Do regional government green innovation preferences promote industrial structure upgradation in China? Econometric assessment based on the environmental regulation threshold effect model

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China has been upgrading the industrial structure (ISU) at the regional level through innovation to achieve socioeconomic progress, but there is less known about the complex intermediary mechanisms regulating the government's green innovation preference (GGIP)-ISU nexus from a regional perspective in China. Experts agree that varying environmental regulations (ER) intensity alters the relationship dynamics between innovation and ISU. Thus, using regional panel data (2005–2019), the paper develops an ER-based threshold regression model to assess the GGIP-ISU nexus under various ER levels in China. Following the statistically acceptable stationarity test outcomes, the regression corroborated the GGIP had disrupted ISU in China. Second, the ER-threshold model depicted that GGIP flexibility and ER rigidity were found interconnected, while the GGIP-ISU connection was characterized by a U-shaped relationship in which ER acted as a threshold variable. Third, the region-based heterogeneity test reflected that there was significant disparity in the inhibitory effect of GGIP on ISU between resource and non-resource-based regions, i.e., GGIP had a more significant inhibitory influence on the ISU in the non-resource-based regions than in the resource-based regions. The paper recommends critical policy implications for the enhancement of ISU in China.

KEYWORDS

government green innovation preference, environmental regulation, industrial structure upgrade, threshold effect, innovation, China

1 Introduction

Rapid economic progress in the emerging and developed economies has uplifted human living standards, but it has simultaneously produced ecological issues, e.g., desertification and pollution. As environmental governance issues and high economic quality have become important issues for sustainable development, many economies have optimized and upgraded their industrial structures (hereafter ISU) to accomplish sustainable development and growth. As an emerging global economy, China mainly relies on cheap labor, abundant resources, and large-scale production. China has been facing the problem of excess capacity in traditional industries and a low proportion of high-tech, low-carbon, and environmental protection industries (Ali et al., 2021; Alvarado et al., 2022; Baig et al., 2022; Hussain et al., 2022; Isik et al., 2022). Experts argue that an imbalanced industrial structure creates improper resource allocations and environmental pollution (cf. Hsieh & Klenow, 2009; Sarwar et al., 2019), posing a threat to sustainable development goals. In the 19th congress, many top Chinese Communist Party leaders emphasized the need to shift the Chinese economic growth model from high-speed to high-quality. The government has been trying to replace the traditional economic growth model of high energy consumption and pollution with an intensive economic growth model dominated by high-end manufacturing and the tertiary industry. Therefore, the central and provincial governments of China are promoting rationalization and ISU as the way forward for economic transformation. Chinese President Xi Jinping, in the Fourth Plenary Session of the 19th CPC Central Committee, stated that the innovation would promote the mechanism transformation of scientific and technological achievements by actively developing new driving forces, strengthening standardized guidance, and improving the essential capacity of the industry and the modernization of the industrial chain. Green technology innovation (GTI) is an effective way to promote the transformation of environmental governance from end-to-end governance to cleaner production and to achieve ISU (Zhong et al., 2022). Li and Zou (2018) noted that government preference for GTI could meet the practical needs of ISU and technology transformation in China. ISU is a vital way to achieve coordinated development, resource efficiency, and environmental up-gradation to address the current constraints of resources, energy, environment, and other factors. Beyond the above, ISU can enable China to manage the new domestic and international "dual-circulation" patterns while addressing the challenges of global climate change (Liao et al., 2020).

From a research viewpoint, growing global emphasis on achieving economic transformation using high-quality development has attracted significant academic focus where many studies have factors promoting ISU. Advocates of urban development recognize technological innovation (TI) and ISU as central to modern and sustainable urbanization while recognizing the role of government as critical to the whole process (e.g., Mieg, 2012; Wei et al., 2021). While Nilssen (2019) emphasized innovation typology as a critical matrix for defining smart urban cities and development, others (e.g., Pan et al., 2020) recommended inter-industry spillovers as a vital instrument for efficient urban land uses and economic prosperity. In a series of studies, Yao et al. highlighted the significance of social and innovation networks in shaping urban communities and cities (Yao et al., 2020; Yao et al., 2022). Academically, ISU is driven by different factors, including domestic enterprises (Brandt & Thun, 2010), regional innovation capability (Pickles, 2006), human capital level (Zhou, 2018), financial development (Jiang et al., 2020; Wang & Wang, 2021), economic growth (Dong et al., 2020), digital economy (Su et al., 2021), openness (He & Zeng, 2013), and environmental policies (Blair & Hite, 2005; Liu X. et al., 2021). In the development of cities, there is a coupling effect between ER, TI, and green development (Yin et al., 2022). Based on the causal inference framework of policy spillover effect, Gao and Yuan (2022) proved that the innovation intervention represented by the national innovative city pilot has a positive impact on the urban innovation performance and innovation convergence of the local and surrounding areas. Past academic view supports a close relationship between TI and green development (Zhao et al., 2019), which provides a series of theoretical bases for the relevant research in this paper. To summarize, there is a consensus among scholars that ISU and government support for innovation enable coupling, coordination, and innovative industrial development for socioeconomic development.

Therefore, many economists have mainly focused on the internal mechanisms governing the relationship between government innovation and industrial structure (Zhou & Li, 2012; Li & Lin, 2017; Zhu, 2022). Governments shape the market and drive the upgrading of enterprises through task-oriented innovation investment (TOII) and R&D subsidies (Mazzucato, 2016). The role of ISU can be traced back to Schumpeter's "innovation theory." Varum et al. (2009) used the same notion to defend that government innovation facilitates high productivity and growth in different industries to realize ISU, yet there are mixed views concerning this argument. For instance, Cai and Wang (2018) argued that government innovation stimulates industrial development by improving TI, production efficiency, and demand structure. Li and Yang (2015) contradict that inappropriate and unreasonable innovation investments hinder the ISU advancement to an advanced level, leading to ISU solidification. He and Zeng (2013) state that, under the existing capacity levels in China, only TI and improvement of production efficiency can break through the development of the low-end position of the industrial chain but marginally promote ISU as a whole. These contrasting views and the scarcity of empirical data

make it difficult to claim whether [or not] GGIP's influence on ISU is positive, negative, linear, or non-linear across regions in China. More so, there is little data on the relationship dynamics of GGIP, ISU, and ER in resource and non-resource-based regions.

In terms of the knowledge gap, there is an absence of a unified research framework combining GGIP, ER, and ISU, although many studies have documented various influencing factors of ISU, including environmental regulations (hereafter ER), technological innovation, financial policy, human capital, and other aspects (Martić and Savić, 2001; Ngai & Pissarides, 2007; Guo & Yuan, 2020; Han & Ma, 2020; Luo & Qi, 2021). Despite the plethora of previous academic research on ISU, the existing research has the following limitations: Firstly, the existing literature mainly focuses on the internal mechanism of government innovation and the influencing factors of the industrial structure or generally classifies the government's influence on the industrial structure as an external driving factor. Only a few studies have explored the precise influence mechanism of government innovation preference on industrial structure. Moreover, scholars have studied the relationship between ER, GGIP, and industrial structure transformation. Yet, there is scarce information on the relationship between ER preference, GGIP, and ISU from the perspective of green motivation (Chen J. et al., 2021; Liu S. et al., 2022; Quan et al., 2022).

The main purpose of this paper is to explore the influence mechanism of GGIP and ISU in resource-based and non-resource-based areas of China. Taking ER as a threshold variable, this paper uses panel data from 30 provinces in China from 2005 to 2019 to verify the non-linear relationship using the double-threshold regression model. This paper uses green patents as a proxy for the GGIP. This factor has important implications for deeply understanding the importance of technological innovation and implementing appropriate ER. At the same time, ISU means that several high-polluting, high-energy-consumption, and low-value-added enterprises will be eliminated, thereby optimizing the industrial structure (Pan and Chen 2021; Deng and Zhao 2022; Miao et al., 2022). Therefore, this study is devoted to the influence of the GGIP on ISU and explores the threshold effect of ER and the linkage effect between the "flexible" GGIP and "rigid" ER, a novel aspect distinguishing this paper from existing literature.

The current research contributes to existing theory and research. First, the paper constructs a novel ER-based threshold model to explain the internal mechanism of ISU from an under researched context (China) while explaining how "flexible" GGIP and "rigid" ER are interconnected. Second, existing research generally regards GGIP as a general concept from the macro perspective (Tao et al., 2020). This paper discusses the influence of government innovation on ISU from the perspective of green motivation, providing a new perspective for studying ISU.

The rest of this paper can be divided into four parts: The second part is a literature review, which introduces the research status of government green innovation preference, environmental regulation, and industrial structure. The third part elaborates on the research design and empirical model analysis, variable selection, and data sources. The fourth section makes recommendations based on previous empirical evidence.

2 Literature review

The topic of innovation has gained popularity in the urban development literature. Technological innovation (TI) and ISU are considered the main ways to promote new urbanization (Wei et al., 2021). Green TI and ISU can achieve the economy's green transformation through environmental regulation (Du et al., 2021). Therefore, scholars have incorporated innovation into various studies of urban development. For instance, Mieg (2012) discussed commonalities between sustainable urban development and innovation, further explaining that identity seems as a particular governance-related resource in the relationships based on a resource-based view of urban project management. Nilssen (2019) comprised four dimensions of innovation (i.e., technological, organizational, collaborative, and experimental) to analyze empirical data from a Norwegian urban development project triggered by a critical juncture. The author supported the need for a typology of smart cities as multifaceted urban innovation. Furthermore, Pan et al. (2020) considered cross-industry spillovers as a missing link between land-use planning and urban economic futures and found that cross-industry spillovers positively impacted local employment on growth. Adopting a social network perspective, Yao et al. (2020) linked urban innovation with its location in the urban network. They confirmed that city innovation is not only determined by local innovation activities but also is enhanced when cities are deeply embedded in inter-city innovative networks. Yao et al. (2022) focused on the relationships between compact city indicators and comprehensive/technical efficiency, a multi-indicator system of compact cities, including population density, boundary limitation, and road density. The following part reviews the important studies on the relationships of ISU with ER and GGIP.

2.1 Green innovation preference and industrial structure upgrading

Economists agree that science and technology development is pivotal for industrial structure transformation (Ma & Yuan, 2004; Fu et al., 2013). Low-cost growth based on labor-intensive products is not sustainable without technological innovation (TI). Industrial upgradation and success often push wage rates

and multiply costs in developing economies, yet the developing or under-developed competing countries benefit from low wage rates. Tech innovation can break through the original technical level, improve production efficiency, create new emerging industries and new markets (Zhou et al., 2016), adjust the structure of production and utilization demand, and promote the flow of factors (Ji, 2018), a few factors enabling ISU. Yan et al. (2020) noted that renewable energy-led TI significantly and positively uplifted green productivity in cases where a region's relative income level exceeded a critical turning point. In another study, Jiang and Ji (2019) observed that, besides optimizing ISU at the local level, TI had contributed to the rational development of the adjacent regional economies. The authors stressed that the direction and intensity of the impact of innovation on the ISU vary among different regions, especially in China. Thus, there may be a non-linear relationship between innovation and ISU due to the synergistic and crowding effect of industrial agglomeration.

In the same vein, Endrikat et al. (2014) stated that achieving a win-win scenario appears impossible because green production and economic interests may be at odds with each other or sometimes even in a severe conflict. When the degree of outward diffusion of TI is relatively low, the demand for technological products will become the main driving force pushing the adjustment of the industrial structure. When the technological diffusion level is large, the allocation of technological elements and the demand for technological products are two factors (Chen Y. et al., 2021; Wu and Zhu 2021; Sheng et al., 2022). The combined effect of various aspects has reduced the industrial efficiency, thus making the industrial structure adjustment develop in the opposite direction. Therefore, the ISU adjustment and optimization (due to TI) create an inverted U-shaped relationship (Li & Dong, 2018). In a series of studies, Wang et al. (2020) found that green TI can promote total factor productivity, thereby driving the transformation of the economy to green and sustainable growth. In another study, Wang L. et al. (2021) asserted that implementing green innovation strategies can improve the resource utilization rate of enterprises, encourage the conversion of development models (from traditional labor-intensive to knowledge-based), enabling sustainable development of firms, a view consistent with many studies (e.g., Zhang et al., 2019; Zhang et al., 2020).

2.2 Industrial structure upgrading and environmental regulation

Previous works reflect an acute emphasis on the effects of the pollution-haven hypothesis on the adjustment of industrial structure. Most studies have concluded that variations in the standards of ER contribute to the production cost of carbon-

intensive industries, affecting the industrial structure in a region (Kheder & Zugravu, 2012). Based on the relevant US data (1979–1990), Shadbegian and Gray, (2004) empirically analyzed the ER-production efficiency nexus for the steel, paper, and petroleum industries. The author observed a significant upsurge in the production costs and lower productivity due to ER in the selected industries. In another study, Gray and Shadbegian (1995) found that the high intensity of ER inhibits polluting enterprises from improving their production efficiency and offers a low financial incentive for adopting environmentally friendly production methods. Therefore, some experts assert the need for balanced and incremental implementation of ER policies, enabling enterprises to improve innovation capabilities and scientifically allocate resources, thereby enhancing their competitiveness (Michael et al., 1995). Another study by Cole et al. (2005) examined how formal and informal ER affect ISU. The author observed that ISU demonstrated a significant U-shaped threshold characteristic when the intensity of formal ER increased. Chen L. et al. (2022) found that informal ER exhibited a double-threshold effect in China. In another study, Wang M. et al. (2021) empirically tested the impact of heterogeneous ER on ISU, deducing that compared to command-controlled ER (CER) and the voluntary public participation ER (VER), market-incentive ER (MER) had a stronger effect on ISU.

Nonetheless, the majority of previous findings reflect two opposing views: 1) ER pushes ISU; 2) the relationship between ER and ISU is uncertain. In line with the former perspective, Lu (2007) found that ER pushes technological progress and promotes ISU. In another study, Gao et al. (2012) observed a positive correlation between the intensity of ER and the optimization of the industrial structure of the manufacturing industry. As per Qu and Wang (2002), the implementation of strict ER standards is conducive to ISU in the long run. Xue (2016) stated that ER affects the industrial structure of the regional equipment manufacturing industry by affecting economic growth. Alternatively, in support of the second perspective, Wu et al. (2019) drew from previous studies to conclude that the effect of ER on ISU in the manufacturing industry differs across different regions in China, i.e., the progress in East China is superior to the Central and West China. Some recent studies show that ER suppresses ISU if the industries exhibit a low level of TI. If the industry holds a medium and high level of scientific and TI, ER can promote the ISU (Sun et al., 2020). Another study explained that ER significantly inhibits ISU in industries with a low level of human capital, but it encourages ISU in industries with a medium or high level of human capital. Considering the industrial modernization of China, some economists argue that ER has played a substantial role in ISU of major cities, even though it is not easy to gauge the intensity and scope of such effect across different stages

(early-middle) of development in different cities in China (Cheng et al., 2017).

2.3 Green innovation preference and environmental regulations

Per the traditional neoclassical economic theory, ER produces a cost effect of compliance, inhibiting enterprises from actively carrying out TI (Altman, 2001). The revisionist school represented by Porter believes that ER generates innovation compensation effects. ER effectively incites firms to pursue innovation (scientific or technological) and develop green technologies, processes, and products for the following reasons: 1) enhance enterprise core competitiveness; 2) partially or entirely offset economist costs generated by environmental regulations (Song et al., 2022a; Chen Y. et al., 2022). Only when the innovation's compensation effect (led by environmental regulation) exceeds the cost-effectiveness of compliance can enterprises get the opportunity to promote their transformation and upgrading through green TI, which unifies the Porter hypothesis and traditional neoclassical economic theory (Liu X. et al., 2022). At present, the current literature on the topic is dominated by the following three main viewpoints. The first perspective, built on the compensation cost theory, advocates that environment-related laws and legislation inhibit green TI. Extra funds for waste disposal (in response to ER) drain out the capital investment of firms for TI (Qiao et al., 2022). Yuan (2022) analyzed A-share listed data (2011–2019) to conclude that environmental protection tax significantly inhibited the green TI of firms based in Shanghai and Shenzhen, China. Compared to the non-state-owned enterprises, the environmental protection tax significantly inhibited the green TI ability of state-owned enterprises.

The second perspective, based on the tenets of the innovation compensation theory, proposes that ER promotes green TI (Song et al., 2022b; Chen L. et al., 2022). The increasing intensity of ER can indirectly stimulate enterprises to enhance scientific and TI, offsetting the cost of pollution prevention and control, thereby promoting TI (Lanoie et al., 2008). Drawing from the strong Porter hypothesis, Jaffe and Palmer (1997) state that stimulating enterprises to innovate in production technology can benefit enterprises in two ways. While the benefits obtained by ER can significantly offset the cost of improving the environment, they can simultaneously trigger an innovation compensation effect, enabling enterprises to yield sustainable development dividends. Strict and efficient ER and high-intensity R&D investment, coupled with independent R&D at the core, can generate a high level of regional green TI (Gao et al., 2022). Based on the uncertainty theory, the third perspective considers the ER-green TI nexus as non-linear, claiming no significant relationship exists between the two factors. Lu (2022) used the panel data of thirty provinces in China (2011–2019) to support the U-shaped connection between green TI and ER.

3 Methodology

3.1 Data and variables

This paper selected the panel data of thirty provinces in China, covering a period from 2005 to 2019. Tibet data were excluded from the sample due to missing items. Table 1 shows the data sources, descriptions, annotations, and variables.

3.2 Variables

In GGIP, the independent variable, was adopted in this study, measured by the sum of green patents. Previous studies (e.g., Pei et al., 2019) have used the sum of the number of utility models (granted) and invention patents as the measurement index. A high index number reflects that GTI is high. The natural logarithm processing of the index was used to obtain GGIP.

Advanced industrial structure (*ln* TS), a proxy of ISU, was adopted as the dependent variable. Even though most researchers, following Clark's Law, have used the proportion of non-agricultural output value as the measure of the ISU, it fails to reflect the new trend, i.e., service-oriented economy. The information technology revolution after the 1970s greatly impacted the industrial structure of major industrialized countries. The servitization of the economic structure driven by informatization is a key feature of the ISU, in that tertiary industries have grown faster than secondary industries in the economic servitization. Following the work of Gan et al. (2011), the paper adopted the tertiary-secondary industry output ratio as a measure of the advanced industrial structure. This indicator reflects the servitization tendency of the economic structure and indicates whether the industrial structure is developing in the direction of servitization. An increase in the advanced industrial structure value represents the economy moving toward superior servitization and the industry structure improving.

This study integrated environmental regulation (ER) into the model as the threshold variable. Following the approach of Ye et al. (2018), Hao and Zhang, (2016), and Ren et al. (2020), the current study incorporated the emissions of three industrial wastes to obtain the intensity of comprehensive ER. A high ER value indicates high pollution emissions, while a weak ER intensity denotes low pollution. ER was computed in the following way. First, the steps involved standardizing the industrial wastewater discharge per unit of output value, the industrial SO_2 discharge per unit of output value, and the industrial smoke and dust discharge per unit of output value, as seen in Eq. 1 below:\

$$UE_{ij}^S = \left[UE_{ij} - \min(UE_j)\right] / \left[\max(UE_j) - \min(UE_j)\right] \quad (1)$$

Where, UE_{ij} = the discharge/per unit output value of the *j*th pollutant in city i, and UE_{ij}^S is the standardized result of the index;

TABLE 1 Summary of the variables.

Variables		Notation	Description	Source
Dependent variable	Advanced industrial structure	TS	Advanced industrial structure	Statistical Yearbook of China (2005–2019)
Independent variable	Government green innovation preference	lnGR	Invention patents plus utility model patents granted	Chinese Research Data Services
Control variable	Financial input	FN	Total Fiscal Expenditure/GDP	Statistical Yearbook of China (2005–2019)
	Human capital level	lnHC	The logarithm of employment at the end of the year	Statistical Yearbook of China (2005–2019)
	Financial development	FD	Financial sector value added/GDP	Statistical Yearbook of China (2005–2019)
	Regional economic development	lnED	The logarithm of GDP	Statistical Yearbook of China (2005–2019)
	Degree of openness	lnOP	The logarithm of total exports	Statistical Yearbook of China (2005–2019)
	Infrastructure	lnINF	Take the logarithm of the length of the city road	Statistical Yearbook of China (2005–2019)
Threshold variable	Environmental regulation	ER	A comprehensive index of environmental regulation intensity	China Stock Market & Accounting Research Database

$\max(UE_j)$ = the maximum value of emission per unit output value of the jth pollutant in all cities; $\min(UE_j)$ = the minimum value of the emission per unit output value of the jth pollutant in all cities.

As depicted in Eq. 2, the weight of various pollutants was computed as follows:

$$W_j = UE \Big/ \overline{UE_{ij}} \qquad (2)$$

Where, $\overline{UE_{ij}}$ = the average level of emission per unit output value of the jth pollutant of thirty municipalities, provinces, and autonomous regions directly under the central government each year.

As shown in Eq. 2, the comprehensive index of environmental regulations for the city i was calculated as follows:

$$ER_i = \frac{1}{3} \sum_{j=1}^{3} W_j UE_{ij}^{S} \qquad (3)$$

Following Hansen (1999), Eq. 4 reflect the basic model for testing the effect of government green innovation preference on industrial structure upgrading, whereas Eq. 5 depicts the panel threshold regression with ER as the threshold variable.

$$TS_{it} = \alpha_0 + \alpha_1 \ln GR_{it} + \beta \sum Control + Year_i + \mu_i + \varepsilon_{it} \qquad (4)$$

$$TS_{it} = \alpha_0 + \alpha_1 LNGR_{it}(ER \leq \lambda) + \alpha_2 \ln GR_{it}(ER > \lambda)$$
$$+ \beta \sum Control_{it} + Year_i + \mu_i + \varepsilon_{it} \qquad (5)$$

Where, i = region; t = year; $Year_i$ = the year fixed effect; μ_i = the individual fixed effect; ε_{it} = the residual item; λ = the threshold value.

The paper incorporated different control variables, including financial input (FN), human capital level (lnHC), financial development (FD), regional economic development (lnGDP),

TABLE 2 Descriptive statistics.

Variable	N	Mean	Std. Dev	Min	Max
TS	450	1.174	0.65	0.527	5.234
lnGR	450	6.798	1.657	0.693	10.436
FN	450	0.237	0.108	0.092	0.758
lnINF	450	8.952	0.865	6.323	10.805
lnHC	450	7.589	0.797	5.696	8.853
lnOP	450	14.361	1.666	10.134	17.984
FD	450	5.69	3.182	1.465	19.628
lnGDP	450	9.432	0.988	6.298	11.587
ER	450	0.534	0.529	0	2.585

Note: ***, **, * represent significant at the 1%, 5%, and 10% levels, respectively, with t values in brackets. Abbreviations: TS, Industrial structure upgrading; LNGR, Government green innovation preference; FN, Financial input; LNINF, Infrastructure; LNHC, Human capital level; LNOP, Degree of opening; FD, Financial development; LNGDP, Regional economic development; ER, Environmental regulation.

degree of opening to the outside world (lnOP), and infrastructure (lnINF)—for the following reasons. Firstly, the quantity and quality of human capital directly determine the success or failure of upgrading the industry at the local and national levels. Secondly, financial support and financial investments provide a certain financial guarantee for ISU (TS) by providing necessary economic support for ISU (TS). Thirdly, the level of regional economic development facilitates ISU (TS), determining whether the ISU (TS) can be realized. Fourthly, the degree of opening to the outside world (lnOP) is reflected in the absorption of advanced technologies and experience from developed countries and international trade of products, thereby affecting ISU (TS) to varying degrees. Fifthly, infrastructure (lnINF) provides the basic material guarantee for ISU (TS).

TABLE 3 Stationarity and unit-root outputs: Augmented Dickey-Fuller (ADF) test.

Stationary testing

At level			
Variables	Z	Pm	P
ISU (TS)	1.40	−0.28	56.90
GGIP (ln GR)	1.17	−0.26	57.11
*ln*INF	5.17	−3.24	24.49
FN	−4.32***	13.60***	208.95***
*ln*HC	3.88	−2.07	37.35
*ln*OP	2.64	−2.21	35.84
FD	3.61	−2.66	3.62
*ln*GDP	5.93	−4.13	14.79
At first difference			
TS	−6.83***	10.71***	177.35***
InGR	−15.13***	34.92***	442.48***
*ln*INF	−17.89***	46.16***	565.68***
FN	−7.28***	9.76***	166.90***
*ln*HC	−9.88***	15.06***	224.96***
*ln*OP	−7.13***	9.76***	166.89***
FD	−8.07***	11.96***	191.00***
*ln*GDP	−4.01***	6.04***	126.18***

Note: ***, **, * represent significant at the 1%, 5%, and 10% levels, respectively.
Abbreviations: TS, Industrial structure upgrading; *ln*GR, Government green innovation preference; FN, Financial input; *ln*INF, Infrastructure; ln HC, Human capital level; *ln*OP, Degree of opening; FD, Financial development; *ln*GDP, Regional economic development; ER, Environmental regulation.

4 Result and Discussion

4.1 Descriptive statistical analysis of variables

The descriptive statistics of each variable are illustrated in Table 2. The mean value, standard deviation, maximum value, and minimum value of ISU (TS) was 1.174, 0.65, 5.234, and 0.527, respectively, reflecting a large gap in different provinces. The GGIP (LNGR) average was 6.798. More so, the standard deviation was 1.657. The min-max values were 0.693–10.436, indicating that the innovation level was largely unbalanced during the study period in different regions of China.

4.2 Stationarity testing

The unit root and stationarity test results provided empirical ground for the stationary of all variables at the first difference level (depicted in Table 3).

4.3 Regression model: Random- and fixed effect

Preliminary Hausman test results offered support for the application of regression analysis with fixed (FE)- and random effect (RE) model as a reference, as shown in Table 4. The two models corroborated the inhibitory effect of GGIP (*ln*GR) on ISU (TS) in China (i.e., RE = −0.0752 and FE = −0.1757), supporting the FE model outputs of Li and Yang (2015). A logical explanation is that government grants more green patents to the secondary industries, stimulating a market change from tertiary to secondary industry. This shift effects GGIP (*ln*GR) in a manner that (rather than supporting) it inhibits the advancement of ISU (TS) to the next stage. Consistent with the previous studies (e.g., Liu & Wang, 2021), the FE coefficient indicated the following effects of different variables on ISU (TS) at 1% significance: insignificant (financial investments, FN = 0.0449, Ln GDP = 0.449); negative (infrastructure, *ln* INF = -0.1962, degree of openness, *ln*OP = -0.0809), and positive (human capital level, *ln*HC = 0.3690).

4.4 Threshold regression

The threshold regression results with ER as the threshold variable are shown in Table 5. The model only passed the single-threshold test (threshold value = 0.0041), reflecting an inverted U-shaped effect of ER on ISU (TS). As seen below, GGIP (*ln*GR coefficient = 0.212, 1% significance level) promoted ISU (TS) when the ER value was less than 0.0041. In contrast, GGIP (*ln*GR coefficient = −0.0648) disrupted ISU (TS) when the ER value exceeded 0.0041. The threshold predictions implied that technological advancement and cost reduction (through patents and other tolls) in the early stages of ER implementation had facilitated industrial transformation and upgrading (ISU) in China. The model outputs signaled that the government restrained the development of polluting industries through various measures (e.g., ER taxation and pollution fines) after reaching a certain threshold in the development of environmental protection technology and formalization of ER laws, consequently slowing down the new round of development and progress of ISU.

4.5 Robustness estimation

The robustness check results are given below in Table 6. The robustness check of the research results was carried out in the following two ways. Method one comprised change of the time interval (cf. Zhang et al., 2022), while the

TABLE 4 Panel regression output: Random- and fixed effect.

Variables	Random-effects regression	Fixed-effects regression
	Model (1)	Model (2)
GGIP (*ln*GR)	−0.0752**	−0.1757***
	(0.0309)	(0.0299)
FN	−0.7096***	0.0449
	(0.2157)	(0.2213)
*ln*INF	0.0310	−0.1962***
	(0.0505)	(0.0531)
*ln*HC	−0.0759	0.3690***
	(0.0669)	(0.0968)
*ln*OP	−0.1677***	−0.0809***
	(0.0225)	(0.0230)
FD	0.1532***	0.0834***
	(0.0082)	(0.0094)
*ln*GDP	0.2427***	0.0449
	(0.0681)	(0.0846)
Constant	1.3984**	1.2031
	(0.5473)	(0.9493)
N	450	450

Note: ***, **, * represent significant at the 1%, 5%, and 10% levels, respectively, with t values in brackets. Abbreviations: ISU (TS), Industrial structure upgrading; *ln*GR, Government green innovation preference; FN, Financial input; *ln*INF, Infrastructure; *ln*HC, Human capital level; *ln*OP, Degree of opening; FD, Financial development; *ln*GDP, Regional economic development; ER, Environmental regulation.

TABLE 5 Threshold estimations.

Threshold effect and level

Threshold variable	Threshold quantity	Threshold value	F-value
ER	Single threshold	0.0041***	147.59
	Double threshold	0.0006	32.65
Variable		Threshold coefficient	*t*-value
GGIP (lnGR) (ER ≤ 0.0041)	0.212***	5.91	
GGIP (lnGR) (ER > 0.0041)	−0.0648**	−2.41	
Constant		2.125**	2.55
Control variable	control		
N	450		

Note: ***, **, * represent significant at the 1%, 5%, and 10% levels, respectively. Abbreviations: ISU (TS), ndustrial structure upgrading; GGIP (*ln*GR), Government innovation preference; ER, Environmental regulation.

explanatory variables was replaced in Method 2. Instead of using the sum of invention patents and utility model patents for GGIP (*ln*GR), ISU (TS) was regressed with the replacement of authorized invention patents. Overall, the signs and coefficient valves of all variables in the two methods of the robustness test were in line with Table 4, indicating that the model fitting and construction of regression results were robust.

4.6 Heterogeneity analysis: Resource-based vs non-resource-based regions

As the policy environment and industrial structure vary among different regions in the vast territory of China, the sample was divided into resource-based and non-resource-based regions according to the differences in regional industrial structure and resource endowments. Resource-based regions included Hebei,

TABLE 6 Robustness test results.

Variable	Method (1)	Method (2)
GGIP (lnGR)	−0.244***	
	(−7.37)	
lnAIP		−0.0672***
		(−2.66)
FN	2.252***	0.132
	(7.56)	(0.54)
lnINF	0.0267	−0.240***
	(0.36)	(−4.43)
lnHC	0.482***	0.353***
	(3.24)	(3.52)
lnOP	−0.0946***	−0.0782***
	(−4.22)	(-3.23)
FD	0.0820***	0.0755***
	(8.88)	(7.90)
lnGDP	0.216**	−0.0482
	(2.53)	(−0.57)
Year	control	control
Constant	−2.899**	1.826*
	(−2.55)	(1.88)
N	300	449

Note: ***, **, * represent significant at the 1%, 5%, and 10% levels, respectively, with t values in brackets. Abbreviations: ISU, Industrial structure upgrading; GGIR, Government green innovation preference; LNAIP, authorized invention patents; FN, Financial input; LNINF, Infrastructure; LNHC, Human capital level; LNOP, Degree of opening; FD, Financial development; LNGDP, Regional economic development.

TABLE 7 Region-based heterogeneity analysis results.

Variable	Resource-based (1)	Non-resource-based (2)
GGIP (lnGR)	−0.0912**	−0.2327***
	(0.0413)	(0.0404)
FN	1.7749***	0.0182
	(0.3459)	(0.2704)
lnINF	−0.0746	−0.0816
	(0.1438)	(0.0624)
lnHC	−0.2889**	0.8634***
	(0.1132)	(0.1495)
lnOP	−0.1457***	−0.0464
	(0.0291)	(0.0310)
FD	0.1314***	0.0599***
	(0.0160)	(0.0116)
lnGDP	0.3223***	−0.2912**
	(0.1054)	(0.1446)
Constant	2.6022***	−0.6624
	(0.8902)	(1.6346)
N	150	300

Note: ***, **, * represent significant at the 1%, 5%, and 10% levels, respectively, with t values in brackets. Abbreviations: TS, Industrial structure upgrading; lnGR, Government green innovation preference; FN, Financial input; lnINF , Infrastructure; lnHC, Human capital level; lnOP, Degree of opening; FD, Financial development; lnGDP, Regional economic development; ER, Environmental regulation.

Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Sichuan, Guizhou, Yunnan, Shaanxi, and Xinjiang, while the remaining provinces were considered non-resource-based regions. As reported in Table 7, GGIP had a stronger inhibitory effect on the ISU (TS) in non-resource-based regions (lnGR = −0.2327) than resource-based regions (lnGR = = −0.0912) of China. For control factors, government financial expenditure (FN) and the degree of opening (lnOP) had a significant controlling role in the resource-based regions, yet the impact of these factors on ISU (TS) was weak.

5 Conclusion and discussion

The key objective of this article was to measure the impact of GGIP on ISU under different levels of ER using Chinese provincial panel data from 2005 to 2019. All the variables in the study passed the unit root test and stationarity testing. The regression analysis suggested that GGIP prevented ISU in Chinese regions, while FN and GDP had insignificant effect on ISU, infrastructure and OP had a negative effect on ISU, and HC positively impacted ISU. The main regression method, with ER as a threshold variable, confirmed the non-linear inverted U-shaped relationship between GGIP and ISU

through the coefficient of the quadratic term (e.g., Zhang et al., 2022). The threshold regression delineated that the ER rigidity controlled the inhibitory role of GGIP in improving ISU. More so, the heterogeneity analysis demonstrated non-resource-based region and resource-based region differed in the intensity of inhibitory influence of GGIP on ISU, as the inhibitory effect was relatively more significant in non-resource-based regions.

The paper proposes the following recommendations according to the current findings. First, the government should create a conducive atmosphere and continuously improve the level of TI. Regional governments can enhance emphasis on basic research and original innovation to provide a source for GTI progress by continuously expanding the R&D frontiers in different regions; deepening the protection of intellectual property rights in GTI; by actively introducing market mechanisms to build a platform for the transformation of GTI projects to promote advanced technology for enhancing the development of enterprises; by mobilizing the role of ER in promoting ISU. Second, the current findings assert the need for simultaneous development of GTI and ER. The central and local governments should introduce a balanced approach in terms of implementation, rules, incentives, and penalties, considering the restraining effect of GTI on ISU. Third, the current findings indicate that the rationalization of the industrial structure should be realized in cooperation with ER. With nascent insight into the dynamics of ER, the rapid

expansion of the tertiary industry in China could be harmful. Under the self-regulating action of the market, the government should give good play to the dispatching role of government regulations so that the industrial structure can be upgraded at an appropriate speed and the industrial structure can be rationalized appropriately in a systematic manner. Fourth, the current findings call for promulgation of indigenous policies tailored to local conditions to prevent the inhibitory effects of GGIP on ISU in different regions, particularly non-resource-based regions. It is necessary to provide corresponding industrial policy support to realize the adaptive development and balance between resource-based and non-resource-based regions. While achieving green development, the government should support the industrial policy of various regions and achieve coordinated and high-quality development.

Although the paper brings fresh insight into regional innovations in China, it has the following shortcomings. First, the current findings are limited in representing the interaction among GGIP and ISU of provincial governments in thirty provinces of China. Second, the paper explored the impact of GGIP on the rationalization of ISU in addition to ISU. As the results were not ideal, they were excluded. It appears that GTI has not sufficiently affected the rationalization of the industrial structure, yet its significant impact on the rationalization of the industrial structure cannot be underestimated in other parts of the world. Third, it is assumed that the province panel data cannot fully reflect the effect of GGIP on industrial structure. Given that prefecture-level city or micro-enterprise data may be able to make the research more representative (Long et al., 2017), follow-up research is expected to bring fresh insight.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

SK: Supervision, conceptualization, Editing. AK: Proofreading MK: Supervision JL: Introduction part, preparation ZP: Literature review part, preparation CL: Data handling, methodology, statistical software.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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