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Original Research

Research on the Impact of Green Technology Innovation in the Manufacturing Industry on the High-Quality Development of the Manufacturing Industry Under "Dual Circulation"

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Abstract

Taking the high-quality development of the manufacturing industry and the level of green technological innovation of the manufacturing industry in 30 provinces in mainland China, except for Tibet, from 2012 to 2022 as the research object, we follow the research design of "Theoretical analysis-variable measurement-empirical test-countermeasure suggestion". Following the research design of "theoretical analysis-variable measurement-empirical test-countermeasure suggestion", we analyze the impact of green technological innovation on the high-quality development of the manufacturing industry under the new development pattern of dual circulation. Firstly, we organize the literature related to the green technology innovation of double-loop manufacturing and the high development of the manufacturing industry, analyze the theory of the three by distinguishing their connotations, construct a theoretical model, and put forward the research hypotheses. Secondly, establish the evaluation index system of green technology innovation and high-quality development of the manufacturing industry, and carry out empirical analysis and test. It is concluded that green technological innovation in the manufacturing industry positively promotes the development of the internal cycle, the internal cycle positively promotes the high-quality development of the manufacturing industry, green technological innovation in the manufacturing industry can further promote the high-quality development of the manufacturing industry by driving the internal cycle, and the external cycle positively regulates the relationship between the internal cycle and the high-quality development of manufacturing industry. Finally, according to the empirical results, this paper puts forward targeted policy recommendations for the high-quality development of China's manufacturing industry.

Keywords: Green technological innovation in manufacturing, dual circulation, high quality development of manufacturing, moderated mediation effect

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Introduction

Since the new crown epidemic in 2020, China's economy has suffered a huge impact. The international consumer market continues to decline because the domestic manufacturing industry is too dependent on the international big market, affected by the lack of power of the international big cycle, and many of China's manufacturing enterprises continue to reduce the scale of exports. At present, China's manufacturing industry is still at the low and middle end of the global value chain positioning. In the context of rising protectionism, due to the United States holding the high-end technology of manufacturing, to China's manufacturing enterprises to implement the great technical pressure, China should gradually move away from over-reliance on the global supply chain, and turn to the international and domestic dual circulation. Among the global manufacturing powers, China has failed to enter the ranks of manufacturing powers due to the development model of "high input, high emission, high pollution, and low efficiency". High-quality development of China's manufacturing industry is a necessary requirement for China's manufacturing industry to rank among the ranks of manufacturing powers, which requires that China's manufacturing industry must be in the whole process of production, manufacturing, and sales to achieve a high level of sustainable development with low input of factors of production, high efficiency of resource allocation, excellent quality of the ecological environment, and good economic and social benefits. Green technology innovation will achieve high-quality development of the manufacturing industry, adjust the industrial structure, and accelerate the green transformation and upgrading of manufacturing enterprises in an important way. Among them, green technology innovation is an important driving force for realizing green development and forming new quality productivity, and it is the expansion and enhancement of the traditional technology innovation system on the basis of following the ecological principle and the law of ecological economic development. For example, China's Golan Energy Conservation adheres to the concept of green development and continuously improves the level of green technological innovation, which promotes the structural adjustment and transformation of the company's products and accelerates the pace of new industrialization; Germany's BMW, Audi and others have improved their production efficiency and product quality through the adoption of advanced green innovation technology; and the United States' Tesla, Ford, and others have achieved highly efficient and green production through green innovation technology.

As a result, advanced technologies in manufacturing are being held hostage by advanced countries and green and low-carbon development has slowed down the process of high-quality manufacturing. In the face of this historic change of the times, and in the face of the new development strategy of the "dual circulation" environment, exploring the establishment of a high-quality industrial development model of China's manufacturing industry is undoubtedly a key issue that needs to be investigated in depth.

Literature Review

Research on High-Quality Development of the Manufacturing Sector

The concept of "high-quality development" has been elaborated and interpreted by many experts from different perspectives. Based on the perspective of high-quality development of China's economy, Jin (2018) argues that as people's pursuit of quality life continues to grow, high-quality development can better meet this need [1]. Li Jinchang et al. (2019) suggest that high-quality development is a sustainable development model that is people-centered, driven by green technological innovation, and focuses on environmental protection and benefits [2]. Wang Yiming (2018) believes that high-quality development should be examined from the macro, micro, and meso levels, in which the macro aspect is mainly measured by the overall quality of economic development, the micro aspect can be examined from the quality of products and services, and the meso aspect is mainly measured by the quality of industry and regional development [3]. From the perspective of high-quality development of the manufacturing industry, Huang Qunhui (2018) said that under the new development concept, high-quality development of the manufacturing industry is more in line with the development of social needs [4]. Luo Wen (2018) believes that high-quality development is the development that pays more attention to quality and efficiency [5]. Guo Kesha (2019) believes that the high-quality development of the manufacturing industry in the future will be the development of innovation, integration, and openness based on innovation and focusing on brand and service [6]. Li (2018) puts forward the new idea of "out with the old and in with the new" to promote the upgrading and transformation of China's manufacturing industry [7]. On the one hand, it is necessary to cut down on the consumption of resources that are not beneficial to production; on the other hand, it is necessary to strengthen the investment in research on green technology and encourage enterprises to actively carry out independent scientific research, and at the same time, it is also necessary to further deepen the cooperation between industrial chains in order to improve the overall competitiveness level. Lin Chunyan et al. (2018) pointed out that in order to cope with the new economic development model and address the imbalances and deficiencies in the manufacturing industry, upgrading the quality of the supply system has become a key strategy. They emphasized four key areas: smart manufacturing, service-oriented manufacturing, green manufacturing, and quality manufacturing,

and regarded them as the core strategies to promote high-quality development [8].

Green Technology Innovation and High-Quality Development of the Manufacturing Industry

In recent years, domestic and foreign scholars focus their attention on exploring the influencing factors of high-quality development of the manufacturing industry, Wang and Li (2021) conducted a study by establishing a nonlinear threshold regression model, pointing out that the capacity utilization rate, profitability, foreign direct investment, and government participation have a significant positive impact on the high-quality development of manufacturing industry [9]. Liu Xiaohui (2018) found that the effect of green technology innovation is better than factor-driven by studying the current situation of manufacturing development in Henan Province, and the core of the manufacturing industry to realize high-quality development is green innovation [10]. Chen Zhao and Liu Yingman (2019) empirically examined the mediating role of low carbon economy on the influence effect between green technology innovation and high-quality development of the manufacturing industry by establishing a mediating effect model and examined the specific role mechanism of green technology innovation affecting the high-quality development of regional economy [11].

Dual Circulation and High-Quality Development of Manufacturing

In terms of the meaning of the new development model of dual circulation, Chinese scholars have explored this a lot, but there are still disagreements about the determination of the concept of dual circulation. Tang Doduo et al. (2020) define dual circulation as the cycle between supply and demand elements at the macro level. Among them, the inner-cycle economy is based essentially on the domestic supply and demand sides to realize the fit, provide products for the domestic market, and use domestic factors of production, and the outer-cycle economy introduces the foreign market, so that the domestic and foreign supply and demand sides can realize the smooth flow, provide products for the foreign market and use foreign factors of production [12]. Li Feng (2021) reveals through the study of the value chain that the internal circular economy practiced in China is essentially an economic system that is fully developed and completed within China, while the external circular economy is an economic model that relies on foreign resources such as raw materials, processing and manufacturing, and sales channels [13]. Long Shaobo et al. (2021) define the meaning of internal circular as the external circular economy is the flow of products, services, technology, and capital between domestic and international markets [14]. Based on the input-output perspective, Lu Jiangyuan (2021) explains his view on the concept of the "inner cycle", which implies that all stages of factor inputs, rationalization of the income distribution, balancing of inputs and outputs in various industries, and satisfying consumer demand are not involved in the process of global value creation. It is argued that the "inner loop" implies that all stages of factor inputs, rationalization of revenue allocation, balancing inputs and outputs across industries, and satisfying consumer demand are not involved in the process of global value creation, whereas the "outer loop" involves global value creation in one or more of these steps [15].

Existing literature mainly explores the impact of dual circulation on the high-quality development of the manufacturing industry from both theoretical and empirical aspects. At the theoretical level, Guo Kesha and Tian Xiaoxiao (2021) point out that reconstructing the manufacturing industry chain with the domestic big market as the leading one and relying on the international cycle level, domestic and international mutual promotion can coordinate the regional layout to promote the high-quality development of the manufacturing industry [16]. At the empirical level, Wang Yuyan et al. (2021) empirically derived the result that the domestic big cycle can enhance the international cycle by constructing a model, and the manufacturing industry can further grow and develop in the international cycle [17]. Sun Wei et al.(2022) studied the relationship between external demand, internal demand, and asset reallocation in the manufacturing industry from the micro perspective, and proposed that both domestic and international markets should be taken into account in order to effectively promote the reallocation of assets in manufacturing enterprises [18]. Du Pengcheng (2021) discussed in depth the relationship between the evolution of the dual circulation model, the degree of environmental protection, and the optimization of the structure of the manufacturing industry on the improvement of the quality of the development of the manufacturing industry, and put forward that we should focus on building an ecological environment conducive to the sustainable development of the manufacturing industry according to the new strategy of the "dual circulation" [19].

Commentary

Combing through the existing literature, it is found that in the current research on how to adjust the structure of the manufacturing industry to meet the needs of the current high-quality development of the economy in the relevant literature, there may be two deficiencies: first, there are more achievements in researching the enhancement of green technological innovation, connotative characteristics of high-quality development, and factors affecting high-quality development from a qualitative perspective, and relatively fewer achievements in researching the enhancement of green technological innovation and its impact on high-quality development of the manufacturing industry

from a quantitative perspective. There may be two shortcomings: firstly, there are more results from a qualitative perspective on the enhancement of green technology innovation and its impact on high-quality development, while there are relatively few results from a quantitative perspective on the enhancement of green technology innovation and its impact on high-quality development of the manufacturing industry; secondly, the existing research focuses on the coordination of internal elements of the manufacturing industry, with less consideration given to the economic environment external to the industry, and the construction of the evaluation system lacks comprehensiveness and objectivity, and the lack of in-depth exploration of a complete conduction mechanism, and the discussion on the heterogeneity of the development of green technological innovation in the manufacturing industry is not in-depth enough. In order to improve the shortcomings of the existing research, this paper tries to explore how green technology innovation affects the high-quality development of manufacturing industry under the new development pattern of dual circulation based on the theory of "dual circulation" and utilizing the provincial data of national manufacturing industry from 2012 to 2022. Through the related research on green technology innovation, dual circulation, and high-quality development of the manufacturing industry, the intrinsic connection between the three is found, and then the mechanism of the three is explored in detail and empirically examined, and policy suggestions for promoting high-quality development of manufacturing industry are put forward from the perspectives of green technology innovation, inner cycle, and outer cycle.

The contribution of this paper lies in the following: firstly, it is the first time that green technological innovation, double-cycle, and high-quality development of the manufacturing industry are studied under a unified framework, and the direct impact of green technological innovation on high-quality development of the manufacturing industry under the double-cycle pattern is analyzed in depth at the theoretical level, and the mechanism of the role of green technological innovation on high-quality development of manufacturing industry is investigated from the inner and outer cycles, which is of great academic significance to the current development of manufacturing industry. It explores the impact of green technological innovation on the high-quality development of the manufacturing industry from the double-cycle pattern and puts forward specific and precise related policies, which provide scientific and practical guidance for constructing a new development pattern of double-cycle, promoting the level of green technological innovation and accelerating the high-quality development of manufacturing industry.

Material and Methods

Theoretical Mechanisms and Assumptions

Direct Effects of Green Technology Innovation on the High-Quality Development of the Manufacturing Industry

A new innovation model led by green technology innovation plays a key role in driving high-quality growth in manufacturing. It can make the production chain of the manufacturing industry more flexible, thereby improving the accuracy of products and further advancing the progress of decentralized production, which provides an opportunity to improve the current high-volume production methods. At the same time, with the help of new technologies, the effectiveness of work and production capacity along the existing manufacturing chain can be effectively enhanced. In addition, green technological innovation has given birth to a whole new category of goods and services, and these new technologies have also brought about the development of new products, business opportunities, and even industry sectors, which in turn have triggered huge market demand and also stimulated economic growth. Finally, green technological innovation plays an important role in promoting the transformation and upgrading of the manufacturing industry, laying the foundation for its high-quality development. In addition, green technology innovation also helps to enhance the global competitive advantage of the manufacturing industry, through the combination of scientific research results and practical applications, strong business drivers to achieve technological breakthroughs and major innovations, which has a positive impact on enhancing the scale and strength of manufacturing enterprises [20]. The demand for green technology is strongest in the manufacturing industry, which plays a leading role in innovation based on the concept of green development. Green technology innovation changes the traditional production process, meets the inherent requirements of upgrading the traditional manufacturing industry and improving the quality of the modern manufacturing industry, and plays a crucial positive impact on the development of the industry. Therefore, based on the literature review and the above discussion, the following hypotheses are proposed.

H1: Green technology innovation has a positive contribution to the high-quality development of the manufacturing industry.

Mediating Effects of Internal Circulation between Green Technology Innovation and High-Quality Manufacturing Development

Green technology innovation, with green development at its core, has a profound impact on national consumer behavior patterns and volumes, which continue to stimulate China's business environment

and tap into potential market space. Responding to the public's desire to purchase environmentally friendly products or provide new green services through green technology will improve the quality of their lives and the environment in which they shop; this will not only facilitate the development of large networks within the Chinese economy but also further strengthen the linkages between domestic and international trade, and the changes brought about by green technological innovation will redefine the traditional way of manufacturing. This change brought about by green technological innovation will redefine the traditional way of manufacturing. At this stage, the structural imbalance of China's manufacturing development is more prominent, seriously restricting the operation of the internal and external dual circulation market, and the manufacturing industry urgently needs to be transformed into high-quality development. The arrival of green technology innovation breaks the traditional distribution channels and structures of previous products and promotes the optimization of manufacturing structure and the expansion of consumption scale [21]. Therefore, based on the literature review and the above discussion, the following hypotheses are proposed.

H2: Green technological innovation positively contributes to endogenous development.

The internal cycle is not the closed economy of the past, which has successfully realized the internalization of the shift from external capital and market, thus effectively mitigating the negative effects brought about by over-reliance on external investment and consumption demand [22]. Therefore, in order to optimize the degree of product satisfaction, manufacturers need to adjust or improve their production resources and processes, and promote the industry to shift from traditional manufacturing to service-oriented, digital smart manufacturing, so as to achieve the goal of high-quality development [23]. Therefore, based on the literature review and the above discussion, the following hypotheses are proposed.

H3: Internal circulation positively contributes to high-quality development in manufacturing.

The application of green technologies enhances and supports the "inner circle" of economic development. New green technology tools can make the manufacturing process more environmentally friendly and accurate, thus promoting the development of decentralized factories, bringing opportunities to improve the existing large-scale production lines, and enhancing the effectiveness and capacity of the old and new industrial chains [24]. In addition, the results of the emerging green technology have bred new green goods and services, which not only generate a large number of business opportunities but also generate a series of new industry sectors. At the same time, it can also effectively promote the modernization and upgrading of traditional industries, which provides a strong guarantee for the high-quality development of the manufacturing industry. Therefore, based on the literature review and the above discussion, the following hypotheses are proposed.

H4: Green technology innovation further promotes high-quality development of the manufacturing industry by driving the inner cycle.

The domestic and international cycles of the economy constitute the basic pattern of economic operation, which is closely related to industrial upgrading, and is conducive to opening up various links in the production process and injecting vitality into high-quality development [25]. In the face of external economic pressures, the country can rapidly integrate its domestic innovation chain, increase labor productivity, and drive manufacturing up the global value chain [26]. Therefore, based on the literature review and the above discussion, the following hypotheses are proposed.

H5: The relationship between positive regulation of the inner cycle by the outer cycle and high-quality development in manufacturing.

Econometric Modeling

In the mid-1980s, Baron and Kenny proposed the stepwise test factor method, which consists of three main stages: the first step is to test for significant differences in factor C; the second step is to analyze the two factors, A and B, individually; and the third step is to determine that they act as mediators if the results of the first two steps are shown to be unambiguous, or else to fail to confirm their mediating effect. However, this process involves a lot of modeling, so it is time-consuming and inefficient, especially when the mediating effect is weak, and it is likely to lead to results that fail to prove the mediating utility. In order to solve this problem, in 2004, Wen Zhonglin and other scholars improved the Sobel test and constructed a complete process of the mediation effect test. Referring to Wen Zhonglin [27], the following econometric model is constructed from the direct effect, the mediating effect, and the moderating effect, respectively:

$$MF_{i,t} = \alpha_0 + \alpha_1 GTI_{i,t} + \lambda \mathrm{Con}_{i,t} + \varepsilon_{i,t}$$

$$NEI_{i,t} = \beta_0 + \beta_1 GTI_{i} + \lambda \mathrm{Con}_{i,t} + \varepsilon_{i,t}$$

$$MF_{i,t} = \alpha_0 + \alpha_2 NEI_{i,t} + \lambda \mathrm{Con}_{i,t} + \varepsilon_{i,t}$$

$$MF_{i,t} = \alpha_0 + \alpha_1 GTI_{i,t} + \alpha_2 NEI_{i,t} + \lambda \mathrm{Con}_{i,t} + \varepsilon_{i,t}$$

$$MF_{i,t} = \alpha_0 + \alpha_2 NEI_{i,t} + \alpha_3 WAI_{i} + \alpha_4 NEI_{i,t} * \mathrm{WAI}_{i,t} + \lambda \mathrm{Con}_{i,t} + \varepsilon_{i,t}$$

where $MF_{i,t}$ represents the level of high-quality development of the manufacturing industry in province i in year t, $GTI_{i,t}$ represents the level of green technology innovation in province i in year t, $NEI_{i,t}$ represents the level of endocycling in province i in year t, $WAI_{i,t}$

represents the level of exocycling in province i in year t, $NEI_{i,t}*WAI_{i,t}$ represents the interaction term between endocycling and exocycling, which is used to test the moderating effect of exocycling, $Con_{i,t}$ represents a series of control variables, and $\varepsilon_{i,t}$ represents a randomized perturbation term.

Selection and Description of Indicator Variables

Explained Variables

Manufacturing high-quality development level. The level of high-quality development of the manufacturing industry is defined according to the connotation of high-quality development of the manufacturing industry, and drawing on the research of Huang Qunhui et al. [28]. The high-quality development of the manufacturing industry is measured in terms of the servitization of the manufacturing industry, greening, and intelligentization. The data are mainly from the China Statistical Yearbook, the China Industrial Statistical Yearbook, and the High Technology Industry Statistical Yearbook. In the selection of evaluation methods, this paper chooses the entropy value assignment method. The entropy assignment method, according to the degree of variation of the data of each indicator, gets the information entropy value of the indicator and then calculates the coefficient of variation of the indicator. The greater the coefficient of variation, the more information contained in the indicator, which can determine the weight of each indicator.

Core Explanatory Variables

Green technology innovation level. This paper adopts the use of the total number of green patent applications of enterprises to measure the level of green technology innovation. The data are mainly from the China Statistical Yearbook.

Mediating Variables

Inner Circulation. Drawing on the approach of scholars such as Liu Jinquan and others [29], total retail sales of consumer goods are utilized as a measure of internal circulation. Data are mainly from the China Statistical Yearbook.

Moderating Variables

Outer Circulation. Drawing on the research methodology of Jiang Xiaojuan et al. to construct an indicator system for external circulation [30], this paper constructs the outer-cycle economic system from three aspects: the export proportion of foreign-invested enterprises, the export proportion of processing trade, and the dependence on foreign trade. The data are mainly from the China Statistical Yearbook.

Control Variables

Human capital. This indicator is measured using full-time equivalents of R&D personnel; R&D intensity. The indicator is measured using internal expenditure on RD funding; Industrialization level. The indicator is measured using industrial value added; foreign investment. This indicator is measured by foreign direct investment; Technology market development level. The indicator is measured by technology market turnover. The data are mainly from the China Statistical Yearbook.

Results and Discussion

Baseline Regression

The choice of panel model estimation method depends on the characteristics of the data. This paper combines the results of the Hausman test and uses the fixed effect method to verify the relationship between green technological innovation and the high-quality development of the manufacturing industry. Stepwise regression is used to verify the research hypotheses. First, as seen in Table 1, green technology innovation ($\alpha1 = 3.399$, $p<0.01$) positively affects the high-quality development of the manufacturing industry, and thus, hypothesis H1 is supported. Secondly, the mediating role of the internal cycle between green technology innovation and the high-quality development of the manufacturing industry is tested step by step. As seen in Table 1, green technology innovation ($\beta1 = 0.974$, $p<0.05$) has a significant positive effect on the internal cycle, and thus, hypothesis H2 is verified. In Table 2, the internal cycle ($\alpha2 = 2.876$,$p<0.01$) positively promotes the high-quality development of the manufacturing industry, and thus, hypothesis H3 is verified. At the same time, green technology innovation and internal circulation are added for regression, as seen in Table 1. Green technology innovation ($\alpha1 = 2.861$, $p<0.01$) and internal circulation ($\alpha2 = 1.054$, $p<0.01$) both pass the test of significance, and thus, hypothesis H4 is established, and the mediating role of internal circulation is further tested by the Bootstrap test. The sample size is set to 1000, the confidence interval is 95%, the results are shown in Table 2, and the indirect effect Bootstrap confidence interval does not contain 0, indicating that the mediating effect of the inner loop is significant. The conclusion of this test is consistent with the findings of the aforementioned theoretical analysis, which once again verifies the research hypothesis H4 proposed in the previous section, that is, green technological innovation can influence the high-quality development of the manufacturing industry through the channel of the inner loop.

This paper further introduces the outer loop from the perspective of the moderating effect to analyze the influence of the outer loop on the relationship between

green technological innovation, the inner loop, and the high-quality development of the manufacturing industry, and in order to eliminate the problem of covariance, the independent variables and moderating variables are centered. In Table 2, the interaction term between the inner loop and the outer loop is added, and the coefficient of the interaction term ($\alpha 4 = 0.0429$, $p<0.1$) passes the significance test, indicating that the outer loop positively regulates the relationship between the inner loop and the high-quality development of the manufacturing industry, and the hypothesis H5 is verified.

The regression model analysis shows that hypotheses H1, H2, H3, and H4 pass the significance test, which concludes that: green technological innovation positively promotes the development of the internal cycle, the internal cycle positively promotes the high-quality development of the manufacturing industry, and green technological innovation can further promote the high-quality development of the manufacturing industry by driving the internal cycle. From the test of regional heterogeneity, it can be seen that for different regions with different levels of high-quality development of the manufacturing industry, the inner cycle plays an intermediary effect. High-quality development of the manufacturing industry requires a high-quality development concept. In the era of rapid change in market demand, a single internal conceptual level of innovation will not only directly affect the quality of manufacturing enterprises, but also seize the external market advantages brought by the internal cycle to domestic manufacturing enterprises, improving the green technology innovation capacity, promoting the development of domestic cycle, and indirectly leading

Table 1. Benchmark regression results.

	(1)	(2)	(3)	(4)	(5)
	MF	NEI	MF	MF	MF
GTI	3.399***	0.974**		2.861***	2.222***
	(6.720)	(2.965)		(13.015)	(5.200)
NEI			2.876***	1.054***	0.765***
			(9.796)	(8.867)	(8.548)
WAI					0.0304
					(0.0319)
NEI*WAI					0.0429*
					(0.0242)
HC	59.308***	34.844**	34.897**	6.119	27.784*
	(5.619)	(2.595)	(2.571)	(0.900)	(1.774)
R&D	52.654***	123.945***	124.881***	71.911***	45.525***
	(4.833)	(3.110)	(3.122)	(13.118)	(3.817)
IL	-0.0260	0.455	-0.0170	-0.0274	-0.0336
	(0.0536)	(0.359)	(0.0532)	(0.0521)	(0.0544)
FDI	0.0011*	0.0477*	-0.0011	0.0009	0.0009
	(0.0010)	(0.0387)	(0.0011)	(0.0010)	(0.0011)
TDL	0.0068*	-0.6460*	-0.0071	0.0088*	0.0095
	(0.0171)	(0.327)	(0.0165)	(0.0156)	(0.0134)
_cons	13.887***	0.014***	8.601***	11.378***	10.459***
	(157.124)	(4.808)	(15.641)	(55.937)	(10.667)
province	No	No	No	Yes	Yes
year	No	No	Yes	No	Yes
N	300.000	300.000	300.000	300.000	300.000
r2	0.953	0.983	0.952	0.827	0.965
r2_a	0.946	0.980	0.918	0.818	0.959

Table 2. Results of the test for the mediating role of the internal circulation.

	Coef	Std. Err	Z	P	95% confidence interval
Indirect effect	0.0475	0.0119	2.30	0.021	[0.0041,0.0509]
Direct effect	0.4004	0.0523	7.77	0.000	[0.3039,0.5090]

to the high-quality development of the manufacturing industry.

Robustness Tests

In order to avoid chance results in the indicator selection of variables, some of the control variables are replaced for the robustness test, and the ratio of net fixed assets to the number of people employed in the industry is used as a proxy variable for the domestic investment intensity factor to regress the model, and the results of the regression are shown in Table 3. In terms of significance and coefficients, the regression results of the core variables basically remain the same as the regression of the previous section, and in the mediation effect test, the inner loop fails the significance test. Therefore, the Bootstrap test is used to test the mediating effect of the inner loop, and the results are shown in Table 4, the Bootstrap confidence interval of the indirect effect does not contain 0, indicating that the mediating effect of the inner loop is significant. The conclusion of this test is consistent with the previous results and the model is validated again.

Table 3. Robustness test based on the replacement indicator method.

	(1)	(2)	(3)	(4)	(5)
	MF	NEI	MF	MF	MF
GTI	3.319***	0.913**		2.055***	2.007***
	(6.523)	(2.633)		(12.265)	(4.977)
NEI			2.318***	0.949***	0.788***
			(9.497)	(8.034)	(8.618)
WAI					0.0284
					(0.0340)
NEI*WAI					0.0445*
					(0.0249)
HC	48.231***	37.712**	31.682**	5.247	21.753*
	(5.315)	(2.449)	(2.107)	(0.811)	(1.543)
R&D	43.156***	96.852***	104.439***	66.108***	31.076***
	(4.711)	(3.094)	(2.914)	(11.994)	(3.441)
IL	0.394	0.566***	0.562***	0.808**	0.131
	(1.231)	(3.017)	(1.231)	(1.980)	(0.302)
FDI	-0.590	0.375**	-0.590	-4.989***	-1.225
	(-0.727)	(1.165)	(-0.727)	(-4.338)	(-1.341)
TDL	5.008	0.534**	5.008	-11.620***	1.393
	(1.590)	(0.849)	(1.590)	(-5.435)	(0.502)
_cons	13.887***	0.014***	8.601***	11.378***	10.459***
	(157.124)	(4.808)	(15.641)	(55.937)	(10.667)
r2	0.933	0.961	0.935	0.811	0.948
r2_a	0.914	0.932	0.901	0.796	0.923

Table 4. Robustness test results for the mediating role of the inner loop.

	Coef	Std. Err	Z	P	95% confidence interval
Indirect effect	0.0336	0.0100	3.35	0.001	[0.0140,0.0533]
Direct effect	0.3433	0.0483	7.11	0.000	[0.2487,0.4380]

Endogeneity Test

The endogeneity problem is mainly caused by measurement bias, omitted variables, and two-way causation. Four control variables were included in the regression analysis and appropriate regression models were selected to reduce endogeneity. However, the question of whether there is bidirectional causality among the variables has not been addressed. Therefore, DI lagged one period as an instrumental variable was used as a regression test using the 2SLS method. The instrumental variables are tested by the Kleibergen-Paap rk LM test, Cragg-Donald Wald test, and Hansen J test. The specific regression results are presented in Table 5, which shows that the coefficients of the main variables as well as the interaction terms of the moderator variables are significant and the results pass the test.

Heterogeneity Test

The development of China's manufacturing industry still faces the challenge of regional imbalance, which has led to differences in the role of green technology innovation in promoting the high-quality development of the manufacturing industry in different regions. Table 6 examines the relationship between variables in regions with lower levels of high-quality development in manufacturing. Table 6 shows that green technological

Table 5. Endogeneity test.

	(1)	(2)	(3)	(4)	(5)
	MF	NEI	MF	MF	MF
GTI	4.399***	0.974**	4.006***	2.993***	2.049***
	(6.956)	(3.533)	(5.045)	(13.247)	(5.486)
NEI				0.912***	0.811***
				(8.268)	(8.266)
WAI					0.0314**
					(0.0141)
NEI*WAI					0.0726***
					(0.0150)
HC	57.102***	30.566**	31.712**	6.002	23.107*
	(5.134)	(2.356)	(2.417)	(0.811)	(1.302)
R&D	49.458***	120.120***	112.438***	61.754***	39.114***
	(4.013)	(3.024)	(3.018)	(13.118)	(3.374)
IL	-0.0043	1.306***	-0.0961***	-0.0149	-0.0159
	(0.0265)	(0.372)	(0.0342)	(0.0264)	(0.0262)
FDI	-0.0079***	0.0010	0.0016	-0.0063**	-0.0042
	(0.0028)	(0.0399)	(0.0036)	(0.0028)	(0.0029)
TDL	-0.0387***	-1.0580***	-0.0239**	-0.0291***	-0.0435***
	(0.0073)	(0.1030)	(0.0112)	(0.0084)	(0.0090)
_cons	13.887***	0.014***	8.601***	11.378***	10.459***
	(157.124)	(4.808)	(15.641)	(55.937)	(10.667)
r2	0.989	0.993	0.966	0.896	0.987
r2_a	0.955	0.983	0.921	0.835	0.961

innovation (α1 = 1.398, p<0.01) passes the significance test, i.e., green technological innovation plays a positive role in promoting the lower level of high-quality development of the manufacturing industry in the region. Green technological innovation (β1 = 6.974, p<0.05) has a significant promotion effect on the internal cycle, and the internal cycle (α2 = 0.0135, p<0.01) passes the test of significance in Model 3, i.e., the internal cycle has a positive impact on the regions with a lower level of high-quality development of the manufacturing industry. The mediating and independent variables are added in Model 4, in which the coefficients of the mediating variable inner circulation (α2 = 1.223, p<0.01) all pass the significance test, indicating that the inner circulation plays a mediating role in the region with a lower level of high-quality development of the manufacturing industry. The coefficient of the interaction term between the inner loop and the outer loop is significant (α3 = 0.0203, p<0.1), indicating that the outer loop can effectively regulate the relationship between green technological innovation and high-quality development of manufacturing in regions with lower levels of manufacturing development. As the level of internal circulation is low in regions with a low level of manufacturing industry and various resources cannot be effectively combined, there is an urgent need to absorb and utilize various resources from the external circulation.

Table 7 tests the relationship between the variables in regions with higher levels of high-quality manufacturing development. Table 7 shows that the independent variable (α1 = 3.206, p<0.01) passes the significance test, i.e., green technological innovation has the same positive promotional effect on regions with higher levels of high-quality development of the manufacturing industry, and the effect is higher than that in regions with low levels of manufacturing. Green technology innovation (α1 = 1.036, p<0.05) also has a positive effect on the inner cycle. Model 3 shows that the inner cycle (α2 = 3.064, p<0.01) passes the significance test, indicating that the inner cycle has the same positive promotion effect on the region with a higher level of high-quality development of the manufacturing industry, and the effect is more significant. Adding the independent variable and the mediating variable, in which the coefficient of the

Table 6. Regression Results for Regions with Lower Levels of Manufacturing Development.

	(1)	(2)	(3)	(4)	(5)
	MF	NEI	MF	MF	MF
GTI	1.398***	6.974**		0.881***	0.862***
	(2.129)	(6.337)		(1.015)	(0.957)
NEI			1.439***	1.223***	0.789***
			(3.642)	(3.567)	(8.634)
WAI					-0.1940**
					(0.0816)
NEI*WAI					0.0203*
					(0.0102)
HC	55.657***	30.137**	31.018**	6.001	26.124*
	(5.312)	(2.301)	(2.165)	(0.743)	(1.994)
R&D	50.108***	119.130***	114.017***	63.324***	41.931***
	(4.662)	(3.003)	(2.946)	(12.336)	(3.059)
IL	-0.0072*	-0.6470***	0.0020	0.0026	0.0030
	(0.0052)	(0.1160)	(0.006)	(0.0051)	(0.0054)
FDI	0.0011*	0.0713*	-0.0006	-0.0007	-0.0002
	(0.0010)	(0.0571)	(0.0008)	(0.0005)	(0.0004)
TDL	-0.0025	-0.6410**	0.0038	0.0086*	0.0044
	(0.0072)	(0.3690)	(0.0058)	(0.0063)	(0.0058)
_cons	13.887***	0.014***	8.601***	11.378***	10.459***
	(157.124)	(4.808)	(15.641)	(55.937)	(10.667)
r2	0.951	0.936	0.934	0.854	0.945
r2_a	0.933	0.922	0.921	0.816	0.931

mediating variable (α2 = 2.369, p<0.01) passes the significance test, indicating that the inner cycle also plays a mediating role in the region with a higher level of high-quality development of the manufacturing industry. The interaction term between the inner and outer cycles is not significant, indicating that the outer cycle does not have a significant moderating effect in regions with better manufacturing development. Perhaps the reason lies in three points: firstly, the main regions of manufacturing industry development are usually located in higher stages, and their internal resources can be efficiently integrated together, so the demand for all kinds of resources from the external cycle is relatively low; secondly, when the internal cycle accelerates the circulation of the elements, it will make the production factors more inclined to migrate to the places with high level of economic development, which helps to increase the circulation within the core regions of the manufacturing industry. This helps to increase the speed of circulation within the core manufacturing region and reduce the dependence on elements from the external circulation; finally, regions with a lower level of manufacturing development may have a simpler consumption pattern and a single product, and the development of the external circulation can bring more novel consumption patterns and choices of consumer goods to regions with a lower level of manufacturing development, stimulate the increase of the consumption level of such regions, and promote the impact of the internal circulation on the high-quality development of the manufacturing industry.

Table 7. Regression Results for Regions with Higher Levels of Manufacturing Development.

	(1)	(2)	(3)	(4)	(5)
	MF	NEI	MF	MF	MF
GTI	3.206***	1.036**		2.856***	2.210***
	(6.669)	(2.982)		(12.019)	(5.096)
NEI			3.064***	2.369***	0.810***
			(9.967)	(9.869)	(8.779)
WAI					0.0457
					(0.0266)
NEI*WAI					-0.0232
					(0.0330)
HC	49.028***	32.779**	31.103**	5.991	24.109*
	(5.233)	(2.595)	(2.571)	(0.900)	(2.006)
R&D	49.105***	121.187***	120.557***	69.471***	45.109***
	(4.112)	(3.110)	(3.122)	(13.118)	(3.746)
IL	-0.0456*	-1.0680**	-0.0164	-0.0238	-0.0256
	(0.0242)	(0.2020)	(0.0204)	(0.0276)	(0.0268)
FDI	-0.0068	-0.0779	0.0061	-0.0052	-0.0039
	(0.0073)	(0.1170)	(0.0114)	(0.0067)	(0.0067)
TDL	0.0879*	0.0396	0.1170**	0.0869*	0.099*
	(0.0606)	(0.7440)	(0.0751)	(0.0569)	(0.0574)
_cons	13.887***	0.014***	8.601***	11.378***	10.459***
	(157.124)	(4.808)	(15.641)	(55.937)	(10.667)
province	No	No	No	Yes	Yes
year	No	No	Yes	No	Yes
N	300.000	300.000	300.000	300.000	300.000
r2	0.949	0.956	0.916	0.813	0.937
r2_a	0.921	0.941	0.903	0.802	0.921

Conclusions

Based on the impact mechanism of green technology innovation on the high-quality development of the manufacturing industry under the dual circulation development pattern, this paper focuses on the impact of green technology innovation on the high-quality development of the manufacturing industry through the mediating variable of the inner cycle by using the panel data of 30 provincial-level regions in China from 2012 to 2022, and the conclusions are as follows.

1. The regression model analysis shows that hypothesis H1 passes the significance test, which concludes that: green technological innovation is conducive to accelerating the high-quality development of the manufacturing industry. China's manufacturing industry is based on a large enough scale that manufacturing enterprises need to improve their independent innovation capacity and use green technology innovation to realize the high-quality development of the manufacturing industry.

2. The regression model analysis shows that hypothesis H2 passes the significance test, which concludes that: green technological innovation positively promotes the development of the internal cycle, and the growth of green technological innovation will pull the level of domestic consumption, thus promoting the growth of the internal cycle.

3. The regression model analysis shows that hypothesis H3 passes the significance test, which leads to the conclusion that the internal cycle has a positive contribution to the high-quality development of the manufacturing industry. Through the transformation of the internal cycle, higher consumer demand emerges from domestic consumers, thus promoting the growth of the manufacturing industry.

4. The regression model analysis shows that hypothesis H4 passes the significance test, from which it is concluded that green technological innovation further promotes the high-quality development of the manufacturing industry by driving the domestic cycle. In the context of dual circulation, manufacturing enterprises carry out more advanced production activities through green technological innovation, which promotes the development of the domestic cycle and indirectly drives the high-quality development of the manufacturing industry.

5. The regression model analysis shows that hypothesis H5 passes the significance test, which concludes that: the external circulation positively regulates the relationship between internal circulation and the high-quality development of the manufacturing industry. From the test of regional heterogeneity, it can be seen that, for manufacturing high-quality development levels of different regions and consumption structure levels of different regions, the role of the external cycle is different. For regions with lower levels of high-quality development of manufacturing and lower levels of consumption structure, the outer cycle plays a positive regulatory effect. Therefore, policies should be implemented according to the characteristics of each region in order to maximize the effect of policies.

Suggestions

1. Focus on core green technology innovation

The government should guide the eastern high green technology manufacturing industry to transfer to the central and western parts of the country, so as to realize the transformation of the country from low-end high-carbon production to high-end color-filtering manufacturing, and should actively release the value of the government's green resources, and promote the integration of core green technology with the production and operation mode of manufacturing enterprises.

2. Increasing effective domestic supply

The government should start with the quality of green products in the market, strictly control the quality of green products, supervise the market, and improve the market governance. Manufacturing enterprises should grasp and utilize the consumer information returned from the market, analyze the consumer consumption behavior and further subdivide the consumers, give different green products and services to different consumer groups, stimulate the consumers to carry out green consumption, actively develop the varieties of green consumption products, encourage the consumers to carry out on-line consumption by using the network platform, maintain and optimize the process of on-line consumption, and broaden the online sales channels to form an organic combination that meets the needs of different consumers.

3. Absorption of quality technology and investment from abroad

The government should continue to optimize the policy of enterprise introduction, explore a more diversified and flexible new mode of attracting capital, advocate overseas enterprises to invest in Chinese enterprises with patented technology, reduce the introduction of foreign-funded enterprises that use our country as a production and processing base, and introduce more foreign-funded enterprises that have outstanding spillover effects of green technology.

4. Development of differentiated regional policies

The government should combine with the actual situation of each region, according to the local conditions, to formulate policy combinations suitable for the level of economic development and enterprise characteristics of the region. Local governments should grasp the strength to optimize the industrial policy system and innovation incentive system and develop a series of ways to promote the high-quality development of the manufacturing industry in the region. In conclusion, fully considering regional differences and promoting regional innovation capacity building with the concept of coordination is conducive to promoting

the coordinated development of the region and the high-quality development of the manufacturing industry.

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Conflict of Interest

The authors declare no conflict of interest.

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