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Original Research

The Impact of Decentralization on Carbon Productivity in Chinese Manufacturing: The Perspective of Industrial Policy

Li Song*, Jiali Yuan, Ting Li

School of Internet Economics and Business, Fujian University of Technology, Fuzhou, Fujian, China

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Abstract

With the increasing severity of global climate change, realizing the win-win situation between industrial development and carbon reduction through localized policy formulation has become an important goal for developing countries, which is especially vital for large economies that require decentralized systems. Therefore, this paper aims to explore the relationship between Chinese-style decentralization, industrial policy, and manufacturing carbon productivity to shed light on promoting low-carbon transformation by fine-tuning the decentralizing system. This study measures low-carbon total factor productivity based on the SBM-GML method and sectoral manufacturing data of 30 provinces in China from 1997 to 2019, and found that fiscal decentralization has a positive effect on industrial policy in promoting manufacturing low-carbon transformation, especially in promoting the implementation effect of the local government industrial policies, but has a limited effect on industrial policies implemented by the central government alone. However, environmental decentralization has an impeding effect on the role of industrial policy in increasing carbon productivity, which is mainly reflected in the central government's industrial policy. Furthermore, energy structure and green innovation are two important channels affecting carbon productivity. The findings of this paper provide new evidence for optimizing the decentralization system and the positioning of industrial policy between the central and local levels to promote industrial transformation and carbon emission reductions.

Keywords: Chinese-style decentralization, five-year plan, industrial policy, manufacturing carbon productivity

Introduction

Achieving a balance between industrial growth and carbon emissions reduction represents a global challenge, with particular relevance for China as it strives for a harmonious relationship between humans and the environment. This objective is encapsulated in the concept of carbon productivity, which assesses the efficiency of an economy in producing industrial output while minimizing carbon dioxide emissions. This metric serves as a critical indicator of the equilibrium between economic expansion and environmental sustainability

*e-mail: songdm520@hotmail.com

[1]. Since 2013, China has pursued a strategy of green industrialization, emphasizing resource conservation and ecological protection. This strategic shift is designed to improve carbon productivity and promote a low-carbon, green, and sustainable industrial economy. In this context, transforming China's manufacturing sector toward low-carbon processes is crucial for promoting ecological civilization and achieving high-quality development. Additionally, this transformation is essential for addressing global climate change and strengthening the global community's shared destiny.

To achieve this goal, both central and local governments must clearly define the allocation of responsibilities and coordinate cooperation. Decentralization involves shifting authority and responsibilities from central to local or regional governments, aiming to improve governance and address local needs more effectively. In China, fiscal decentralization marries local economic autonomy with central political control, a blend that has propelled the country's rapid economic growth since its reforms. However, recent years have exposed the limitations of this strategy, especially in achieving the goals of carbon neutrality and carbon peak. The current arrangement, which centralizes financial authority and distributes administrative responsibilities to local governments, often leads to inadequate incentives and skewed behaviors in environmental governance. The efficacy of government interventions in environmental protection – a sector riddled with externalities – is undermined by these discrepancies. Moreover, the mismatch between the diverse development goals of local governments and the uniformity of their financial resources can leave them ill-equipped for effective environmental management. Thus, it is vital to assess whether boosting local fiscal capacities can enhance their environmental governance capabilities. Additionally, while the central government sees environmental decentralization as a key strategy for refining the governance system, it remains unclear whether this approach is skewed by economic objectives or if it genuinely aids local governments in improving environmental management. These unresolved issues highlight the complexity of balancing economic development with environmental sustainability within China's decentralization framework.

The relationship of decentralization needs to be mediated through policy implementation to produce environmental consequences, with industrial policy being an important yet overlooked topic in this context. Industrial policy encompasses strategies and actions undertaken by governments to stimulate economic growth and development within specific industries, with the aim of boosting innovation and fostering structural upgrading. In China, market mechanisms often prove insufficient for steering industries toward low-carbon transitions, highlighting the critical role of government policies. The transition to low-carbon manufacturing relies extensively on environmental regulations and state interventions instead of market forces. Local governments implement directives from the central government, exerting substantial pressure on enterprises. This top-down approach tends to result in passive compliance from businesses, which is typically inadequate for achieving significant low-carbon changes. Conversely, a more proactive industrial policy could effectively catalyze this transition by enhancing resource allocation and stimulating technological innovation.

The study closest to the findings of this paper confirms that the differences in the role of different decentralization systems have varying impacts on achieving the environmental Porter effect [2]. On one hand, fiscal decentralization promotes carbon emission reduction [3], primarily through alleviating budget constraints [4]. On the other hand, environmental decentralization overall has a negative effect on industrial pollution [5], but its specific impact depends on government goal-setting and governance behavior [6]. However, none of the existing studies have taken into account the fact that decentralized systems do not produce environmental effects directly, but act indirectly on environmental governance by influencing government behavior and policy implementation, which is what makes this study unique.

Based on the above background, and utilizing data from 36 two-digit industries across 30 provincial regions in China, this paper uses a panel fixed effects model that spans provinces, sectors, and years to empirically investigate the impact of two types of decentralization – fiscal and environmental – on the carbon productivity of the manufacturing sectors through government industrial policies enacted under the "Five-Year Plan". The paper finds that industrial policy increases carbon productivity in support sectors, and fiscal decentralization reinforces this effect because increased fiscal capacity facilitates policy implementation. However, environmental decentralization inhibits this effect because the separation of fiscal and administrative powers among local governments leads to insufficient constraints on environmental decentralization. Fiscal decentralization mainly promotes industrial policies that are jointly supported by the central government and local governments or supported by local governments alone, while it has little effect on policies supported by the central government alone. Environmental decentralization has a negative effect on industrial policies supported by the central government alone and has no significant effect on other types of policies. Further, energy structure and green innovation are two important channels affecting carbon productivity.

This paper makes significant contributions to the academic literature in several ways. First, it clarifies the mechanisms through which industrial policy shapes environmental governance outcomes in decentralized systems. Unlike much existing research that directly assesses the impact of decentralization on environmental pollution, this study narrows the research gap by delving into the complexities of the system-to-behavior process. The paper establishes a comprehensive theoretical framework that delineates the interactions between decentralization, industrial policy implementation, and carbon productivity. This framework provides a new explanatory pathway for understanding the relationship between decentralization and environmental protection, highlighting that the effects of fiscal and environmental decentralization need to be considered together in the formulation of industrial policies to promote carbon productivity and sustainable development. Secondly, the study introduces new empirical evidence and a conceptual model to explain the varied effects of different decentralization strategies. While previous studies often considered the impacts of fiscal or environmental decentralization in isolation, this paper uniquely examines and systematically explains these effects through the lens of industrial policy implementation, offering a fresh perspective on the diverse impacts of decentralization systems. Third, it addresses a gap in the literature that typically focuses on the effects of decentralization on either economic development or environmental pollution, seldom exploring how decentralization influences low-carbon transformation or sustainable development. Utilizing a unique database of regional manufacturing data, this study explores how decentralization systems impact carbon productivity, thereby enhancing the discourse on the relationship between institutional frameworks and both sustainable development and low-carbon transitions.

Literature Review

Literature related to this paper mainly includes studies on the impact of fiscal decentralization and environmental decentralization on pollution emissions and environmental governance.

Environmental Impact of Fiscal Decentralization

The existing literature has not reached a consistent conclusion on the environmental impacts of fiscal decentralization. Part of the literature argues that fiscal decentralization has a clear positive impact on emission reduction and environmental governance. Fiscal decentralization at the county level is more effective in generating carbon emission reductions relative to administrative decentralization [7]. Fiscal decentralization can also promote the win-win development of economic growth and emission reduction [8]. Some literature finds that local fiscal imbalance can hinder industrial upgrading and technological innovation and thus lead to environmental degradation, which is indirect evidence that fiscal decentralization is beneficial to environmental governance [9]. At the same time, an increase in fiscal expenditure rather than revenue decentralization makes local governments more capable of investing in abatement technologies, thus enhancing green total factor productivity [10].

There is also literature that argues that fiscal decentralization is detrimental to carbon emission reduction. Chinese-style fiscal decentralization has weakened the carbon abatement effects of environmental policies implemented in the eastern and central regions, possibly stemming from the excessive fiscal pressure or the fiscal capacity of these provinces that has still not crossed the threshold [11]. It has also been argued that fiscal centralization, rather than decentralization, induces industrial emission reductions, but this effect may originate from the reinforcement of surveillance by the central government [12].

Most of the literature suggests that fiscal decentralization has a complex nonlinear relationship with carbon intensity [13] or that it has a negative short-term but positive long-term effect [14]. The reason is that the effect of fiscal decentralization is affected by various factors, such as government behavior and industry characteristics. The carbon-reducing effect of fiscal decentralization is mainly found in regions with a low degree of industrial structure development [3]. Part of the literature argues that fiscal decentralization does not directly affect environmental pollution, but produces governance effects through the indirect effects of government behavior, such as increasing emissions reduction expenditures and increasing pollution management fees [15]. The direct effect of fiscal decentralization on green total factor productivity is not significant, but fiscal decentralization can enhance green total factor productivity through an appropriate degree of environmental regulation [16]. In addition, fiscal decentralization can provide financial support for pollution control behaviors, thus weakening the pollution shelter effect [17]. Fiscal decentralization can play a direct role in abatement as well as an indirect role in abatement by enhancing institutional quality [18]. Specifically, fiscal decentralization can reduce local fiscal pressures and promote competition among governments, thereby increasing incentives to reduce emissions and attracting cleaner firms [4].

Environmental Impact of Environmental Decentralization

Research on environmental decentralization in China started late, and some studies have found that Chinese environmental decentralization has a bottom-up competition effect, i.e., environmental decentralization exacerbates emissions from industrial firms [5], especially when competition among local governments is intense [19].

More studies have argued that the relationship between environmental decentralization and environmental governance is complex and non-linear or dependent on other factors. Vertical environmental decentralization between the central and local levels has an inverted "U" shape, i.e., there is a moderate range of environmental decentralization, and excessive expansion of local environmental management power reduces total factor carbon productivity [20], and the same nonlinear relationship exists for carbon emissions [21]. The reason for this is that environmental decentralization acts on environmental consequences by influencing government behavior. For example, environmental decentralization can inhibit the contribution of environmental regulatory actions to total factor energy efficiency [22] and may also inhibit environmental investment in the short term [23].

In addition, there is heterogeneity in the effects of different types of environmental decentralization. Some studies found that environmental administrative decentralization is conducive to green development, while the opposite is true for monitoring decentralization [24]. Under the pressure of economic growth targets, decentralization of environmental monitoring worsens pollution emissions, but other environmental decentralization does not produce this effect [6].

Summarizing Comments

Overall, on the one hand, although previous studies have explored the environmental impacts of fiscal and environmental decentralization separately, few have directly compared their effects in a consistent manner. On the other hand, the effectiveness of both fiscal and environmental decentralization in governance and pollution reduction hinges on specific government actions. While most research has concentrated on behaviors related to environmental regulation, there's a notable gap in understanding how the decentralization system influences environmental outcomes through the development and execution of industrial policies. Therefore, this paper aims to examine the impact of fiscal and environmental decentralization on environmental outcomes by focusing on the role of government industrial policies.

Theoretical Analysis and Hypothesis

Fiscal Decentralization, Industrial Policy, and Manufacturing Carbon Productivity

The implementation of industrial policy in China is intricately linked to the decentralized governance structure between the central and local governments. Industrial policies, enacted through five-year plans, typically exhibit a pronounced "top-down" approach, where the central government's priorities in industrial objectives directly shape the formulation and execution of policies at the local level [25]. If the central government prioritizes the shift of key industries towards low-carbon development, local governments, influenced by their own political and economic interests, are likely to increase their focus on similar choices that align with both industrial growth and environmental protection [26]. Consequently, possessing greater financial capacity enables local governments to more effectively enhance the carbon productivity of key industries through targeted industrial policies [27].

Further, the effectiveness of centrally formulated industrial policies hinges partly on the cost-benefit calculations of local governments and their ability to harness intrinsic developmental incentives. Local governments experiencing a higher degree of fiscal decentralization typically have less immediate need to drive manufacturing towards low-carbon transformations for short-term gains. Instead, they focus on achieving the low-carbon development goals set by the central government [28]. As a result, local governments with robust financial capabilities are more motivated and equipped to foster high-quality local development. For these governments, enhancing low-carbon transformations aligns with long-term local interests [29]. Therefore, if the central government can successfully integrate low-carbon objectives into the strategic goals of local administrations, regions with greater fiscal decentralization might more effectively implement industrial policies that promote low-carbon industrial development, thus achieving a dual win in boosting output and enhancing environmental protection.

Based on the above theoretical analysis, the research hypothesis is formulated as follows:

H1: A higher level of fiscal decentralization is conducive to the government's ability to promote carbon productivity in targeted industries, and this effect exists mainly in the local government's industrial policy.

Environmental Decentralization, Industrial Policy, and Manufacturing Carbon Productivity

Environmental decentralization reflects the structure of environmental responsibilities between the central and local governments. While the local competition pattern shaped by the Chinese decentralization system has long been an effective incentive for local governments to emphasize economic development, the separation of financial and environmental governance powers has also led to a failure of coordination between the central and local governments. Therefore, how environmental decentralization affects the role of industrial policy in the low-carbon transformation of industry under the existing central-local decentralization pattern is an important real-world question that has yet to be answered.

According to the classical decentralization theorem, public goods should be delegated to the lower levels of government when regional preferences vary significantly and spillover effects are minimal [30]. In the context of China, this implies that if local governments are sufficiently motivated to protect the environment, the principle of "incentive compatibility" should apply. This principle suggests that environmental management powers ought to be allocated to the government level that possesses the most relevant information, typically the local governments [31]. Ideally, local authorities would spearhead the environmental governance of key industries, thus supporting industry-specific policies. Conversely, if significant negative externalities exist in industrial pollution control, delegating the authority to monitor and manage pollution in key industries to provincial governments could result in responsibility avoidance or the adoption of self-serving control schemes by local governments [32]. Such scenarios often lead to coordination failures, ultimately undermining the potential carbon productivity benefits of industrial policies.

Environmental decentralization, while theoretically designed to leverage local knowledge and foster competitive incentives for better governance, may actually impede effective carbon emission reduction. This is due, in part, to the costs associated with local government agencies often exceeding the benefits of reduced information asymmetry between central and local governments. As a result, decentralizing environmental management can lead to less effective governance outcomes [33]. In practice, environmental decentralization in China operates under a "de facto" system where responsibilities are shared between the central and local governments but lack a robust legal framework. Since the establishment of the State Environmental Protection Administration (SEPA) in 1988, the pattern of shifting between decentralization and centralization has revealed significant challenges. [34]. Notably, the absence of a strong ecological compensation system and a comprehensive environmental performance appraisal system has critically weakened the central government's ability to enforce environmental policies effectively. This deficiency allows local governments, often prioritizing economic growth over environmental standards in their quest for higher political positions, to undermine decentralization efforts. Consequently, despite numerous environmental regulations enacted by the central government, their impact on reducing carbon emissions remains minimal [35]. Moreover, the division of fiscal and administrative powers complicates the central government's reliance on local governments for implementing environmental management, thus compromising the autonomy of local environmental agencies and further detracting from the goals of environmental decentralization [36]. This structure not only weakens enforcement but also diminishes the potential for significant carbon emission reductions. Based on this theoretical analysis, the following hypothesis is proposed:

H2: Environmental decentralization is not conducive to the driving effect of industrial policy on carbon productivity, which exists mainly in the central government's industrial policy.

Research and Data Methodology

Model

Following the approach of existing literature, this article constructs a moderation effect model to examine how the decentralization system influences carbon productivity within the implementation of industrial policy [37, 38]. The specific model involves incorporating an interaction term between decentralization and industrial policy as the core explanatory variable in a fixed effects model:

$$CP_{i,j,t} = \alpha + \beta IP_{i,j,t} \times Dec_{i,t} + \beta_1 IP_{i,j,t} + \beta_2 Dec_{i,t} + \sum \gamma X'_{i,j,t} + \mu_i + \lambda_j + \theta_t + \epsilon_{i,j,t} \tag{1}$$

where the explanatory variables $CP_{i,j,t}$ are carbon productivity, $Dec_{i,j,t}$ is central decentralization, including fiscal decentralization (FD) and environmental decentralization (ED), $IP_{i,j,t}$ is industrial policy, $X'_{i,j,t}$ is other control variables that may affect carbon productivity, ijt is province, industry, and year-fixed effects, respectively, and $\epsilon_{i,j,t}$ is the error term. Here, the coefficient of interest is β. If β is significantly positive, it indicates that the higher the degree of central-local decentralization, the greater the promotion effect of industrial policy on carbon productivity. Conversely, if the coefficient is significantly negative, it indicates that the increase in the degree of central-local decentralization inhibits the effect of industrial policy on carbon productivity.

Variables

Outcome Variable

The outcome variable is carbon productivity. Treating carbon emissions as undesired outputs, this paper adopts the Slack-based Measure (SBM) model of super-efficiency, combined with the decomposition method of the Global Malmquist-Luenberger (GML) index, to calculate the low-carbon total factor productivity of Chinese manufacturing, which is widely used to measure productivity considering global technology constraints and undesirable output [39, 40]. The algorithm for the super-efficient SBM can be expressed as:

$$min\ \rho = \frac{\frac{1}{m}\left(\sum_{i=1}^{m} \frac{\bar{x}}{x_{ik}}\right)}{\frac{1}{r_1 + r_2}\left(\sum_{w=1}^{r_1} \frac{\bar{y}_w}{y_{wk}} + \sum_{u=1}^{r_2} \frac{\bar{p}_u}{p_{uk}}\right)}$$

$$\text{s.t.} \begin{cases} \bar{x}_i \geq \sum_{j=1,\neq k}^{n} x_{ij}\lambda_j, i = 1,2,\ldots,m; \\ \bar{y}_w \leq \sum_{j=1,\neq k}^{n} y_{wj}\lambda_j, w = 1,2,\ldots,r_1; \\ \bar{p}_u \geq \sum_{j=1,\neq k}^{n} p_{uj}\lambda_j, u = 1,2,\ldots,r_2; \\ \lambda_j \geq 0, \bar{x}_i \geq x_{ik}, \bar{y}_w \leq y_{wk}, \bar{p}_u \geq p_{uk}; j = 1,2,\ldots,n(j \neq k); \end{cases} \tag{2}$$

In the model, x_{ik}, y_{wk}, and p_{uk} represent the inputs, desired outputs, and undesired outputs, respectively, where the desired output is industrial value added, the non-desired output is carbon emissions, and the input variables are capital stock, number of people employed, and energy consumption. λ denotes the weights of the indicators, and ρ represents the efficiency values of the decision-making units. If ρ>1, it indicates that the decision-making unit is efficient; otherwise, the DMU is deemed inefficient. After calculating the efficiency values, the carbon productivity is further computed using the GML method:

$$\begin{aligned} GML_k^{t,t+1} &= \frac{1+D^G(x_k^t,y_k^t,p_k^t)}{1+D^G(x_k^{t+1},y_k^{t+1},p_k^{t+1})} \\ &= \frac{1+D^t(x_k^t,y_k^t,p_k^t)}{1+D^{t+1}(x_k^{t+1},y_k^{t+1},p_k^{t+1})} \times \\ &\left[\frac{1+D^G(x_k^t,y_k^t,p_k^t)}{1+D^t(x_k^t,y_k^t,p_k^t)} \times \frac{1+D^{t+1}(x_k^{t+1},y_k^{t+1},p_k^{t+1})}{1+D^G(x_k^{t+1},y_k^{t+1},p_k^{t+1})}\right] \\ &= EC_k^{t,t+1} \times TC_k^{t,t+1} \end{aligned} \tag{3}$$

The term $GML_k^{t,t+1}$ represents the change in industrial low-carbon total factor productivity from period t to $t + 1$. If $GML_k^{t,t+1}$>1, it indicates that the low-carbon total factor productivity has improved in period $t + 1$; conversely, if $GML_k^{t,t+1}$<1, it signifies a relative decrease in low-carbon total factor productivity.

Explanatory Variables

The first core explanatory variable is decentralization. Fiscal decentralization can be measured by fiscal expenditure, fiscal revenue, and fiscal freedom [15]. Based on the theory of public finance, fiscal decentralization refers to the relative dominance of fiscal revenues or expenditures between the central government and local governments. The method known as the fiscal income (expenditure) approach calculates fiscal decentralization using the ratio of local government budget income (or expenditure) to central government budget income (or expenditure) as the proxy variable. Another concept, fiscal autonomy, measures the fiscal capacity of local governments by the ratio of their budgeted incomes to their budgeted expenditures. Regardless of the method used, a higher value of the fiscal decentralization variable indicates greater fiscal capacity at the local government level [9]. In the benchmark regression, the fiscal revenue method is used to calculate the fiscal decentralization index:

$$\mathrm{FD}_{i,t} = \frac{per\ capital\ local\ fiscal\ income}{per\ capital\ central\ fiscal\ income} \tag{4}$$

The second core explanatory variable is environmental decentralization. Environmental decentralization, on the other hand, refers to the relative autonomy of central or local governments in environmental administration, supervision, or enforcement. Existing studies regard the relevant institutions and personnel in the government as the carriers of the realization of the government's environmental decentralization function [34]. This paper uses the ratio of the standardized size of environmental protection-related departments between central and local governments as a measure to depict the level of environmental decentralization between the central and local governments [10]:

$$ED_{i,t} = \left[\frac{\frac{P_{i,t}}{pop_{i,t}}}{\frac{N_t}{pop_t}}\right]\left[1-\left(\frac{GDP_{i,t}}{GDP_{i,t}}\right)\right] \tag{5}$$

Where $P_{i,t}$ is the size of the environmental protection agency in local government, N_t is the size of the environmental protection department in central government, pop_t is the population size, and $GDP_{i,t}$ is the gross domestic product. Central environmental decentralization can be viewed as the ratio of the relative size of local government environmental agencies to the relative size of central government environmental agencies, deflated by the relative size of the local economy. A higher degree of environmental decentralization indicates that the local government has a higher degree of discretion in environmental matters relative to the central government.

Moderator Variable

The moderating variable in this study is industrial policy. This paper uses the industrial policies enacted by central and local governments as a starting point to explore the effects of the decentralization system on carbon productivity. In line with existing literature, industrial policy is defined as a dummy variable: if an industry is designated as a key, targeted, or supported industry in either the central or local government's five-year plans, the industrial policy variable is set to 1; if not, it is set to 0 [41].

Control Variables

Manufacturing low-carbon transformation may be affected by multiple factors, and to obtain the effect of industrial policy on manufacturing low-carbon transformation, control variables need to be included in the regression analyses to strip out other influencing factors [42-44]. (1) Environmental regulation (ER), using the frequency of environmental words in the government work report, i.e., the proportion of the number of words related to environmental protection to the total number of words in the report, as a proxy variable for environmental regulation. (2) Per capita output (Prod), measured by dividing the value added of industry by province and industry by the average number of all employees. (3) Government intervention (Gov), measured by the ratio of the sum of state capital

Table 1. Descriptive statistics.

Variable	N	Mean	S.D.	Min.	Median	Max
CP	12570	3.4184	2.7769	.1568	2.3682	10.4397
FD	12570	0.0969	0.0971	0.0025	0.0537	0.3303
ED	11460	0.0825	0.0731	0.0155	0.0537	0.3721
IP	12570	0.4559	0.4981	0	0	1
ER	12570	0.0042	0.0033	0.0020	0.0064	0.0151
Prod	12570	38.8115	58.2978	29.8360	20.2567	197.2267
Gov	12570	0.2635	0.2684	0.0067	0.1559	0.8877
Size	12570	4.6478	1.5025	2.0794	4.8110	7.1148
Profit	12570	0.0359	0.0589	-0.0579	0.0250	0.1836
Aver_firm	12570	0.0341	0.0293	0.0097	0.0235	0.1222
Cap_inten	12570	26.1463	40.8401	12.0782	11.2500	148.0588

and collective capital to total corporate capital. (4) Size, measured by the logarithm of the number of enterprise units. (5) Profit, measured by the ratio of total profit to industrial value added. (6) Average enterprise size (Aver_firm), measured by dividing the average annual number of employees by the number of enterprise units. (7) Capital Intensity (Cap_inten), measured by the ratio of the current year's capital stock to the annual average number of employees by province and by industry.

Data

This study utilizes data from the China Industrial Economic Statistics Yearbook and the China Carbon Accounting Database to compile input-output and environmental data for 30 provincial regions across China and 36 industrial sectors (at the two-digit level) from 1997 to 2019. This approach aims to offer a precise measure of carbon productivity within China's industrial sectors.

In terms of explanatory variables, this paper calculates the indicators of fiscal decentralization in each province from 2009 to 2019, using the original data obtained from the China Statistical Yearbook. In addition, this paper obtains relevant data from the China Environmental Yearbook and calculates the indicators of environmental decentralization for each province in China from 2004 to 2015. Data on targeted (key) industrial policies is obtained from the five-year national economic and social development plan outlines issued by the Central People's Government of the People's Republic of China and local governments in each province. Table 1 reports descriptive statistics for the main variables.

Results and Discussion

Baseline Results

Table 2 reports the results of the baseline regressions. Overall, the coefficient on industrial policy (IP) is always significantly positive, suggesting that policy-supported industries are more carbon efficient relative to unsupported industries. Columns (1) and (2) use fiscal decentralization and industrial policy to construct the interaction term (IP × FD). Column (1) includes only province, industry, and time-fixed effects, while column (2) reports the full model with control variables. The coefficients on the interaction terms we are interested in show that the higher the degree of fiscal decentralization, the more industrial policy can increase carbon productivity. The reason for this is that the increase in fiscal capacity helps the government better implement industrial policy to achieve win-win development in terms of economic growth and emission reduction. Under the regulation and guidance of the central government, local governments not only have the incentive to promote economic development in the industries that are the focus of their policies but are also more capable of promoting the low-carbon transformation of industry.

Columns (3) and (4) report the results of the baseline regressions for environmental decentralization. It can be seen that while the coefficient of environmental decentralization is significantly positive, the coefficient of the interaction term between environmental decentralization and industrial policy (IP × ED) is significantly negative, implying that environmental decentralization inhibits the promotion of carbon productivity by industrial policy. The reason is that local government's financial and administrative powers have been continuously separated, and the decentralization of administrative powers does not match the financial

Table 2. Baseline regression.

	(1)	(2)	(3)	(4)
IP×FD	0.462**	0.508**		
	(0.205)	(0.206)		
FD	0.0274***	0.0254***		
	(0.00342)	(0.00354)		
IP×ED			-1.224**	-0.876**
			(0.534)	(0.392)
ED			1.649***	1.382***
			(0.430)	(0.462)
IP	0.387***	0.586***	0.224***	0.499***
	(0.0506)	(0.0910)	(0.0663)	(0.102)
Constant	0.0287	-0.196**	0.476***	0.144
	(0.0452)	(0.0932)	(0.0424)	(0.0943)
Control variables	No	Yes	No	Yes
Province	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Obs	12570	11721	11460	10653
adj. R^2	0.472	0.506	0.491	0.522

Standard errors in parentheses * $p<0.1$, ** $p<0.05$, *** $p<0.01$

powers possessed by local government environmental protection agencies, so environmental decentralization from the central government to the local governments cannot play a sufficiently constraining role in improving carbon productivity.

Robustness Tests

To ensure the robustness of the results of the benchmark model, the following robustness tests are conducted, and the results are presented in Table 3. On the one hand, to prevent measurement errors, the proxy variables for fiscal decentralization are replaced with fiscal expenditure decentralization (fd_ex) and fiscal freedom decentralization (fd_fr). With fiscal expenditure decentralization as the explanatory variable, columns (1) and (2) report the unincorporated control variables and the full model, respectively, while columns (3) and (4) use fiscal freedom as the explanatory variable. The results suggest that both the expansion of local fiscal spending power and freedom can contribute to the carbon productivity-enhancing effects of industrial policy. On the other hand, to mitigate the measurement error of environmental decentralization, this paper recalculates the environmental supervision decentralization index (IP×ed_sup) using the number of environmental supervision agencies, and the regression results are shown in columns (5) and (6). It can be seen that the regression results are consistent with the research hypotheses, and the increase in the level of environmental supervision decentralization also hinders the carbon productivity effect of industrial policy.

Additionally, this paper uses a more intuitive dependent variable for robustness testing: carbon emission intensity (the carbon emissions per unit of industrial output, taken as the natural logarithm). As defined, higher carbon productivity implies lower carbon emission intensity. Therefore, columns (7) and (8) report the result of the robustness test with the replacement of the dependent variable; the expected regression coefficient should be opposite to that of the baseline regression. The empirical results in the table confirm this. Hence, the core conclusions of this paper remain robust after the replacement of the dependent variable.

Heterogeneity Tests

The Effect of Fiscal Decentralization on the Heterogeneity of Industrial Policies from Different Sources

First, the impact of fiscal decentralization on the implementation effects of industrial policies from

Table 3. Robustness test.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
IP×fd_ex	0.385*	0.402**						
	(0.203)	(0.204)						
fd_ex	0.0233***	0.0214***						
	(0.00355)	(0.00366)						
IP×fd_fr			0.00518	0.578***				
			(0.144)	(0.144)				
fd_fr			0.532***	0.570***				
			(0.200)	(0.200)				
IP×ed_sup					-0.861**	-0.427**		
					(0.421)	(0.208)		
ed_sup					1.920***	1.308***		
					(0.329)	(0.346)		
IP×FD							-0.237**	
							(0.1000)	
FD							-0.691***	
							(0.141)	
IP×ED								1.236***
								(0.386)
ED								-1.176***
								(0.323)
IP	0.392***	0.595***	0.860***	0.491***	0.205***	0.457***	0.0456	0.00294
	(0.0519)	(0.0917)	(0.0820)	(0.0895)	(0.0627)	(0.0984)	(0.0571)	(0.0467)
Constant	0.0534	-0.172*	-1.016***	-0.942***	0.438***	0.152*	-1.216***	-2.094***
	(0.0497)	(0.0955)	(0.107)	(0.115)	(0.0375)	(0.0905)	(0.0758)	(0.0310)
Control variables	No	Yes	No	Yes	No	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	12570	11721	12570	12570	11460	10653	11077	10716
adj. R^2	0.471	0.505	0.552	0.600	0.492	0.522	0.815	0.847

different sources is examined. Specifically, industrial policies are classified into three categories: jointly supported by the central and local government (IPcp), central government only (IPoc), and local government only (IPop). The interaction terms are constructed with all the proxy variables for fiscal decentralization and industrial policy. Table 4 reports the regression results. As can be seen from columns (1) and (2), fiscal decentralization significantly contributes to the implementation effect of industrial policy with joint central-local support (IPcp×fd_in) as well as industrial policy with local support only (IPop×fd_in). Meanwhile, the regression coefficients of the interaction term between centrally-supported industrial policy only and fiscal decentralization (IPoc×fd_in) are negative and insignificant, suggesting that fiscal decentralization does not contribute to the manufacturing low-carbon transformation effect of central government-exclusive industrial policy. The results in columns (3) - (6) illustrate that the results remain consistent after replacing the measure of fiscal decentralization with fiscal expenditure decentralization and fiscal freedom

Table 4. Heterogeneity test for the effect of fiscal decentralization on the heterogeneity of industrial policies from different sources.

	(1)	(2)	(3)	(4)	(5)	(6)
IPcp×fd_in	1.214***	1.208***				
	(0.291)	(0.291)				
IPoc×fd_in	-0.188	-0.108				
	(0.256)	(0.257)				
IPop×fd_in	0.710**	0.769***				
	(0.279)	(0.279)				
fd_in	0.0316***	0.0296***				
	(0.00349)	(0.00362)				
IPcp×fd_ex			1.124***	1.090***		
			(0.290)	(0.289)		
IPoc×fd_ex			-0.216	-0.158		
			(0.255)	(0.256)		
IPop×fd_ex			0.573**	0.595**		
			(0.276)	(0.276)		
fd_ex			0.0274***	0.0254***		
			(0.00363)	(0.00375)		
IPcp×fd_fr					0.384**	0.794***
					(0.192)	(0.189)
IPoc×fd_fr					-0.502***	-0.0800
					(0.183)	(0.182)
IPop×fd_fr					0.292	0.869***
					(0.210)	(0.206)
fd_fr					0.567***	0.662***
					(0.200)	(0.200)
IPcp	0.258***	0.485***	0.254***	0.488***	0.560***	0.372***
	(0.0718)	(0.102)	(0.0736)	(0.104)	(0.110)	(0.114)
IPoc	0.341***	0.562***	0.348***	0.575***	1.060***	0.842***
	(0.0611)	(0.0895)	(0.0627)	(0.0906)	(0.102)	(0.106)
IPop	0.520***	0.735***	0.528***	0.752***	0.892***	0.584***
	(0.0664)	(0.0996)	(0.0682)	(0.101)	(0.119)	(0.121)
Constant	-0.0142	-0.261***	0.00791	-0.240***	-1.027***	-1.082***
	(0.0463)	(0.0900)	(0.0509)	(0.0926)	(0.107)	(0.113)
Control variables	No	Yes	No	Yes	No	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Obs	12570	11734	12570	11734	12570	12570
adj. R^2	0.474	0.508	0.473	0.507	0.554	0.601

decentralization. The above results suggest that fiscal decentralization promotes carbon productivity mainly by improving the implementation of local government-related industrial policies.

The Effect of Environmental Decentralization on the Heterogeneity of Industrial Policies from Different Sources

On the other hand, how environmental decentralization affects the implementation effects of industrial policies from different sources is to be examined. As in the previous analysis, industrial policies are classified into three categories, namely, simultaneous central and local support (IPcp), central support only (IPoc), and local support only (IPop), and interaction terms are constructed and added to the model with proxies for environmental decentralization, respectively.

Table 5 presents the regression results. Columns (1) and (2) report the regression results of the interaction term between environmental administrative decentralization and the three types of industrial policies, while columns (3) and (4) use environmental

Table 5. The effect of environmental decentralization on the heterogeneity of industrial policies from different sources.

	(1)	(2)	(3)	(4)
IPcp×ed_adm	-0.684	-0.466		
	(0.924)	(0.935)		
IPoc×ed_adm	-3.333***	-3.425***		
	(0.802)	(0.818)		
IPop×ed_adm	0.100	0.618		
	(0.641)	(0.653)		
ed_adm	1.519***	1.254***		
	(0.434)	(0.463)		
IPcp×ed_sup			-0.927	-0.608
			(0.760)	(0.767)
IPoc×ed_sup			-1.818***	-1.803**
			(0.702)	(0.709)
IPop×ed_sup			-0.191	0.351
			(0.500)	(0.508)
ed_sup			1.831***	1.230***
			(0.334)	(0.350)
IPcp	0.206**	0.481***	0.236**	0.486***
	(0.100)	(0.126)	(0.0945)	(0.121)
IPoc	0.00313	0.270**	0.0387	0.287***
	(0.0830)	(0.107)	(0.0780)	(0.102)
IPop	0.474***	0.781***	0.380***	0.662***
	(0.0858)	(0.118)	(0.0826)	(0.114)
Constant	0.488***	0.148	0.447***	0.153*
	(0.0428)	(0.0921)	(0.0382)	(0.0881)
Control Variable	No	Yes	No	Yes
Provinces	Yes	Yes	Yes	Yes
Sector	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Obs	11460	10663	11460	10663
adj. R^2	0.492	0.523	0.492	0.523

supervision decentralization as a proxy variable. There are significant differences in the impact of environmental decentralization on the effects of different sources of industrial policy implementation. The negative impact of environmental decentralization on industrial policy implementation is mainly found in central-exclusive policies (IPoc×ed_adm and IPoc×ed_sup); the effect of environmental decentralization on central-local joint support for industrial policy is negative, and the effect on local-only support for industrial policy is positive, but neither of them is significant. This result confirms that environmental decentralization by the central government is not effective in promoting the low-carbon transformation effect of industrial policy, which is another proof of the important role of local governments in improving carbon productivity.

Mechanism Analysis

Referring to the explanations of pollution emissions in environmental economics and the conclusions of existing literature, this paper selects two important variables influencing mechanisms: energy structure [45] and green innovation [46]. On one hand, the cleaner the energy structure, the less fossil energy is used for the same output, thus the higher the total factor carbon productivity. Energy structure is measured by the proportion of non-fossil energy in total energy consumption, with all units converted to ten thousand tons of standard coal equivalent [47].

On the other hand, green innovation is a crucial driver of total factor carbon productivity. More green innovation, with constant factor inputs, can achieve more output and produce less carbon emissions, thus increasing carbon productivity [48]. The total number of green patent applications is used as a proxy variable for green innovation. To avoid the impact of zero values, ln (total green patent applications + 1) is used to proxy green innovation.

In terms of modeling, to test how different decentralization systems affect carbon productivity through the implementation of industrial policies, this paper replaces the dependent variable in the baseline model with the mechanism variables for testing [49]. Table 6 columns (1) and (2) report the test results for the energy structure impact mechanism. IP×FD is significantly positive, indicating that the higher the degree of fiscal decentralization, the more industrial policy support can promote the cleaning of the energy structure, thereby enhancing carbon productivity. IP×ED is significantly negative, suggesting that the higher the degree of environmental decentralization, the more industrial policy support will reduce the proportion of non-fossil energy, thereby inhibiting

Table 6. The regression results of the mechanism analysis.

	(1)	(2)	(3)	(4)
	Energy structure		Green innovation	
IP×FD	0.00664***		0.213**	
	(0.00169)		(0.0862)	
FD	-0.00255		0.893***	
	(0.00239)		(0.126)	
IP×ED		-0.0159***		-1.044***
		(0.00524)		(0.364)
ED		0.00643		0.726**
		(0.00434)		(0.367)
IP	-0.00509***	0.00248***	-0.0948*	0.111***
	(0.000966)	(0.000640)	(0.0531)	(0.0403)
Constant	0.0302***	0.0266***	-0.171**	0.482***
	(0.00128)	(0.000421)	(0.0743)	(0.0336)
Controls	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	10583	10866	5695	5506
adj. R^2	0.868	0.988	0.555	0.753

carbon productivity. Table 6 columns (3) and (4) report the regression results for the green innovation impact mechanism. Similarly, IP×FD is significantly positive, indicating that fiscal decentralization promotes an increase in the number of green patent applications through the implementation of industrial policies, while IP×ED is significantly negative, indicating that the expansion of environmental decentralization inhibits the incentivizing effect of industrial policy implementation on green innovation.

Conclusions

Main Findings

Achieving the dual goals of economic growth and carbon reduction is the core orientation of China's future development, which requires effective coordination between the government's decentralization system and policy implementation. This paper examines the impact of fiscal and environmental decentralization, within the context of China's unique central-local government relationships, on the low-carbon transformation of the industrial sector via industrial policy. Analyzing data from the manufacturing sectors (at the 2-digit code level) across 30 provinces from 1997 to 2019, the study reveals that fiscal decentralization supports the effectiveness of industrial policies in fostering low-carbon transformation. This support is evident in policies backed by both central and local governments, as well as those specific to local governments, whereas the influence of central government-exclusive policies appears minimal. In contrast, environmental decentralization seems to hinder the carbon productivity benefits of industrial policies, particularly those set by the central government. Furthermore, energy structure and green innovation are two important channels affecting carbon productivity.

Discussion

Compared to existing studies, this paper better quantifies the impact of decentralization on carbon productivity in the industrial sector. Overall, this paper is at the same level of abatement effects found in other fiscal decentralization papers [10], but it finds that the existing literature underestimates the adverse effects of environmental decentralization on carbon abatement in the industrial sector through industrial policy [5].

These findings highlight the relevance of public choice theory in environmental regulation, indicating that local governments, with their intricate knowledge and capacity to capitalize on regional advantages, are better suited to facilitate the low-carbon transition of industries within their jurisdictions. Conversely, the central government, although equipped with a wider view of industrial evolution, might face difficulties in directly engaging with regional environmental policies or may need more efficient regulatory instruments.

Social Implications

On the one hand, this study reveals that within the current fiscal decentralization framework, easing fiscal constraints on local governments facilitates the effectiveness of industrial policies aimed at low-carbon transformation. Consequently, future reforms should further deepen the fiscal decentralization system, moving away from a model that centralizes revenue collection but decentralizes expenditure. A more rational division of public responsibilities between central and local governments, coupled with an equitable distribution of financial power, could prevent local governments from diverting funds away from environmental protection. This would ensure that local authorities have adequate financial resources to support initiatives such as low-carbon and energy-saving innovations, technological upgrades, and local industry investments in low-carbon solutions. Ultimately, this can enhance the low-carbon competitiveness of key industries, fostering a positive feedback loop for local finances and creating a virtuous cycle [50, 51].

On the other hand, this study concludes that the current model of decentralized environmental governance between the central and local governments does not effectively support low-carbon transformations. To enhance the impact of industrial policy implementation, it is recommended that environmental decentralization, particularly in terms of administration and supervision, shift towards a more centralized approach. This can be achieved by appropriately expanding the central government's responsibilities in environmental administration, supervision, and management, while also curbing excessive local government intervention in environmental governance. Such adjustments are expected to reduce instances of local governments offloading environmental responsibilities.

Managerial Implications

On the one hand, the above implications will result in urging regions with insufficient local financial capacity to support low-carbon transformation by establishing and improving the low-carbon environmental protection transfer payment system. Firstly, the central government must regulate the use of low-carbon environmental protection special transfer payments through the scientific and reasonable development of special transfer payment projects and standard systems to ensure that funds can be targeted for the implementation of key industrial carbon reduction and energy-saving projects and to enhance the local government's ability to govern the low-carbon transformation. Secondly, it is necessary to continue to deepen the financial transfer between local governments. The central government can take the lead in establishing a horizontal transfer payment system, play a leading role in low-carbon finance in high-income provinces, break through the constraints of local administrative jurisdictions, and stimulate the enthusiasm of local governments for low-carbon transformation through the construction of an inter-regional financial transfer payment system to eliminate as much as possible the free-riding behavior of local governments. Finally, the central government's fiscal expenditure can further strengthen the investment in infrastructure construction related to low-carbon transformation, give full play to the environmental protection spillover effect of low-carbon infrastructure, and promote the low-carbon transformation of industry.

However, on the other hand, although decentralized environmental regulation cannot assist carbon management, the environmental authority also needs to analyze specific problems and adopt targeted policy measures for different types of environmental authority divisions. Concerning the decentralization of environmental administration, taking into account the local information advantages of local governments in environmental planning and local environmental regulations, the central government should strengthen its efforts to guide local governments to improve their capacity for environmental administration, but it should not give local governments too much power over environmental administration. The power of environmental supervision can be appropriately transferred upwards, and the central government's environmental protection supervision system can be strengthened to form an environmental supervision system mainly based on the central government. However, in the long run, to promote the low-carbon transformation of industry, it is still necessary to strengthen the construction of the local government's environmental monitoring system and encourage local governments to form an incentive for environmental monitoring.

Limitations and Future Research

Due to data limitations, this paper is unable to examine new developments in the relationship between centralized decentralization and carbon productivity in recent years. In addition, the measurement of industrial policy needs to be further refined in the future, and other government behaviors need to be included in the influence mechanism of central-local relations.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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