results in they will not adopting technical achievements with higher practice costs, even though these achievements are very environmentally friendly (Tang et al., 2018).

Third, green innovation efficiency has significant regional differences, that is, the innovation efficiency of industrial firms in the eastern region is far higher than in the central and western regions. Generally, environmental preservation is related to regional economic development to some extent (Zhang and Li, 2021). For central and western regions with less developed industrial economies, the primary task of local government is developing the economy but not protecting the environment. Conversely, the eastern region has gone through a period of extensive economic development, and is now starting to improve environmental quality and reduce pollution emissions, and aim to realize the coordinated development of the economy and environment through adjusting the industrial structure and introducing green technology (Xie et al., 2017).

5.2 The influence and mechanism of local environmental regulations on green innovation efficiency

Based on the results of efficiency evaluation, this study further examines whether local environmental regulation (ER) can improve the green innovation efficiency of industrial firms, and force firms to transfer into other regions with loose regulation employing the Tobit regression model.

First, in terms of total effect analysis, this study found that the local ER can improve the green innovation efficiency of industrial firms. This finding is consistent with Wang et al. (2022) and Luo et al. (2021). Given the mandatory nature of ER, firms must make changes such as technological innovation to reduce pollution (Cai and Ye, 2022) and avoid administrative penalties (Guo and Yuan, 2020).

Second, in terms of indirect effect analysis, this study revealed that the local ER also plays a suppressing role in green innovation efficiency by forcing industrial firms to transfer to other regions with loose regulations. This finding has wide support for the pollution haven hypothesis, but also some unexpected findings. On the one hand, this finding implies that the local strict ER will cause some local firms to transfer to other regions, especially in neighboring regions with lower regulations, to avoid the additional environmental cost (Chen et al., 2019). For firms, the increasing strictness of local ER means that they will face additional expenses to control pollution emissions and implement green innovation (Zhao et al., 2020). This forces some weaker firms to choose industrial transfer. On the other hand, this finding also indicates the behaviors that firms located in other regions transfer into the local region are conducive to improving the green innovation efficiency of local industrial firms. According to innovation diffusion theory, green innovation largely depends on the exchange of knowledge, talents, and technologies (Wang and Yang, 2022). Therefore, a possible reason is that such industrial transfer behavior results in industrial agglomeration, and breaks the communication obstacle between firms, which in turn greatly reduces the innovation cost and enhances the innovation efficiency.

5.3 The influence mechanism of strategic synergy between local-neighborhood environmental regulations on green innovation efficiency

Further, this study examined whether and how the strategic synergy between local-neighborhood environmental regulations (SSER) can improve the green innovation efficiency of industrial firms based on the Tobit regression model. The results are novel and have been rarely discussed by prior literature.

First, in terms of total effect analysis, this study discerned the influence of SSER on the green innovation efficiency of industrial firms is U-shaped. It is in line with our conjecture, but not consistent with the conclusion of the study based on the game theory of Deng et al. (2019) that argued the influence of SSER on green innovation efficiency is expected as linear and positive. The results of this study can be explained by that SSER cannot emanate the selection effect like local ER to mask the low innovation efficiency caused by compliance cost in the short term, because the firm's behavior transferring into the neighborhood is restrained. Specifically, in the short term, firms cannot transfer to other regions when local and neighborhood ERs tend to be consistent, the high pollution governance cost of firms crowd out innovation expenditure and leads to inefficiency of innovation activities; in the long term, the SSER can emanate compensation effect for innovation activities of industrial firms to offset the additional cost, thus improve innovation efficiency.

Second, in terms of indirect effect analysis, this study revealed the influence mechanism of SSER on the green innovation efficiency of industrial firms. As expected, the influence of SSER on green innovation efficiency is partially mediated by inhibiting the behavior of firms transferring into other regions. On the one hand, the results indicate that the high level of SSER inhibits industrial transfer behavior (into the neighborhood) of firms because it cannot achieve the purpose of reducing the compliance cost of firms. On the other hand, the results confirm the behavior of firms located in other regions transferring into the local region is a positive factor to improve the green innovation efficiency of local industrial firms. This also has been discussed in the last section from the perspective of industrial agglomeration.

6. Conclusion, implications, and limitations

6.1 Main conclusion

Although environmental regulation (ER) is an essential means to improve green innovation efficiency and realize sustainable development, it may not play the desired effect in the context of Chinese-style decentralization. Facing strict local ER, the firms can avoid this pressure by transferring to other regions with loose regulations. In this case, the strategic synergy between local-neighborhood environmental regulations (SSER) can be expected as an efficient tool to solve this environmental governance dilemma, despite little literature providing empirical evidence to confirm this view.

To fill the above knowledge gap, this study takes the Chinese industrial firms from 2005 to 2019 as a typical research object and uses it to explore the role of SSER for industrial firms in improving green innovation efficiency. First, the network SBM method is used to evaluate the green innovation efficiency of industrial firms, the results show that the firm’s innovation efficiency still has great room for improvement, and the inefficiency of the green achievement transformation stage is the internal cause for hindering innovation efficiency improvement. Second, the Tobit regression model is used to explore the role of local ER on the green innovation efficiency of industrial firms, the results show that although the total effect of local ER on innovation efficiency is positive, the indirect effect of ER on innovation efficiency through industrial transfer is negative. That is, local ER can exert a negatively indirect effect on innovation efficiency by forcing industrial firms to transfer to other regions with loose policy environments. Finally, this study reveals that the SSER not only directly improves the firm's green innovation efficiency but also indirectly improves by inhibiting the behavior of industrial firms transferring into other regions.

6.2 Theoretical contributions

This study provides some theoretical contributions to existing literature. This study explores the effectiveness of the SSER in improving the green innovation efficiency of industrial firms, which is a helpful trial to extend the research field of the Porter hypothesis and the Pollution haven hypothesis. Theoretically, the SSER can effectively restrict industrial transfer even pollution transfer emanated by regional differences of ER, and promote firms to implement green innovation; but little research has hitherto analyzed the strategic synergy which leaves little understanding of its importance. Therefore, this study acknowledges the active role of local ER but also emphasizes that the strategic synergy between local and neighbor governments can play a more important effect. In this case, this study encourages further research to consider the role of the SSER, and develop further analysis.

6.3 Managerial implications

Moreover, this study also provides many practical implications to industry practitioners and policymakers. For industry practitioners, it is necessary to enhance the firm's achievement transformation capability. According to the results of this study, the inefficiency of the green achievement transformation stage is the main reason for restricting the improvement of green innovation efficiency. Therefore, this study suggests industrial practitioners pay more attention to the management and transformation of technical achievements such as green products and technologies to overcome the above dilemma. On the one hand, industrial practitioners should deeply study the pain points and difficulties faced by the market and firm before formulating innovation plans, thus ensuring that their green innovation achievement meets the firm's actual needs. On the other hand, industrial practitioners should positively purchase the green technology that is needed in their production practice to reduce pollution emissions and energy consumption through technology trading platforms.

For local governments, it is suggested to increase the fiscal expenditures to promote firms implementing green innovation and construct technology trading platforms to accelerate the technology transaction and achievement transformation across firms. In addition, the policymakers of local governments should also continuously improve their environmental policy system to remedy market failures and force firms to enhance green innovation efficiency. For the central government, the environmental governance dilemma emanating from regional differences in ER seriously restricts the process of their sustainable development strategy. Therefore, it is suggested for policymakers of the central government construct a coordination mechanism involving multi-regional common environmental governance from a holistic perspective. Such as, promoting regional governments to sign cooperation agreements on collaborative environmental governance or establishing cooperative institutions, focusing on forcing regional governments to jointly formulate ER to tackle cross-regional environmental pollution problems and improve the green innovation efficiency of industrial firms.

6.4 Limitations

Inevitably, this study still has some limitations that could inspire future related studies. For instance, given the data availability, the choice of agent variable for industrial transfer is limited. With increasingly more firm statistical data to be released, the future study can integrate more accurate agent variables for industrial transfer into the empirical model for a more comprehensive and reasonable analysis. In addition, given the significant gaps in economic development across different cities within a province, the relationship between ER and green innovation activities of industrial firms may differ across cities. Therefore, it is significant and reasonable to discuss the relationship of these indicators for different cities when prefecture-level data become available. Comparing the use of province-level data, the use of prefecture-level data could enhance the explanatory power of the empirical model of the significant increase in sample size.

Reference

Awan, U., Kraslawski, A., and Huiskonen, J., 2018. The Impact of Relational Governance on Performance Improvement in Export Manufacturing Firms. *Journal of Industrial Engineering and Management*, 11, 349-370. https://doi.org/10.3926/jiem.2558.

Awan, U., and Sroufe, R., 2022. Sustainability in the Circular Economy: Insights and Dynamics of Designing Circular Business Models. *Applied Sciences*, 12. https://doi.org/10.3390/app12031521.

Besley, T., and Coate, S., 2003. Centralized Versus Decentralized Provision of Local Public Goods: A Political Economy Approach. *Journal of Public Economics*, 87, 2611-2637. https://doi.org/10.1016/S0047-2727(02)00141-X.

Cai, W., and Ye, P., 2021. Local-Neighborhood Effects of Different Environmental Regulations on Green Innovation: Evidence from Prefecture Level Cities of China. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-01635-2.

Cai, W., and Ye, P., 2022. Does Carbon Emission Trading Improve Low-Carbon Technical Efficiency? Evidence from China. *Sustainable Production and Consumption*, 29, 46-56. https://doi.org/10.1016/j.spc.2021.09.024.

Cai, X., Lu, Y., Wu, M., and Yu, L., 2016. Does Environmental Regulation Drive Away Inbound Foreign Direct Investment? Evidence from a Quasi-Natural Experiment in China. *Journal of Development Economics*, 123, 73-85. https://doi.org/10.1016/j.jdeveco.2016.08.003.

Chen, J.-X., Zhang, Y., and Zheng, S., 2019. Ecoefficiency, Environmental Regulation Opportunity Costs, and Interregional Industrial Transfers: Evidence from the Yangtze River Economic Belt in China. *Journal of Cleaner Production*, 233, 611-625. https://doi.org/10.1016/j.jclepro.2019.06.117.

Combes, P.-P., Duranton, G., Gobillon, L., Puga, D., and Roux, S., 2012. The Productivity Advantages of Large Cities: Distinguishing Agglomeration from Firm Selection. *Econometrica*, 80, 2543-2594. https://doi.org/10.3982/ECTA8442.

Cui, J., and Moschini, G., 2020. Firm Internal Network, Environmental Regulation, and Plant Death. *Journal of Environmental Economics and Management*, 101, 102319. https://doi.org/10.1016/j.jeem.2020.102319.

D'Amato, A., Mazzanti, M., Nicolli, F., and Zoli, M., 2018. Illegal Waste Disposal: Enforcement Actions and Decentralized Environmental Policy. *Socio-Economic Planning Sciences*, 64, 56-65. https://doi.org/10.1016/j.seps.2017.12.006.

Deng, H., Zheng, X., Huang, N., and Li, F., 2012. Strategic Interaction in Spending on Environmental Protection: Spatial Evidence from Chinese Cities. *China & World Economy*, 20, 103-120. https://doi.org/10.1111/j.1749-124X.2012.01304.x.

Deng, Y., You, D., and Wang, J., 2019. Optimal Strategy for Enterprises' Green Technology Innovation from the Perspective of Political Competition. *Journal of Cleaner Production*, 235, 930-942. https://doi.org/10.1016/j.jclepro.2019.06.248.

Dong, Z., He, Y., Wang, H., and Wang, L., 2020. Is There a Ripple Effect in Environmental Regulation in China? – Evidence from the Local-Neighborhood Green Technology Innovation Perspective. *Ecological Indicators*, 118, 106773. https://doi.org/10.1016/j.ecolind.2020.106773.

Dou, J., and Han, X., 2019. How Does the Industry Mobility Affect Pollution Industry Transfer in China: Empirical Test on Pollution Haven Hypothesis and Porter Hypothesis. *Journal of Cleaner Production*, 217, 105-115. https://doi.org/10.1016/j.jclepro.2019.01.147.

Du, K., Cheng, Y., and Yao, X., 2021. Environmental Regulation, Green Technology Innovation, and Industrial Structure Upgrading: The Road to the Green Transformation of Chinese Cities. *Energy Economics*, 98, 105247. https://doi.org/10.1016/j.eneco.2021.105247.

Du, X., Guo, H., Zhang, H., Peng, W., and Urpelainen, J., 2020. Cross-State Air Pollution Transport Calls for More Centralization in India's Environmental Federalism. *Atmospheric Pollution Research*, 11, 1797-1804. https://doi.org/10.1016/j.apr.2020.07.012.

Dwivedi, A., Moktadir, M. A., Jabbour, C. J. C., and de Carvalho, D. E., 2022. Integrating the Circular Economy and Industry 4.0 for Sustainable Development: Implications for Responsible Footwear Production in a Big Data-Driven World. *Technological Forecasting and Social Change*, 175, 121335. https://doi.org/10.1016/j.techfore.2021.121335.

Espínola-Arredondo, A., and Muñoz-García, F., 2013. When Does Environmental Regulation Facilitate Entry-Deterring Practices. *Journal of Environmental Economics and Management*, 65, 133-152. https://doi.org/10.1016/j.jeem.2012.06.001.

Färe, R., Grosskopf, S., and Whittaker, G., 2007. Network Dea, in: J. Zhu and W.D. Cook (Eds.), Modeling Data Irregularities and Structural Complexities in Data Envelopment Analysis. Springer US, Boston, MA, pp. 209-240.

Fu, S., Ma, Z., Ni, B., Peng, J., Zhang, L., and Fu, Q., 2021. Research on the Spatial Differences of Pollution-Intensive Industry Transfer under the Environmental Regulation in China. *Ecological Indicators*, 129, 107921. https://doi.org/10.1016/j.ecolind.2021.107921.

Galinato, G. I., and Chouinard, H. H., 2018. Strategic Interaction and Institutional Quality Determinants of Environmental Regulations. *Resource and Energy Economics*, 53, 114-132. https://doi.org/10.1016/j.reseneeco.2018.04.001.

Ge, T., Qiu, W., Li, J., and Hao, X., 2020. The Impact of Environmental Regulation Efficiency Loss on Inclusive Growth: Evidence from China. *Journal of Environmental Management*, 268, 110700. https://doi.org/10.1016/j.jenvman.2020.110700.

Guo, R., and Yuan, Y., 2020. Different Types of Environmental Regulations and Heterogeneous Influence on Energy Efficiency in the Industrial Sector: Evidence from Chinese Provincial Data. *Energy Policy*, 145, 111747. https://doi.org/10.1016/j.enpol.2020.111747.

Gupta, H., Kumar, S., Kusi-Sarpong, S., Jabbour, C. J. C., and Agyemang, M., 2021. Enablers to Supply Chain Performance on the Basis of Digitization Technologies. *Industrial Management & Data Systems*, 121, 1915-1938. https://doi.org/10.1108/IMDS-07-2020-0421.

Hansen, M. T., and Birkinshaw, J., 2007. The Innovation Value Chain. *Harvard Business Review Home*, 85, 121-130.

Hayes, A. F., and Preacher, K. J., 2010. Quantifying and Testing Indirect Effects in Simple Mediation Models When the Constituent Paths Are Nonlinear. *Multivariate Behavioral Research*, 45, 627-660. https://doi.org/10.1080/00273171.2010.498290.

Ikram, M., Sroufe, R., Awan, U., and Abid, N., 2022. Enabling Progress in Developing Economies: A Novel Hybrid Decision-Making Model for Green Technology Planning. *Sustainability*, 14. https://doi.org/10.3390/su14010258.

Jabbour, C. J. C., Janeiro, R. C., de Sousa Jabbour, A. B. L., Junior, J. A. G., Salgado, M. H., and Jugend, D., 2020. Social Aspects of Sustainable Supply Chains: Unveiling Potential Relationships in the Brazilian Context. *Annals of Operations Research*, 290, 327-341. https://doi.org/10.1007/s10479-017-2660-7.

Jabbour, C. J. C., Jugend, D., Jabbour, A. B. L. d. S., Gunasekaran, A., and Latan, H., 2015. Green Product

Development and Performance of Brazilian Firms: Measuring the Role of Human and Technical Aspects. *Journal of Cleaner Production*, 87, 442-451. https://doi.org/10.1016/j.jclepro.2014.09.036.

Jiang, T., Ji, P., Shi, Y., Ye, Z., and Jin, Q., 2021. Efficiency Assessment of Green Technology Innovation of Renewable Energy Enterprises in China: A Dynamic Data Envelopment Analysis Considering Undesirable Output. *Clean Technologies and Environmental Policy*, 23, 1509-1519. https://doi.org/10.1007/s10098-021-02044-9.

Kattumuri, R., and Lovo, S., 2018. Decentralisation of Environmental Regulations in India. *Economic and Political Weekly*, 53, 33-38.

Keskin, B., 2021. An Efficiency Analysis on Social Prosperity: Opec Case under Network Dea Slack-Based Measure Approach. *Energy*, 231, 120832. https://doi.org/10.1016/j.energy.2021.120832.

Levinson, A., 2016. Pollution Haven Hypothesis, The New Palgrave Dictionary of Economics. Palgrave Macmillan UK, London, pp. 1-5.

Li, D., Tang, F., and Jiang, J., 2019a. Does Environmental Management System Foster Corporate Green Innovation? The Moderating Effect of Environmental Regulation. *Technology Analysis & Strategic Management*, 31, 1242-1256. https://doi.org/10.1080/09537325.2019.1602259.

Li, H.-l., Zhu, X.-h., Chen, J.-y., and Jiang, F.-t., 2019b. Environmental Regulations, Environmental Governance Efficiency and the Green Transformation of China's Iron and Steel Enterprises. *Ecological Economics*, 165, 106397. https://doi.org/10.1016/j.ecolecon.2019.106397.

Li, H., Qi, Y., Li, C., and Liu, X., 2019c. Routes and Clustering Features of Pm2.5 Spillover within the Jing-Jin-Ji Region at Multiple Timescales Identified Using Complex Network-Based Methods. *Journal of Cleaner Production*, 209, 1195-1205. https://doi.org/10.1016/j.jclepro.2018.10.284.

Li, J., and Du, Y., 2021. Spatial Effect of Environmental Regulation on Green Innovation Efficiency: Evidence from Prefectural-Level Cities in China. *Journal of Cleaner Production*, 286, 125032. https://doi.org/10.1016/j.jclepro.2020.125032.

Li, J., Tan, Q., and Bai, J., 2011. Spatial Econometric Analysis of Regional Innovation Production in China: An Empirical Study Based on Static and Dynamic Spatial Panel Models. *journal of Management World*, 43-55+65. https://doi.org/10.19744/j.cnki.11-1235/f.2010.07.006.

Li, M., Du, W., and Tang, S., 2021. Assessing the Impact of Environmental Regulation and Environmental Co-Governance on Pollution Transfer: Micro-Evidence from China. *Environmental Impact Assessment Review*, 86, 106467. https://doi.org/10.1016/j.eiar.2020.106467.

Li, W., Gu, Y., Liu, F., and Li, C., 2019d. The Effect of Command-and-Control Regulation on Environmental Technological Innovation in China: A Spatial Econometric Approach. *Environmental Science and Pollution Research*, 26, 34789-34800. https://doi.org/10.1007/s11356-018-3678-3.

Lipscomb, M., and Mobarak, A. M., 2017. Decentralization and Pollution Spillovers: Evidence from the Re-Drawing of County Borders in Brazil*. *The Review of Economic Studies*, 84, 464-502. https://doi.org/10.1093/restud/rdw023.

Liu, S., Zhu, Y., and Du, K., 2017. The Impact of Industrial Agglomeration on Industrial Pollutant Emission: Evidence from China under New Normal. *Clean Technologies and Environmental Policy*, 19, 2327-2334. https://doi.org/10.1007/s10098-017-1407-0.

Liu, Y., Zhu, J., Li, E. Y., Meng, Z., and Song, Y., 2020. Environmental Regulation, Green Technological Innovation, and Eco-Efficiency: The Case of Yangtze River Economic Belt in China.

Technological Forecasting and Social Change, 155, 119993. https://doi.org/10.1016/j.techfore.2020.119993.

Lovo, S., 2018. Effect of Environmental Decentralization on Polluting Firms in India. *Economic Development and Cultural Change*, 67, 55-94. https://doi.org/10.1086/697558.

Luo, Y., Salman, M., and Lu, Z., 2021. Heterogeneous Impacts of Environmental Regulations and Foreign Direct Investment on Green Innovation across Different Regions in China. *Science of The Total Environment*, 759, 143744. https://doi.org/10.1016/j.scitotenv.2020.143744.

MacKinnon, D. P., Krull, J. L., and Lockwood, C. M., 2000. Equivalence of the Mediation, Confounding and Suppression Effect. *Prevention Science*, 1, 173-181. https://doi.org/10.1023/A:1026595011371.

Ogbeibu, S., Jabbour, C. J. C., Burgess, J., Gaskin, J., and Renwick, D. W. S., 2022. Green Talent Management and Turnover Intention: The Roles of Leader Stara Competence and Digital Task Interdependence. *Journal of Intellectual Capital*, 23, 27-55. https://doi.org/10.1108/JIC-01-2021-0016.

Ouyang, X., Li, Q., and Du, K., 2020. How Does Environmental Regulation Promote Technological Innovations in the Industrial Sector? Evidence from Chinese Provincial Panel Data. *Energy Policy*, 139, 111310. https://doi.org/10.1016/j.enpol.2020.111310.

Pan, X., Ai, B., Li, C., Pan, X., and Yan, Y., 2019. Dynamic Relationship among Environmental Regulation, Technological Innovation and Energy Efficiency Based on Large Scale Provincial Panel Data in China. *Technological Forecasting and Social Change*, 144, 428-435. https://doi.org/10.1016/j.techfore.2017.12.012.

Peng, H., Shen, N., Ying, H., and Wang, Q., 2021. Can Environmental Regulation Directly Promote Green Innovation Behavior?—— Based on Situation of Industrial Agglomeration. *Journal of Cleaner Production*, 314, 128044. https://doi.org/10.1016/j.jclepro.2021.128044.

Peng, X., 2020. Strategic Interaction of Environmental Regulation and Green Productivity Growth in China: Green Innovation or Pollution Refuge? *Science of The Total Environment*, 732, 139200. https://doi.org/10.1016/j.scitotenv.2020.139200.

Qiu, S., Wang, Z., and Geng, S., 2021. How Do Environmental Regulation and Foreign Investment Behavior Affect Green Productivity Growth in the Industrial Sector? An Empirical Test Based on Chinese Provincial Panel Data. *Journal of Environmental Management*, 287, 112282. https://doi.org/10.1016/j.jenvman.2021.112282.

Rexhäuser, S., and Rammer, C., 2014. Environmental Innovations and Firm Profitability: Unmasking the Porter Hypothesis. *Environmental and Resource Economics*, 57, 145-167. https://doi.org/10.1007/s10640-013-9671-x.

Shao, S., Hu, Z., Cao, J., Yang, L., and Guan, D., 2020. Environmental Regulation and Enterprise Innovation: A Review. *Business Strategy and the Environment*, 29, 1465-1478. https://doi.org/10.1002/bse.2446.

Song, M., Wang, S., and Zhang, H., 2020a. Could Environmental Regulation and R&D Tax Incentives Affect Green Product Innovation? *Journal of Cleaner Production*, 258, 120849. https://doi.org/10.1016/j.jclepro.2020.120849.

Song, M., Zhao, X., Shang, Y., and Chen, B., 2020b. Realization of Green Transition Based on the Anti-Driving Mechanism: An Analysis of Environmental Regulation from the Perspective of Resource Dependence in China. *Science of The Total Environment*, 698, 134317. https://doi.org/10.1016/j.scitotenv.2019.134317.

Song, Y., Zhang, X., and Zhang, M., 2021. The Influence of Environmental Regulation on Industrial Structure Upgrading: Based on the Strategic Interaction Behavior of Environmental Regulation among Local Governments. *Technological Forecasting and Social Change*, 170, 120930. https://doi.org/10.1016/j.techfore.2021.120930.

Tang, K., Qiu, Y., and Zhou, D., 2020. Does Command-and-Control Regulation Promote Green Innovation Performance? Evidence from China's Industrial Enterprises. *Science of The Total Environment*, 712, 136362. https://doi.org/10.1016/j.scitotenv.2019.136362.

Tang, M., Walsh, G., Lerner, D., Fitza, M. A., and Li, Q., 2018. Green Innovation, Managerial Concern and Firm Performance: An Empirical Study. *Business Strategy and the Environment*, 27, 39-51. https://doi.org/10.1002/bse.1981.

Tian, P., and Lin, B., 2018. Regional Technology Gap in Energy Utilization in China's Light Industry Sector: Non-Parametric Meta-Frontier and Sequential Dea Methods. *Journal of Cleaner Production*, 178, 880-889. https://doi.org/10.1016/j.jclepro.2018.01.017.

Tone, K., and Tsutsui, M., 2010. Dynamic Dea: A Slacks-Based Measure Approach. *Omega*, 38, 145-156. https://doi.org/10.1016/j.omega.2009.07.003.

Tseng, C.-Y., Lin, S.-C., Pai, D.-C., and Tung, C.-W., 2016. The Relationship between Innovation Network and Innovation Capability: A Social Network Perspective. *Technology Analysis & Strategic Management*, 28, 1029-1040. https://doi.org/10.1080/09537325.2016.1181739.

Wang, Q., Hang, Y., Sun, L., and Zhao, Z., 2016. Two-Stage Innovation Efficiency of New Energy Enterprises in China: A Non-Radial Dea Approach. *Technological Forecasting and Social Change*, 112, 254-261. https://doi.org/10.1016/j.techfore.2016.04.019.

Wang, S., and Yang, L., 2022. Spatial Competition, Strategic R&D and the Structure of Innovation Networks. *Journal of Business Research*, 139, 13-31. https://doi.org/10.1016/j.jbusres.2021.09.037.

Wang, X., Zhang, C., and Zhang, Z., 2019. Pollution Haven or Porter? The Impact of Environmental Regulation on Location Choices of Pollution-Intensive Firms in China. *Journal of Environmental Management*, 248, 109248. https://doi.org/10.1016/j.jenvman.2019.07.019.

Wang, X., Zhang, T., Nathwani, J., Yang, F., and Shao, Q., 2022. Environmental Regulation, Technology Innovation, and Low Carbon Development: Revisiting the Ekc Hypothesis, Porter Hypothesis, and Jevons' Paradox in China's Iron & Steel Industry. *Technological Forecasting and Social Change*, 176. https://doi.org/10.1016/j.techfore.2022.121471.

Wang, Y., Wu, D., and Li, H., 2021. Efficiency Measurement and Productivity Progress of Regional Green Technology Innovation in China: A Comprehensive Analytical Framework. *Technology Analysis & Strategic Management*, 1-17. https://doi.org/10.1080/09537325.2021.1963427.

Wang, Y., and Yu, L., 2021. Can the Current Environmental Tax Rate Promote Green Technology Innovation? - Evidence from China's Resource-Based Industries. *Journal of Cleaner Production*, 278, 123443. https://doi.org/10.1016/j.jclepro.2020.123443.

Wang, Y., and Zhao, Y., 2021. Is Collaborative Governance Effective for Air Pollution Prevention? A Case Study on the Yangtze River Delta Region of China. *Journal of Environmental Management*, 292, 112709. https://doi.org/10.1016/j.jenvman.2021.112709.

Wu, H., Hao, Y., and Ren, S., 2020. How Do Environmental Regulation and Environmental Decentralization Affect Green Total Factor Energy Efficiency: Evidence from China. *Energy Economics*, 91, 104880. https://doi.org/10.1016/j.eneco.2020.104880.

Wu, L., Yang, M., and Wang, C., 2021. Strategic Interaction of Environmental Regulation and Its

Influencing Mechanism: Evidence of Spatial Effects among Chinese Cities. *Journal of Cleaner Production*, 312, 127668. https://doi.org/10.1016/j.jclepro.2021.127668.

Xie, R.-h., Yuan, Y.-j., and Huang, J.-j., 2017. Different Types of Environmental Regulations and Heterogeneous Influence on "Green" Productivity: Evidence from China. *Ecological Economics*, 132, 104-112. https://doi.org/10.1016/j.ecolecon.2016.10.019.

Yilanci, V., Bozoklu, S., and Gorus, M. S., 2020. Are Brics Countries Pollution Havens? Evidence from a Bootstrap Ardl Bounds Testing Approach with a Fourier Function. *Sustainable Cities and Society*, 55, 102035. https://doi.org/10.1016/j.scs.2020.102035.

Yin, J., Zheng, M., and Chen, J., 2015. The Effects of Environmental Regulation and Technical Progress on Co2 Kuznets Curve: An Evidence from China. *Energy Policy*, 77, 97-108. https://doi.org/10.1016/j.enpol.2014.11.008.

Zeng, W., Li, L., and Huang, Y., 2021. Industrial Collaborative Agglomeration, Marketization, and Green Innovation: Evidence from China's Provincial Panel Data. *Journal of Cleaner Production*, 279, 123598. https://doi.org/10.1016/j.jclepro.2020.123598.

Zhang, G., Liu, W., and Duan, H., 2020. Environmental Regulation Policies, Local Government Enforcement and Pollution-Intensive Industry Transfer in China. *Computers & Industrial Engineering*, 148, 106748. https://doi.org/10.1016/j.cie.2020.106748.

Zhang, J., Ouyang, Y., Ballesteros-Pérez, P., Li, H., Philbin, S. P., Li, Z., and Skitmore, M., 2021. Understanding the Impact of Environmental Regulations on Green Technology Innovation Efficiency in the Construction Industry. *Sustainable Cities and Society*, 65, 102647. https://doi.org/10.1016/j.scs.2020.102647.

Zhang, K., Zhang, Z.-Y., and Liang, Q.-M., 2017. An Empirical Analysis of the Green Paradox in China: From the Perspective of Fiscal Decentralization. *Energy Policy*, 103, 203-211. https://doi.org/10.1016/j.enpol.2017.01.023.

Zhang, M., and Li, B., 2021. How Do R&D Inputs Affect Green Economic Development? Evidence from China. *Technology Analysis & Strategic Management*, 1-16. https://doi.org/10.1080/09537325.2021.1959030.

Zhang, W., and Li, G., 2022. Environmental Decentralization, Environmental Protection Investment, and Green Technology Innovation. *Environmental Science and Pollution Research*, 29, 12740-12755. https://doi.org/10.1007/s11356-020-09849-z.

Zhang, Y., Hu, H., Zhu, G., and You, D., 2022. The Impact of Environmental Regulation on Enterprises' Green Innovation under the Constraint of External Financing: Evidence from China's Industrial Firms. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-18712-2.

Zhang, Y., and Wang, S., 2021. Influence of Marine Industrial Agglomeration and Environmental Regulation on Marine Innovation Efficiency—from an Innovation Value Chain Perspective. *Marine Policy*, 134, 104807. https://doi.org/10.1016/j.marpol.2021.104807.

Zhao, X., Liu, C., Sun, C., and Yang, M., 2020. Does Stringent Environmental Regulation Lead to a Carbon Haven Effect? Evidence from Carbon-Intensive Industries in China. *Energy Economics*, 86, 104631. https://doi.org/10.1016/j.eneco.2019.104631.

Zhu, L., Luo, J., Dong, Q., Zhao, Y., Wang, Y., and Wang, Y., 2021. Green Technology Innovation Efficiency of Energy-Intensive Industries in China from the Perspective of Shared Resources: Dynamic Change and Improvement Path. *Technological Forecasting and Social Change*, 170, 120890. https://doi.org/10.1016/j.techfore.2021.120890.

Appendix 1

Table A1. The evaluation results of green innovation efficiency of industry enterprise from 2005 to 2019

Regions	Provinces	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	Beijing	0.6172	0.5643	1	0.9596	0.6858	0.7506	0.9230	1	1	0.9345	1	1	0.9231	1	1
	Tianjin	0.8675	0.5468	0.4172	0.7718	0.7074	0.732	0.7447	0.6558	0.7269	0.6901	0.6541	0.6636	0.5824	0.5867	0.621
	Hebei	0.2239	0.1833	0.1544	0.2267	0.1872	0.1821	0.2781	0.3211	0.3537	0.3291	0.3280	0.3172	0.3139	0.4618	0.4311
	Liaoning	0.2561	0.1866	0.1455	0.2331	0.2107	0.2376	0.3449	0.3955	0.4691	0.4411	0.4348	0.3614	0.3656	0.5467	0.4557
	Shanghai	0.8090	0.5185	0.4191	0.6235	0.7554	0.6976	0.8533	0.8416	0.8566	0.8370	0.7430	0.7291	0.7810	0.7697	0.8049
	Jiangsu	0.3795	0.2996	0.2454	0.4049	0.3172	0.3876	0.6079	0.6434	0.6292	0.6909	0.6392	0.5796	0.5838	0.6115	0.5567
Eastern	Zhejiang	0.4820	0.4072	0.3931	0.5571	0.6112	0.4372	0.697	0.8214	0.7649	0.6731	0.6384	0.5329	0.5453	0.6142	0.6059
	Fujian	0.5233	0.3523	0.2560	0.3743	0.2643	0.303	0.4312	0.4276	0.4236	0.3946	0.3978	0.3764	0.3991	0.4051	0.3905
	Shandong	0.3825	0.3227	0.2628	0.3034	0.2509	0.3783	0.4367	0.4928	0.5136	0.5105	0.4727	0.4215	0.4589	0.4353	0.4375
	Guangdong	0.5760	0.4140	0.3680	0.5066	0.6305	0.5309	0.6739	0.7186	0.7525	0.6759	0.8022	0.7919	1	1	1
	Guangxi	0.2726	0.2567	0.3268	0.3784	0.2700	0.3064	0.329	0.4126	0.5927	0.4382	0.5161	0.4734	0.5032	0.5673	0.4617
	Hainan	1	1	1	0.6880	0.2687	0.5761	0.5667	0.4532	0.5252	0.5485	0.5818	0.5216	0.5393	0.4174	0.4363
	Average	*0.5325*	*0.4210*	*0.4157*	*0.5023*	*0.4299*	*0.4600*	*0.5739*	*0.5986*	*0.6340*	*0.5970*	*0.6007*	*0.5641*	*0.5830*	*0.5833*	*0.6001*

Central	Shanxi	0.1716	0.1409	0.1347	0.1773	0.1495	0.1649	0.2244	0.2848	0.3323	0.2429	0.2559	0.2805	0.2645	0.4643	0.3821
	Inner Mongolia	0.2420	0.2116	0.1452	0.1703	0.1378	0.1528	0.1643	0.1999	0.2378	0.1884	0.2000	0.1782	0.2364	0.3732	0.3228
	Jilin	0.2930	0.3581	0.3332	0.4536	0.4396	0.3038	0.5403	0.577	0.3589	0.4038	0.3847	0.4248	0.4772	0.7400	0.8175
	Heilongjiang	0.2139	0.1786	0.1502	0.1936	0.1987	0.1714	0.1949	0.2264	0.2816	0.2532	0.2684	0.2534	0.2371	0.3556	0.3578
	Anhui	0.3254	0.2541	0.2079	0.3662	0.2778	0.5855	0.6737	0.6713	0.6429	0.6555	0.6415	0.6270	0.6950	0.6967	0.6083
	Jiangxi	0.1757	0.1586	0.1351	0.1909	0.1194	0.1760	0.2688	0.4171	0.4361	0.4416	0.4559	0.4562	0.4858	0.6085	0.5209
	Henan	0.2571	0.2293	0.1963	0.2861	0.2346	0.2075	0.2941	0.3136	0.4113	0.4039	0.4109	0.3390	0.3888	0.5364	0.3822
	Hubei	0.2860	0.2199	0.2259	0.3604	0.2865	0.3273	0.4181	0.4442	0.4847	0.4908	0.5137	0.4983	0.5309	0.6483	0.5824
	Hunan	0.3810	0.3782	0.2350	0.3425	0.4971	0.4857	0.5846	0.5702	0.6064	0.6217	0.6933	0.5952	0.5806	0.5366	0.5284
	Average	*0.2606*	*0.2366*	*0.1960*	*0.2823*	*0.2601*	*0.2861*	*0.3737*	*0.4116*	*0.4213*	*0.4113*	*0.4249*	*0.4058*	*0.4329*	*0.551*	*0.5003*
Western	Chongqing	0.5646	0.5532	0.3277	0.4572	0.5809	0.8425	0.8279	0.5739	0.5787	0.6796	0.7043	0.5773	0.5575	0.4982	0.4812
	Sichuan	0.2986	0.2766	0.2321	0.3286	0.2697	0.2929	0.4461	0.4553	0.4858	0.4981	0.4933	0.4420	0.4673	0.4351	0.4493
	Guizhou	0.2217	0.2273	0.2360	0.3045	0.1814	0.2857	0.3758	0.3607	0.3856	0.3844	0.3519	0.3305	0.3051	0.3713	0.3483
	Yunnan	0.2588	0.4281	0.3458	0.3138	0.2280	0.2384	0.3338	0.3296	0.3869	0.3686	0.3512	0.3099	0.2894	0.3648	0.3350
	Shaanxi	0.2518	0.1706	0.1706	0.2263	0.2263	0.2432	0.3072	0.3093	0.3637	0.3083	0.2849	0.2712	0.3075	0.4017	0.4164
	Gansu	0.2313	0.1913	0.1793	0.2347	0.1609	0.2231	0.3073	0.3792	0.4094	0.3783	0.3171	0.2238	0.2871	0.3400	0.3746

	Qinghai	0.2097	0.2788	0.2442	0.4713	0.1861	0.1011	0.0742	0.1076	0.1502	0.0730	0.1866	0.1993	0.3198	0.5669	0.4869
	Ningxia	0.1648	0.1673	0.1053	0.2064	0.1849	0.2308	0.2670	0.3295	0.4120	0.3035	0.3427	0.2817	0.3047	0.4237	0.3493
	Xinjiang	0.1435	0.1250	0.1672	0.2196	0.1395	0.2179	0.2685	0.3157	0.3892	0.3761	0.3555	0.3126	0.3248	0.4493	0.5116
	Average	*0.2606*	*0.2687*	*0.2231*	*0.3069*	*0.2398*	*0.2973*	*0.3564*	*0.3512*	*0.3957*	*0.3744*	*0.3764*	*0.3276*	*0.3515*	*0.4279*	*0.4170*
Average		*0.3693*	*0.3200*	*0.2920*	*0.3777*	*0.3219*	*0.3590*	*0.4486*	*0.4683*	*0.4987*	*0.4745*	*0.4807*	*0.4457*	*0.4685*	*0.5250*	*0.5152*