sustainability

MDPI

Article

Integration into the International Economic Cycle, Shift in Growth Drivers, and Green Innovation in Manufacturing

Zhengbo Li and Qiaoqiao Zhu *

School of Economics and Management, Xinjiang University, Urumqi 830046, China
* Correspondence: zhuqiaoqiao@xju.edu.cn

Abstract

This study investigates the impact of integration into the international economic cycle (IEC) on green innovation in China's manufacturing sector, a key factor in the country's green strategic transformation. Using multi-regional input–output tables for both global and Chinese contexts from 2012 to 2017, alongside data from listed manufacturing firms, the analysis demonstrates that IEC integration significantly promotes green innovation in Chinese manufacturing enterprises. The mechanisms of innovation-driven development and the upgrading of production capital structure are central to this effect. Economic cycles involving Europe and developing economies exert a strong positive influence on green innovation, whereas demand from North America and East Asia has a comparatively weaker effect. State-owned and high-tech enterprises are identified as primary drivers of green innovation through IEC integration. The findings also indicate a high degree of dependence of China's economy on the IEC. However, reliance on IEC integration alone may result in market failure, underscoring the essential role of government environmental regulation and macroeconomic guidance. The study provides valuable insights into the transformation and advancement of manufacturing and high-quality development within the context of the modernization of China.

Keywords: international economic cycle; shift in growth drivers; green innovation; environmental regulation; macro guidance for economic development

check for updates

Academic Editors: Donato Iacobucci, Marco Ciro Liscio and Paolo Sospiro

Received: 4 September 2025
Revised: 16 October 2025
Accepted: 17 November 2025
Published: 20 November 2025

Citation: Li, Z.; Zhu, Q. Integration into the International Economic Cycle, Shift in Growth Drivers, and Green Innovation in Manufacturing. *Sustainability* **2025**, *17*, 10398. https://doi.org/10.3390/su172210398

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The escalating degradation of ecological systems has heightened focus on eco-friendly transitions within manufacturing sectors. Emerging economies face dual pressures of pursuing industrial-driven economic expansion while addressing mounting ecological management demands. Technological innovation serves as the cornerstone of economic advancement, with its "creative destruction" mechanism driving productivity enhancements, supply chain optimization, and novel demand generation. Consequently, eco-conscious innovation becomes imperative for corporate sustainability transitions and plays a pivotal role in reconciling economic development with environmental stewardship [1]. Notably, substantive advancements in green technologies and disruptive eco-innovations emerge primarily when environmental considerations become integral to organizational strategic planning, rather than through passive compliance with regulatory frameworks [2]. Therefore, more attention should be paid to the mechanisms by which businesses are able to accomplish green transformation through initiative-driven environmental innovation [3].

Advancements in science and technology have accelerated social productivity, intensifying the division of labor and economic globalization. Economies are increasingly

participating in global production networks based on their comparative advantages, leading to more frequent interregional trade. These globalized production activities meet international consumption demands and improve the efficiency of production supply systems, establishing the IEC on a global scale. China's reform and opening-up experience highlights the importance of IEC integration for national economic development, especially for developing countries. China is undergoing a significant transformation in its economic development model, transitioning from a factor-driven, extensive growth model to an innovation-driven development model that balances human and environmental needs. The specific impacts of IEC integration on China's strategic economic development transformation warrant further investigation.

Scholars have posited that participation in the IEC facilitates technological progress. For example, exports can promote technological advancement and independent innovation through mechanisms such as knowledge spillovers, market expansion, and increased competition [4]. Simultaneously, the IEC influences the ecological environment of participating countries. While IEC integration may result in the relocation of polluting industries to developing countries, contributing to the "pollution refuge problem" [5], it can also enhance environmental awareness and mitigate pollution through the diffusion of environmental protection technologies [6]. Despite these dynamics, the impact of the IEC on green-oriented innovation behavior in production enterprises, particularly in developing regions, remain insufficiently studied. In the context of China's pursuit of a new development paradigm and accelerated industrialization, it is essential to investigate how active IEC integration affects green innovation in domestic manufacturing enterprises, the underlying mechanisms, and the critical influencing factors. As a leading developing country with substantial industrial output and carbon emissions, China faces significant pressures in terms of both economic growth and environmental governance. Meanwhile, as a developing country, China's industrialization process holds significant reference value for other developing countries that are also on the path toward industrialization. Therefore, analyzing the influence of the IEC on green-oriented innovation within Chinese manufacturing enterprises provides valuable insights with broad applicability.

This research conducts an empirical investigation into the impact of integration into the IEC on green innovation in China's manufacturing industry, drawing on the World Input-Output Table, China's multi-regional input-output table (2012–2017), and the dataset of listed manufacturing firms (2013–2019). The main contributions are as follows. First, while prior research has typically evaluated the IEC's effect on corporate green innovation through exports, foreign direct investment (FDI), outward FDI (OFDI), and global value chain participation, these approaches do not fully capture domestic production changes attributable to the IEC. This study quantifies the integration of Chinese regions into the IEC by constructing a multi-regional world input–output table that includes Chinese provinces and calculating the total demand pull from global economies on provincial manufacturing production using input–output analysis. Second, this research conducts an empirical evaluation of the impact of IEC integration on corporate green innovation at the micro-enterprise level across provinces in China. Third, the mechanisms through which IEC integration promotes green innovation are analyzed from the perspectives of innovation-driven development transformation and the upgrading of production capital structure, with a focus on the shift in economic growth drivers. Fourth, the study examines the negative consequences of China's economic dependence on the IEC and investigates the role of government agencies in mitigating the IEC's impact on green innovation in the manufacturing sector.

2. Literature Review

Since 2020, when China put forward the new development paradigm featuring "domestic circulation as the mainstay and domestic and international circulations reinforcing each other", scholarly research on the "dual circulations" has been on the rise. Such research primarily encompasses four dimensions: the connotations of the dual circulations strategy [7]; the measurement of the scale and proportion of China's economic dual circulations [8]; the enhancement of China's economic dual circulations [9]; and the impacts of the dual circulations on economic activities like employment and technological innovation [10,11]. Scholars have delved into two sub-segments within dual circulation, focusing more on strengthening the domestic economic cycle in China [12], especially given the increased uncertainty from the international market. Meanwhile, scholars have rarely focused on the IEC. However, economic globalization is an inevitable requirement for the development of human productive forces. China's great economic development achievements through the reform and opening up have fully demonstrated the importance of integrating into the IEC. Therefore, enhancing research pertinent to the IEC is imperative.

The green transformation of manufacturing is an inevitable path to achieving sustainable economic development. Promoting green innovation in manufacturing enterprises is a crucial approach to driving the green transformation of the manufacturing sector. The existing literature has rarely explored the impact of integration into the IEC on green innovation from a global perspective, with scholars mainly focusing on import and export trade [13], FDI [14,15], OFDI [16,17], and GVC embedding [18,19]. Other discussions on the proportion of specific aspects of the IEC have also partially revealed the impact of integration into the IEC on green innovation. Although most scholars generally agree that the IEC is conducive to green innovation of enterprises, some scholars hold different views; for instance, based on data from low- and medium-tech Italian enterprises, Chiarvesio et al. (2015) observed that firms outsourcing their export operations and depending on non-local suppliers exhibit a lower propensity to pursue environmental innovation [20]. Additionally, some research has found that enterprises' green innovation activities are conducive to improving the quality of their export products and integrating into global R&D activities [21,22]. This creates a virtuous interaction between the IEC and environmentally friendly innovation. Prior research examining the influence of the IEC on firms' environmental innovation have primarily focused on the economic effects resulting from the economic activities of enterprises engaged in import and export trade and cross-border investment. However, the economic activities of import and export enterprises, as well as multinational investment enterprises, do not fully reflect a country's integration into the IEC. Considering only the economic activities of these two types of enterprises is insufficiently comprehensive. For the green transformation of a country's economy, the impact of domestic production activities driven by the IEC on green innovation is more worthy of attention. However, the existing literature does not include a more in-depth study on this topic. Unlike research methods that focus on import and export trade, FDI, and GVC embedding, the input–output analysis method can encompass the entire process of capital circulation, from production to consumption. Calculating the impact of foreign consumption on domestic production can more accurately, clearly, and comprehensively measure the economic circulation process between China and other countries worldwide. Therefore, by depicting the input–output relationship between China and other countries, the input–output analysis method can more accurately present the degree to which China's manufacturing industry integrates into the global economy. This provides an effective path for the exploration and verification of economic theories while also enhancing the effectiveness of policy formulation.

The role of government departments has been a key point of discussion in research on promoting green innovation in enterprises. As a primary measure, environmental regulation enables government departments to propel the economy's shift toward green and sustainable growth. There are opposing conclusions in the literature on whether environmental regulation can induce corporate innovation. One perspective argues that environmental regulations may inhibit technological innovation by raising enterprises' costs [23]. Another view holds that well-designed environmental regulations can effectively promote green technological innovation in enterprises [24]. With the aim of further investigating the influences of various categories of environmental regulations, prior studies have analyzed the effects of command-based environmental rules and market-driven environmental regulations on firms' eco-innovation. For example, Li (2021) found that the central environmental inspection campaign had a greater compensatory effect on enterprise innovation than the cost impact of compliance [25], enhancing the degree of firms' pro-environmental innovation in pollution-intensive industries. Some scholars have found that government research and development subsidies have an incentive effect on the green innovation performance of enterprises [26,27]. Green credit policies are also conducive to promoting green innovation among enterprises [28]. However, some studies have suggested that government R&D grants will lead to the diversion of funds originally intended for R&D activities by enterprises to other projects. This creates a crowding-out effect on the green innovation performance of enterprises [29]. In recent years, academic researchers have paid growing attention to investigating the effects of market-oriented environmental regulatory tools on enterprises' green innovation activities, covering such measures as pollutant emission charges, environmental protection taxes, and green finance initiatives [30–32]. A broad consensus has been reached among scholars that market-oriented environmental regulations play a facilitative role in fostering enterprises' green innovation.

In recent years, the burgeoning of digital technologies has offered fresh prospects for the green transition of manufacturing firms. Its impact on green innovation has become a growing area of study for scholars. The openness, mobility, inclusiveness, and virtuality of digital technology enable manufacturing enterprises to reduce operating costs, alleviate financing constraints, and enhance innovation levels during green transformation [33]. Enterprise digital transformation constitutes a pivotal dimension of industrial digitalization advancement and an inexorable trend for firms amid the digital information era. Research has shown that the digital transformation of enterprises is conducive to the development of green innovation and the enhancement of green innovation levels [34]. Based on the resource orchestration theory and employing the case analysis method, Cao (2023) explored the leapfrog evolution law of digital transformation in manufacturing enterprises [35], and analyzed and summarized the internal mechanisms of digitalization that facilitate the green transformation of manufacturing enterprises. Xiao (2023) carried out an empirical investigation by employing data from Chinese listed firms, revealing that enterprise digital transformation remarkably enhances both the quality and quantity of green innovation [36], with a more pronounced impact on the improvement of innovation quality. The input of innovative human resources and innovation capital plays an important mediating role. In addition, existing studies have also examined the impact of digital technology on corporate green innovation from the perspective of regional digital development. Wang et al. (2022) found that regional digitalization has a significant inverted "U"-shaped impact on green technology innovation in resource-based enterprises, both in terms of the overall level and its sub-indicators [37]. An empirical study by Kong and Liu (2023), based on panel data at or above the prefectural level in China, found that the digital economy can drive the green transformation of industry [38].

Drawing on the aforementioned literature review, the extant research still exhibits the following research gaps: ① From the perspective of research angles, existing studies lack investigations into the impact of integration into the IEC on the green innovation of manufacturing firms. ② Regarding the influence mechanism, the transmission path through which the IEC affects green innovation remains ambiguous. ③ In terms of heterogeneity analysis, the heterogeneous effects of the IEC on corporate green innovation under diverse contextual conditions have yet to be explored. ④ Concerning the role of government authorities, it is imperative to clarify the government's functional positioning in the process whereby the IEC exerts an influence on the green innovation of manufacturing enterprises.

Building on the research gaps identified in extant studies, this research further explores the impact and transmission mechanism of IEC integration on the green innovation of manufacturing firms. By means of systematic theoretical analysis, hypothesis development, and empirical verification, this study conducts an in-depth investigation into how IEC integration influences enterprises' green innovation and clarifies the government's functional role in this process.

3. Mechanism Analysis and Research Hypotheses

As social productive forces advance steadily and the division of labor deepens, economic globalization has evolved into an indispensable mode of production organization for global economic development. In this context, domestic production in a country must not only meet the consumption demands of domestic economic entities but also respond to the consumption demands from other countries worldwide, placing increasing demand on domestic production activities. Especially for developing countries, which often face the predicament of insufficient domestic demand and a shortage of capital in the early stages of industrialization, integrating into the IEC will significantly stimulate their economic vitality. Therefore, against the macro backdrop of vigorously advancing the green strategic transformation of social and economic development, integration into the IEC will drive green innovation in domestic manufacturing enterprises. Firstly, when a country's economy is integrated into the IEC, it not only attracts large-scale industrial capital investment to the domestic economy but also changes the market capacity for domestic production enterprises from a single domestic market to both domestic and international markets. The huge potential demand resulting from the surge in market capacity will provide a strong impetus to the domestic production system, creating a solid material foundation for the green innovation activities of domestic producers. Secondly, active participation in the IEC will enable domestic enterprises to better learn and absorb advanced production technologies and management experiences from relevant international fields through technology spillover effects, thereby strengthening their own green innovation capabilities [39]. Through participation in the IEC, domestic enterprises will promote the deepening of globalization in their own R&D activities, not only increasing the frequency of information exchange between enterprises and the outside world, but also enabling enterprises to better understand the technological development frontiers in their respective fields. Furthermore, while integration into the IEC directly facilitates green innovation activities among trade-participating enterprises, it will also propel green innovation of other firms in the industrial chain via the industrial chain's transmission mechanism—thereby advancing the overall green transition of relevant domestic industries [40]. On the basis of the aforementioned analysis, this research puts forward Hypothesis H1.

Hypothesis 1 (H1). *In the broader context of transforming economic development strategies, integration into the IEC will promote green innovation activities among Chinese manufacturing enterprises.*

As the economy develops rapidly and capital accumulates continuously, the industrial structure will undergo ongoing adjustments to adapt to shifts in the social supply and demand structure. Market competition activities will cause the average profit rate to show a downward trend. In this process, the pace of capital accumulation should be accelerated by enhancing the innovation capacity of production entities and improving the composition of production capital. The distribution of economic growth drivers should be transformed in a timely manner to promote continuous productivity improvement and sustained, rapid total profit growth. It follows that for China's economy to transition from primitive extensive development to high-quality, green, and sustainable development, the transformation of economic growth drivers constitutes an inexorable pathway. This shift is primarily reflected in two dimensions: innovation-driven transformation and the upgrading of the production capital structure.

Intense competition in the international market generates a "competitive effect" that facilitates green innovation among domestic enterprises (Wu et al., 2022) [41]. Specifically, the availability of differentiated and green competitive products from global markets compels domestic firms to augment their green innovation investments, elevate innovation efficiency, and foster and strengthen their innovation capacities. Consequently, this "competitive effect" also propels the transformation of economic development drivers from factor-driven to innovation-driven, thereby advancing the shift in economic growth momentum. The IEC will promote green innovation in domestic manufacturing by driving the transformation of the economy to innovation-driven development. Firstly, feedback from consumers in different countries and regions provides rich and valuable information for enterprises participating in the IEC, reduces the risks and uncertainties of enterprise R&D innovation, enhances innovation efficiency, and strengthens the motivation of enterprises to increase investment in green R&D. Second, despite the heightened intensity of international market competition, integration into the IEC expands enterprises' market demand, accelerates their capital accumulation, and lays a more solid foundation for enterprises to conduct green innovation activities and augment innovation investment. Finally, as countries worldwide attach growing importance to environmental issues, requirements for green products and green technological processes in the international market are constantly escalating—even forming certain green trade barriers [42]. Green innovation enables enterprises to comprehensively reduce environmental costs and gain the trust of distinctive suppliers and customers, thereby securing a green competitive edge [2]. To establish a relative competitive advantage in the international market, domestic firms must increase their investment in green R&D to enhance their innovation capabilities, thus better satisfying the demands of the global market.

Integration into the IEC is conducive to upgrading the production capital structure of enterprises. Under the condition that the organic composition of enterprise capital remains unchanged, technological innovation of unchanging capital will enable the input of variable capital per unit of enterprises to form commodity capital on a larger scale and higher quality. With the socially necessary labor time for commodity production remaining unchanged, this implies that enterprises will gain excess surplus value and excess profits—laying a practical foundation for their transformation toward sustainable development and green innovation. Meanwhile, the technological upgrading of constant capital will also place enterprises' production activities at the forefront of industrial technology, rendering production more flexible and efficient and thereby facilitating enterprises' transition to green production. The rapid advancement of digital technologies has triggered a new round of technological transformation, with the integration of digital technology and traditional industries continuing to deepen. In this context, digital transformation will be the inevitable direction for current enterprises to achieve sustainable development. In the

digital information age, the renewal of production capital driven by integration into the IEC will inevitably drive enterprises to pursue the digital transformation of constant capital. The enabling role of digital technology will facilitate enterprises in effectively carrying out green innovation activities. Digital transformation will improve enterprises' resource allocation efficiency and their ability to acquire knowledge. In this innovative environment, enterprises can generate redundant resources, and only then will they likely choose green development strategies with long-term returns [43]. Furthermore, digital transformation empowers enterprises to boost their green innovation management capabilities, thereby elevating green innovation efficiency through strengthened overall planning and integration of green innovation resources [44]. On the basis of the foregoing analysis, this research advances Hypothesis H2.

Hypothesis 2 (H2). *Against the macro backdrop of transforming economic development strategies, integration into the IEC contributes to shifting China's economic growth momentum and advancing the improvement of green innovation levels among domestic manufacturing enterprises—by facilitating the transition toward innovation-driven development and the upgrading of the production capital structure.*

For developing countries—often confronted with such challenges as a weak industrial base, outdated technologies, inadequate domestic demand, and capital scarcity in the early stages of economic development—integration into the IEC will provide robust impetus for their economic advancement. Beyond introducing advanced production technologies and management expertise to domestic enterprises, integration into the IEC will also facilitate knowledge spillovers. These spillovers encourage domestic firms to optimize their production processes to meet the requirements of the international market [45]. At the same time, the IEC will create demand for higher-quality labor in enterprises, drive improvement in labor quality and labor factor structure in enterprises, and enhance the skill level of the labor force, thereby contributing to human capital accumulation. The improvement in technology, accumulation of capital, enhancement of production processes, and improvement in human capital will ultimately result in increased labor productivity. This increase in labor productivity represents the creation of more value per unit of labor input, which will boost the income levels of residents, enhance their willingness to consume, and improve the consumption structure. The increases in both quality and quantity on the demand side will, in turn, have a more effective guiding influence on production on the supply side, creating a virtuous cycle. However, it should be noted that as the economies of developing countries grow, the model of relying on factor input to drive economic growth will eventually encounter a bottleneck. If they do not proactively and promptly consider the development of their own domestic circulation, actively promote industrial structure adjustments, and shift to an innovation-driven and green development model, the technology lock-in from developed countries will gradually reduce the marginal effect of integrating into the IEC on their own labor productivity. Excessive reliance on the economic driving force of the IEC may even hinder the improvement of their own labor productivity. In this situation, developing countries will face greater challenges in escaping the "middle-income trap." The slowdown in the pace of value accumulation will have an adverse impact on green innovation in developing countries, especially where environmental carrying capacity has reached its limit. Based on the above analysis, this study proposes hypothesis H3.

Hypothesis 3 (H3). *When the domestic economic cycle is relatively sluggish, integration into the IEC exerts an inverted "U"-shaped, non-linear impact on labor productivity. Excessive dependence on the IEC is detrimental to green innovation in the domestic manufacturing sector.*

Key issues affecting the green transformation of the economy include internalization of the negative externalities caused by enterprises' pollutant emissions and promoting green innovation, which cannot be solved by the market alone [46]. Against the backdrop of rising global attention to environmental issues, integration into the IEC can advance the enhancement of domestic manufacturing enterprises' innovation capabilities and the upgrading of the production capital structure via demand-pull effects, knowledge spillovers, and market competition—thus laying the groundwork for green innovation. However, without governmental regulatory constraints and directed guidance, driven by profit-seeking motives, enterprises integrating into the IEC will focus more on the significant short-term benefits from the international market and abandon sustainable green innovation activities, leading to market failure. Therefore, the ability of integration into the IEC to ultimately promote green innovation by transforming the growth drivers of the domestic economy relies on the effective regulation of government environmental policies and macroeconomic guidance for economic development. Especially during the rapid industrialization stage in developing countries, the government will undoubtedly play an important role. On the one hand, the government's formulation of appropriate environmental regulations via institutional innovation helps incubate green innovation technologies within enterprises. This in turn facilitates the realization of green innovation value and allows the market to exert a more effective self-regulatory function. On the other hand, when both economic growth and environmental performance become the criteria for promoting government officials, a green and inclusive sustainable development approach will become the primary goal of local government economic development, providing enterprises with greater access to green innovation incentive policies [47].

Hypothesis 4 (H4). *The government's effective environmental regulations, coupled with macro guidance on green and inclusive economic development, can address market failures. These measures play a pivotal and irreplaceable regulatory role in facilitating green innovation among China's manufacturing enterprises via integration into the IEC.*

Based on the above theoretical analysis, the logical analysis framework of this article is shown in Figure 1.

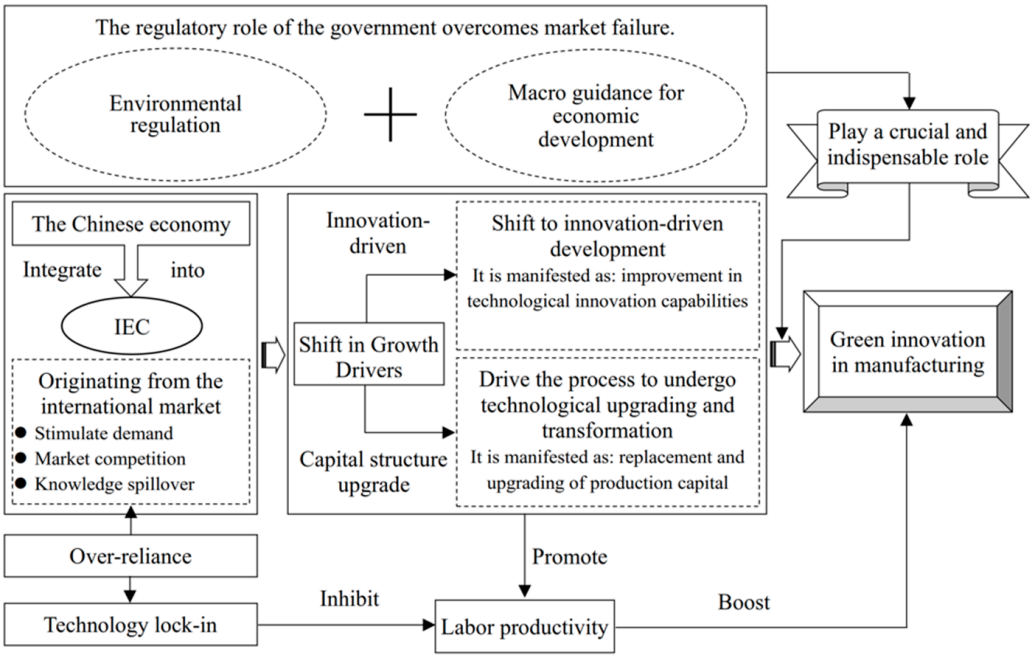

Figure 1. Conceptual logical diagram for basic research hypotheses.

4. Research Design

4.1. Model Setting

This study used green patents as proxy variables to represent corporate green innovation. The data exhibited distinct, discrete, and non-negative characteristics, making them suitable for analysis using a counting regression model. Since the Poisson regression model is based on the premise that the data are evenly dispersed, it was not suitable for this study, as the variance of corporate green patent data is significantly greater than the mean. Therefore, this research adopts the negative binomial regression method—suitable for such data types—to examine the impact of integration into the IEC on green innovation among Chinese manufacturing enterprises. Given the potential time lag in the IEC's effect on firms' green innovation and to alleviate possible endogeneity issues in the model, this study uses the one-period lagged IEC index as the explanatory variable. The model specification is as follows:

$$GI_{ihjt} = \alpha_0 + \beta \cdot IEC_{iht-1} + \boldsymbol{\beta} \cdot \mathbf{Control} + \tau_t + \gamma_h + \varphi_i \times \tau_t + \varepsilon_{ihjt} \quad (1)$$

where GI_{ihjt} represents the green innovation of enterprise j of industry h in Province i of China in year t, including strategic green innovation (GI-S_{ihjt}) and tactical green innovation (GI-T_{ihjt}). $IEC_{iht\text{-}1}$ indicates the extent to which the manufacturing industry h in Province i of China is integrated into the IEC in year $t-1$. Control is a column vector of control variables, including those at the enterprise level and those at the province level where the enterprise is located. τ_t and γ_h represent time and industry fixed effects, respectively. $\varphi_i \times \tau_t$ represents the fixed effect of the province–year combination. ε_{ijt} is the random perturbation term. The robust standard errors are clustered at the provincial level.

This study employed the following empirical model to investigate the mechanism by which the IEC influences corporate green innovation. The method for testing the mediating mechanism in this study was based on the approach of Baron and Kenny (1986) [48].

$$modiator_{ihjt} = \alpha_0 + \beta \cdot IEC_{iht-1} + \boldsymbol{\beta} \cdot \mathbf{Control} + \tau_t + \gamma_h + \varphi_i \times \tau_t + \varepsilon_{ihjt} \quad (2)$$

$$GI_{ihjt} = \alpha_0 + \beta \cdot IEC_{iht-1} + \beta' \cdot modiator_{ihjt} + \boldsymbol{\beta} \cdot \mathbf{Control} + \tau_t + \gamma_h + \varphi_i \times \tau_t + \varepsilon_{ihjt} \quad (3)$$

where $modiator_{ihjt}$ represents the mechanism variables by which the IEC affects corporate green innovation, including the transformation of enterprises' innovation-driven development and the upgrading of production capital structure.

To explore the role of government environmental regulations and macroeconomic guidance in facilitating corporate green innovation via integration into the IEC, this research employs the following empirical model for validation:

$$GI_{ihjt} = \alpha_0 + \beta_1 \cdot IEC_{iht-1} + \beta_2 \cdot IEC_{iht-1} \cdot Government_{it} + \boldsymbol{\beta} \cdot \mathbf{Control} + \tau_t + \gamma_h + \varphi_i \times \tau_t + \varepsilon_{ihjt} \quad (4)$$

where $Government_{it}$ represents two variables: environmental regulation by government departments and macro guidance for economic development.

4.2. Indicator Construction and Data Presentation

4.2.1. Explained Variable: Green Innovation

As R&D investment cannot clearly define the type of innovation or indicate its output, an increasing number of scholars are using more refined and micro-level patent data to measure enterprise innovation. Drawing on the methodological approaches of Li and Zheng (2016) and Ley et al. (2016), this research employs the number of green patent applications as a proxy for corporate green innovation [49,50]. Strategic green innovation and tactical green innovation were measured according to the number of green invention patents and non-invention patent applications of enterprises, respectively.

4.2.2. Explanatory Variable: IEC

For the economic operation of a country, the economic activities involved in the IEC encompass both cross-border trade and the driving effect of these activities on the production of other enterprises within the domestic related industrial chain. Therefore, this study incorporated the input–output tables of each province in China into the global input–output table and calculated the comprehensive pull effect of the final consumption in various countries and regions worldwide on the manufacturing production activities of each province in China. The results represent the participation of China's provinces in the IEC in the manufacturing sector. Firstly, taking into account the differences in industry classification, this study uniformly categorized the industry classifications of the world's input–output tables and those of China's provinces into 33 industry sectors. Secondly, the input–output tables of each province in China were embedded into the world input–output table using the method proposed by Mi et al. (2020), thereby establishing a multi-regional input–output table that reflects the input–output relationships between different countries or regions worldwide and each province in China [51]. Finally, based on the final consumption in other countries or regions around the world, the pull of final consumption in each country or region on the manufacturing production of each province in China was calculated. The results reflect not only the direct and indirect pull of final consumer countries or regions on China's manufacturing production but also the indirect pull of these countries or regions on China's manufacturing production through the consumption of products from other countries. Therefore, compared to the method of using a single indicator, the results of this study more objectively and comprehensively reflect China's overall manufacturing integration into the IEC. The calculation process is shown in Formulas (5)–(7).

$$\mathbf{X} = \begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \vdots \\ \mathbf{x}^n \end{bmatrix}, \mathbf{A} = \begin{bmatrix} \mathbf{a}^{11} & \mathbf{a}^{12} & \dots & \mathbf{a}^{1n} \\ \mathbf{a}^{21} & \mathbf{a}^{22} & \dots & \mathbf{a}^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{a}^{n1} & \mathbf{a}^{n2} & \dots & \mathbf{a}^{nn} \end{bmatrix}, \mathbf{F} = \begin{bmatrix} \mathbf{f}^{11} & \mathbf{f}^{12} & \dots & \mathbf{f}^{1n} \\ \mathbf{f}^{21} & \mathbf{f}^{22} & \dots & \mathbf{f}^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{f}^{n1} & \mathbf{f}^{n2} & \dots & \mathbf{f}^{nn} \end{bmatrix} \tag{5}$$

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{F} = \mathbf{BF} = \begin{bmatrix} \mathbf{b}^{11} & \mathbf{b}^{12} & \dots & \mathbf{b}^{1n} \\ \mathbf{b}^{21} & \mathbf{b}^{22} & \dots & \mathbf{b}^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{b}^{n1} & \mathbf{b}^{n2} & \dots & \mathbf{b}^{nn} \end{bmatrix} \begin{bmatrix} \mathbf{f}^{11} & \mathbf{f}^{12} & \dots & \mathbf{f}^{1n} \\ \mathbf{f}^{21} & \mathbf{f}^{22} & \dots & \mathbf{f}^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{f}^{n1} & \mathbf{f}^{n2} & \dots & \mathbf{f}^{nn} \end{bmatrix} \tag{6}$$

$$\mathbf{IEC}_{ij} = \mathbf{b}^{i1}\mathbf{f}^{1j} + \mathbf{b}^{i2}\mathbf{f}^{2j} + \dots + \mathbf{b}^{in}\mathbf{f}^{nj} \tag{7}$$

where $\mathbf{x}^i$ is the total output matrix of all industries in country i (or Chinese province i). $\mathbf{a}^{ij}$ represents the direct consumption coefficient matrix of country i (or Chinese province i) that country j (or Chinese province j) invests in to conduct production. $\mathbf{f}^{ij}$ is the final consumption matrix from country j (or Chinese province j) to country i (or Chinese province i). $\mathbf{(I\text{-}A)}^{-1}$ is the Leontief inverse matrix. $\mathbf{IEC}_{ij}$ represents the total impact of the final consumption of country j (or Chinese province j) on the output of country i (or Chinese province i); that is, the full effect on the production of various industries in country i (or Chinese province i).

4.2.3. Mediating Mechanism Variables

Innovation-driven development transformation: China's economic development is undergoing a paradigmatic shift from factor-driven to innovation-driven growth, and improvement in the innovation capabilities of manufacturing enterprises is a necessary condition and manifestation of this transformation process. Accordingly, this research

adopted a dual-dimensional framework from the perspectives of "quantity" and "quality," employing innovation input and innovation efficiency to characterize the innovation capabilities of Chinese manufacturing enterprises—thus capturing the extent of their transition toward an innovation-driven development paradigm. (1) Regarding "quantity," R&D investment scale and R&D investment intensity were utilized as proxy indicators. R&D investment scale is measured by the total R&D expenditure of enterprises. R&D investment intensity refers to the average R&D investment per R&D employee within an enterprise. (2) In terms of "quality," this study employed R&D capital efficiency and R&D labor efficiency as corresponding proxy variables. These are reflected by patent output per unit of R&D capital and patent output per unit of R&D personnel, respectively. Furthermore, based on the number of invention patents and non-invention patents, both efficiency indicators were further decomposed into strategic innovation efficiency and tactical innovation efficiency, respectively.

Upgrading of the production capital structure: In the digital information age, the digital transformation of enterprise production capital is the most strategically significant upgrade and replacement direction, and it is currently advancing rapidly. Therefore, this study used the implementation of robots in enterprises as a proxy indicator for the upgrading of the production capital structure. Referring to the practices of Wang and Dong (2020) and Acemoglu and Restrepo (2020), the calculation process is shown in Formula (8) [52,53].

$$\text{Digital}_{ijt} = \frac{\text{robot}_{jt}}{\text{labor}_{jt}} \frac{\text{clabor}_{ijt}}{\text{mlabor}_{jt}} \tag{8}$$

where cs_{ijt} represents the robot implementation rate of enterprise i in industry j of China in year t; $robot_{jt}$ represents the robot usage volume of industry j in China's manufacturing industry in year t; $labor_{jt}$ represents the average number of employees in industry j of China's manufacturing industry in year t; $robot_{jt}/labor_{jt}$ represents the robot implementation rate of industry j in year t of China's manufacturing industry; $clabor_{ijt}$ represents the number of employees of enterprise i in industry j of China's manufacturing industry in year t; $mlabor_{jt}$ represents the median number of employees of all enterprises in industry j of China's manufacturing industry in year t; $clabor_{ijt}/mlabor_{jt}$ reflects the relative scale size of enterprise i among all enterprises in industry j in year t.

4.2.4. Relevant Variables in the Government Sector

This research employs environmental regulation intensity and an environmental regulation index as proxy variables for government environmental regulation. Environmental regulation intensity is measured as the ratio of completed investment in industrial pollution control to the secondary industry added value of each province. This ratio reflects that under government environmental supervision, the scale of pollution control investment required of each economic entity is proportional to the added value generated by the secondary industry—with higher values of this indicator indicating stronger government environmental supervision efforts. The environmental regulation index is constructed via the entropy method, based on the emissions of three major wastes (industrial wastewater, industrial sulfur dioxide, and industrial smoke). Additionally, this study uses the provincial economic growth target values as a proxy indicator for the government's macroeconomic development guidance.

4.2.5. Control Variables

To mitigate endogeneity arising from omitted variables, this research categorizes the model's control variables into two dimensions: enterprise-level and provincial-level. Enterprise-level control variables encompass Tobin's Q, operating costs, selling expenses,

administrative expenses, and net fixed assets. The provincial control variables included per capita GDP, the number of households with Internet broadband, railway mileage, housing prices, and the urban population proportion.

This study utilized China's multi-regional input–output tables for 2012, 2015, and 2017, drawing data from the Carbon Emission Accounts and Datasets (CEADS). The World Input–output Table utilizes the multi-regional input–output table from Organization for Economic Co-operation and Development (OECD), which encompasses input–output relationships among 76 major countries and regions worldwide. Using Chinese manufacturing listed companies as the sample, excluding all enterprises with ST and PT marks that have operational issues, and retaining only those that operate normally during the sample period, a final sample of 1,316 enterprises was obtained. The patent data of enterprises were sourced from the China Research Data Service Platform (CNRDS). Government environmental regulation estimates were retrieved from the National Bureau of Statistics and provincial statistical yearbooks. Government economic growth targets were derived from provincial government work reports and five-year plans that have been developed over the years. Control variables at the enterprise level were obtained from the China Stock Market & Accounting Research Database (CSMAR). The control variable data at the provincial level were obtained from the China Macroeconomic Database, the statistical yearbooks of each province, the China Rural Issues Database, and the China Real Estate Statistical Yearbook. To minimize the impact of heteroscedasticity on the regression results, this study logged the explanatory variable after adding 1. The descriptive statistics of the sample are shown in Table 1.

Table 1. Descriptive statistics.

Names of Variables		Variables	Observations	Mean	Std	Minimum	Maximum
GI		Green Innovation	3948	2.569	16.456	0.000	626
GI-S		Strategic Green Innovation	3948	1.606	11.420	0.000	450
GI-T		Tactical Green Innovation	3948	0.963	6.037	0.000	176
IEC		IEC	6138	4.857	2.230	0.001	13.245
Innovation capacity: "Quantity" aspect	Scale	Scale of innovation investment	3948	9.166	1.812	0.016	16.578
	Intensity	Intensity of innovation input	3948	3.567	1.156	0.001	11.521
Innovation capacity: "Quality" aspect	CE	Innovation capital efficiency	3948	0.210	0.397	0.000	5.655
	CE-S	Strategic innovation capital efficiency	3948	0.098	0.240	0.000	5.550
	CE-T	Tactical innovation capital efficiency	3948	0.138	0.327	0.000	4.252
	LE	Innovation labor efficiency	3948	1.301	1.384	0.000	10.021
	LE-S	Strategic innovation labor efficiency	3948	0.793	1.017	0.000	9.987
	LE-T	Tactical innovation labor efficiency	3948	0.850	1.175	0.000	10.023

Table 1. *Cont.*

Names of Variables		Variables	Observations	Mean	Std	Minimum	Maximum
Digital		Unchanging capital upgrades	7896	3948	1.843	0.000	11.033
Labor		Labor productivity	7896	3948	1.051	0.002	11.123
ER-Index		Environmental regulation index	7896	3948	0.670	0.000	2.585
ER-Intensity		Intensity of environmental regulation	7896	3948	0.002	0.000	0.021
EG-Target		Government macroeconomic guidance on economic development	7896	3948	1.488	5.000	14.000
Enterprise-level control variables	Tobin	Tobin's Q value	3948	1.993	1.272	0.444	19.824
	Cost	Operating costs	3948	0.746	2.683	0.001	88.160
	Sell	Sales expenses	3948	0.457	1.916	0.000	63.420
	Admin	Administrative expenses	3948	0.478	1.383	0.011	36.720
	NFA	Net fixed assets	3948	0.269	0.771	0.000	15.070
Provincial-level control variables	Economy	Per capita GDP	93	7.168	2.793	2.315	14.021
	Internet	Internet broadband number of households	93	1.612	0.993	0.019	3.598
	Traffic	Railway mileage	93	3.618	1.807	0.465	12.766
	House	House price	93	1.021	0.640	0.389	3.382
	Urban	Urban population share	93	6.457	1.218	2.393	8.960

5. Empirical Analysis

5.1. Baseline Regression

Table 2 reports the baseline regression results. It is evident that after sequentially incorporating enterprise-level and provincial-level control variables, integration into the IEC facilitates green innovation among Chinese manufacturing enterprises at the 1% significance level. It also exerts a significant positive impact on both strategic and tactical green innovation. These results align with the viewpoints expressed in the existing literature, suggesting that international economic and trade activities promote green innovation. The regression results for enterprise-level control variables indicate that overvaluation of enterprises in the capital market may strengthen their arbitrage incentives, which is detrimental to green innovation. With the expansion of business scale, enterprises tend to engage more in strategic green innovation activities to pursue sustainable development paths, thereby offsetting the decline in profitability induced by diminishing returns to scale. The reduction in transaction costs, strengthening of management, and improvement in the organic composition of capital contribute to enhancing operational efficiency and capital accumulation in enterprises, which is conducive to the development of green innovation activities. The regression results of the macro-level control variables indicate that the higher the level of regional economic development, the greater its suppression of green innovation activities among enterprises. This could be attributed to the fact that China's economy remains in the transitional phase from a factor-driven to an innovation-driven

model, with the innovation capacity of most regions still relatively underdeveloped. The wealthier regions in the sample period often rose by relying on the traditional economic development model, resulting in greater resistance to green transformation driven by the IEC. Advancements in network and transportation infrastructure, coupled with the advancement of urbanization, have boosted the circulation efficiency of innovation factors and facilitated the sharing of knowledge and information within the region—thereby propelling green innovation initiatives among enterprises. However, the rising rent costs associated with China's rapid urbanization process are not conducive to green innovation in the country's manufacturing industry.

Table 2. Baseline regression results.

Variables	(1) GI	(2) GI	(3) GI-S	(4) GI-S	(5) GI-T	(6) GI-T
IEC	0.0115 *** (0.0020)	0.0105 ** (0.0021)	0.0115 ** (0.0023)	0.0096 *** (0.0023)	0.0149 *** (0.0025)	0.0144 *** (0.0025)
Tobin	−0.1097 *** (0.00268)	−0.1097 *** (0.0039)	−0.1393 *** (0.0046)	−0.1390 *** (0.0046)	−0.1247 *** (0.0051)	−0.1289 *** (0.0052)
Cost	0.0018 (0.0043)	0.0045 (0.0043)	0.0121 ** (0.0053)	0.0099 * (0.0053)	−0.0335 *** (0.0033)	−0.0388 *** (0.0031)
Sell	0.0048 *** (0.0015)	0.0074 ** (0.0037)	−0.0017 *** (0.0004)	−0.0014 *** (0.0004)	0.0054 *** (0.0004)	0.0056 *** (0.0004)
Admin	0.0118 *** (0.0006)	0.0115 *** (0.0006)	0.0164 *** (0.0007)	0.0158 *** (0.0008)	0.0060 *** (0.0006)	0.0064 *** (0.0006)
NFA	0.0027 *** (0.0001)	0.0027 *** (0.0001)	0.0023 *** (0.0001)	0.0023 *** (0.0001)	0.0034 *** (0.0001)	0.0035 *** (0.0001)
Economy		−0.0720 *** (0.0130)		−0.1428 *** (0.0153)		−0.0552 *** (0.0159)
Internet		0.0095 *** (0.0022)		0.0049 * (0.0026)		0.0144 *** (0.0027)
Traffic		0.0055 *** (0.0004)		0.0029 *** (0.0006)		0.0037 *** (0.0020)
House		0.5418 *** (0.0453)		0.7539 *** (0.0537)		0.6678 *** (0.0548)
Urban		−0.0039 *** (0.0012)		−0.0203 *** (0.0042)		−0.0091 ** (0.0043)
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	260,568	260,568	260,568	260,568	260,568	260,568
Observations	0.0918	0.0930	0.1062	0.1080	0.1177	0.1191

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. * Regression coefficients significant at the 10% level. ** Regression coefficients significant at the 5% level. *** Regression coefficients significant at the 1% level.

5.2. Robustness Test

The regression model in this research comprehensively incorporates control variables at both the enterprise and provincial levels, thereby minimizing the potential endogeneity arising from the omission of key variables. The explanatory variables employed herein correspond to enterprise-level and provincial-level data, respectively. Given that individual

micro-enterprises are unlikely to exert a substantial impact on the overall manufacturing production landscape of their respective regions, reverse causality risks are inherently limited. Furthermore, the explanatory variables in this study are constructed using one-period lagged data—meaning the current-year explained variables cannot influence the prior-year explanatory variables. Consequently, the model specification effectively alleviates endogeneity issues stemming from reverse causality.

To verify the robustness of the regression results and further eliminate potential endogeneity concerns, this research further adjusted the sample data by lagging provincial-level control variables by one period. As shown in columns (1) to (3) of Table 3, after lagging the explanatory variable data by two periods, integration into the IEC still facilitates corporate green innovation at the 1% significance level—and the regression coefficient is notably larger than that of the one-period lagged sample. This indicates that the driving effect of the IEC on corporate green innovation gradually intensifies over time. Given the substantial disparities in business scale among the sample enterprises, this study selected a 10% research sample based on enterprise operating cost data. The regression results in columns (4) to (9) of Table 3 demonstrate that after trimming the sample, the results remain significant at the 1% level, regardless of whether one-period or two-period lagged samples are employed.

Table 3. Robustness test after reorganizing the sample data.

Variables	Substitution of Variables (Lag Two Periods)			Sample Tail Trimming (Lag One Period)			Sample Tail Trimming (Lag Two Periods)		
	(1) GI	(2) GI-S	(3) GI-T	(4) GI	(5) GI-S	(6) GI-T	(7) GI	(8) GI-S	(9) GI-T
IEC	0.0261 *** (0.0023)	0.0017 *** (0.0026)	0.0389 *** (0.0030)	0.0136 *** (0.0023)	0.0135 *** (0.0028)	0.0188 *** (0.0029)	0.0284 *** (0.0027)	0.0203 *** (0.0032)	0.0394 *** (0.0035)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	260,568	260,568	260,568	205,326	205,326	205,326	207,900	207,900	207,900
Observations	0.1114	0.1182	0.1557	0.0896	0.1012	0.1183	0.1098	0.1117	0.1577

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

The Poisson model is better suited for count regression analysis under equidispersion conditions, the Logit model applies to binary choice problems, and the OLS model is more appropriate for general scenarios. To further validate the robustness of the regression results, this research relaxed the constraints on the discrete nature of enterprises' green innovation data and re-conducted regression tests using the Logit, Poisson, and OLS regression methods, respectively. As presented in columns (1) to (9) of Table 4, with one-period lagged sample data, integration into the IEC still exerted a driving effect on enterprises' green innovation at the 1% significance level across all three regression methods. The results in columns (10) to (18) of Table 4 demonstrate that the significance of the findings

remained consistent when the sample was replaced with two-period lagged data, regardless of the regression method employed.

Table 4. Robustness tests after replacing the regression method.

Variables	Logit (Lag One Period)			Poisson (Lag One Period)			OLS (Lag One Period)		
	(1) GI	(2) GI-S	(3) GI-T	(4) GI	(5) GI-S	(6) GI-T	(7) GI	(8) GI-S	(9) GI-T
IEC	0.0097 *** (0.0026)	0.0137 *** (0.0028)	0.0138 *** (0.0030)	0.0096 *** (0.0020)	0.0089 *** (0.0024)	0.0133 *** (0.0025)	0.0033 *** (0.0008)	0.0020 *** (0.0007)	0.0027 *** (0.0006)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.1071	0.1180	0.1215	0.1394	0.1510	0.1540	0.2082	0.2057	0.1875
Observations	260,568	260,568	260,568	260,568	260,568	260,568	260,568	260,568	260,568
Variables	**Logit (Lag Two Periods)**			**Poisson (Lag Two Periods)**			**OLS (Lag Two Periods)**		
	(10) GI	(11) GI-S	(12) GI-T	(13) GI	(14) GI-S	(15) GI-T	(16) GI	(17) GI-S	(18) GI-T
IEC	0.0330 *** (0.0028)	0.0241 *** (0.0031)	0.0452 *** (0.0034)	0.0213 *** (0.0023)	0.0134 *** (0.0026)	0.0328 *** (0.0029)	0.0063 *** (0.0008)	0.0029 *** (0.0006)	0.0051 *** (0.0006)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.1413	0.1466	0.1736	0.1691	0.1691	0.2060	0.1944	0.1965	0.1431
Observations	260,568	260,568	260,568	260,568	260,568	260,568	260,568	260,568	260,568

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

This research further constructs instrumental variables (IVs) to alleviate potential endogeneity in the model. The IV construction methodology is as follows: (1) The shortest transportation distances from each provincial capital (or municipality directly under the Central Government) to the province's coastal ports in 2024 were retrieved using AMAP. (2) The instrumental variable for the explanatory variable was generated as the product of the reciprocal of the shortest transportation distances obtained in step (1) and the IEC growth rate during the sample period. On one hand, provinces closer to major ports possess more prominent location advantages for IEC participation, facilitating the exploitation of lower transaction costs and deeper integration into the IEC. Thus, the constructed IVs exhibit a strong correlation with the explanatory variable. On the other hand, the green innovation activities of individual enterprises are virtually incapable of influencing the 2024 transportation distances between provinces and major port cities. Consequently, the IVs satisfy the exogeneity requirement relative to the dependent variable. The regression results in Table 5 not only pass the weak instrument test but also further confirm the robustness of the baseline regression findings.

Table 5. The endogeneity handling of the instrumental variable method.

Variables	First Stage	Second Stage		
	(1) IEC	(2) GI	(3) GI-S	(4) GI-T
IV	0.6335 *** (0.0018)			
IEC		0.1334 *** (0.0334)	0.0509 *** (0.0236)	0.0825 *** (0.0122)
Cragg–Donald Wald F		9.0×10^4		
Kleibergen–Paap rk Wald F		1.1×10^5		
Stock–Yogo critical value (10%)		16.38		
Control variables	Yes	Yes	Yes	Yes
R-squared	260,568	260,568	260,568	205,326
Observations	0.4069	0.1944	0.1694	0.1868

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

The results of the aforementioned robustness tests validate the robustness of the finding that IEC integration promotes green innovation among Chinese manufacturing enterprises.

5.3. Mechanism Testing

5.3.1. Shift to Innovation-Driven Development: Enhancement of Innovation Capacity

Innovation input in terms of "quantity": Regression results in columns (1) and (5) of Table 6 demonstrate that IEC integration exerts a significant promotional effect on innovation input of Chinese manufacturing enterprises, covering both scale and intensity dimensions. The significantly positive results in columns (2) to (4) and (6) to (8) of Table 6 confirm that improved innovation capacity is a critical channel via which the IEC enhances green innovation performance of Chinese manufacturing enterprises regarding the "quantity" of innovation input.

Innovation input in the "quality" dimension: Results in columns (1) and (2) of Table 7 indicate that IEC integration facilitates green innovation in Chinese manufacturing enterprises by improving R&D capital's innovation output efficiency. Regression results in columns (3) to (6) of Table 7 demonstrate that innovation capital efficiency exerts a significant mediating effect, whether from the perspective of strategic or tactical innovation capital efficiency. Columns (1) and (2) of Table 8 show that IEC integration promotes green innovation in Chinese manufacturing enterprises by enhancing R&D labor's innovation output efficiency. As revealed by regression results in columns (3) to (6) of Table 8, innovation labor efficiency serves as a key mechanism for the IEC to boost green innovation in Chinese manufacturing enterprises, covering both strategic and tactical innovation labor efficiency dimensions.

Table 6. Mechanism test of innovation input.

Variables	(1) Scale	(2) GI	(3) GI-S	(4) GI-T	(5) Intensity	(6) GI	(7) GI-S	(8) GI-T
IEC	0.0153 *** (0.0016)	0.0160 *** (0.0020)	0.0158 *** (0.0023)	0.0192 *** (0.0024)	0.0178 *** (0.0011)	0.0122 *** (0.0020)	0.0115 *** (0.0023)	0.0158 *** (0.0025)
Scale		0.2645 *** (0.0030)	0.3111 *** (0.0037)	0.2370 *** (0.0034)				
Intensity						0.1225 *** (0.0035)	0.1452 *** (0.0041)	0.1009 *** (0.0039)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.3027	0.1142	0.1347	0.1364	0.1207	0.0954	0.1111	0.1208
Observations	260,568	260,568	260,568	260,568	260,568	260,568	260,568	260,568

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

Table 7. Mechanism test of innovation capital efficiency.

Variables	(1) CE	(2) GI	(3) CE-S	(4) GI	(5) CE-T	(6) GI
IEC	0.0018 *** (0.0004)	0.0097 *** (0.0020)	0.0012 *** (0.0003)	0.0107 *** (0.0020)	0.0020 *** (0.0003)	0.0096 *** (0.0020)
CE		0.5703 *** (0.0102)				
CE-S				0.9940 *** (0.0255)		
CE-T						0.4529 *** (0.0102)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.0517	0.1012	0.0244	0.1014	0.0626	0.0965
Observations	260,568	260,568	260,568	260,568	260,568	260,568

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

Table 8. Mechanism tests for innovative labor efficiency.

Variables	(1) LE	(2) GI	(3) LE-S	(4) GI	(5) LE-T	(6) GI
IEC	0.0073 *** (0.0014)	0.0085 *** (0.0020)	0.0047 *** (0.0011)	0.0095 *** (0.0020)	0.0092 *** (0.0012)	0.0073 *** (0.0020)
CE		0.3061 *** (0.0025)				
CE-S				0.4137 *** (0.0035)		
CE-T						0.2783 *** (0.0028)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.0710	0.1299	0.0504	0.1257	0.1018	0.1109
Observations	260,568	260,568	260,568	260,568	260,568	260,568

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

Tables 6–8 present regression results confirming that IEC integration elevates innovation input (in both quantity and quality dimensions), which serves to promote green innovation output of Chinese manufacturing enterprises. The improvement in innovation efficiency does not exhibit significant factor bias, supporting the development of sustained innovation capabilities. These discoveries confirm that the IEC drives green innovation in manufacturing through advancing China's economic development transition from a factor-driven paradigm to an innovation-driven one.

5.3.2. Upgrading of Production Capital Structure: Upgrading of Production Capital

Column (1) of Table 9 yields a positively significant regression result at the 1% level, confirming that IEC integration notably accelerates fixed capital upgrading in Chinese manufacturing enterprises. The consistently positive and significant results in columns (2) to (4) of Table 9 (at the 1% level) demonstrate that fixed capital upgrading serves as a key channel through which the IEC encourages green innovation in Chinese manufacturing enterprises. Combined with the regression outcomes from Tables 5–8, this indicates that IEC integration can promote green innovation in China's manufacturing industry by advancing the shift in China's economic growth driving forces.

Table 9. Mechanism test for upgrading the structure of productive capital.

Variables	(1) Digital	(2) GI	(3) GI-S	(4) GI-T
IEC	0.0606 *** (0.0182)	0.0095 *** (0.0020)	0.0087 *** (0.0023)	0.0133 *** (0.0025)
Digital		0.0940 *** (0.0026)	0.0943 *** (0.0026)	0.1245 *** (0.0027)
Control variables	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes
R-squared	0.1749	0.0964	0.1112	0.1251
Observations	260,568	260,568	260,568	260,568

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

5.4. Heterogeneity Analysis

5.4.1. Heterogeneity of External Demand Sources

To investigate the heterogeneous impacts of different economic regions on green innovation in Chinese manufacturing enterprises within the IEC, this research divided the sample into the world's eight major economic regions based on the geographical locations of countries and regions involved. As shown in columns (1) to (6) of Table 10, the demand pull from the international cycle in North America and East Asia did not significantly facilitate green innovation in Chinese manufacturing enterprises. This outcome may be attributed to two factors. Firstly, the large outward transfer of manufacturing from the North American superpower, the United States, and the technological blockade in high-tech fields have limited the extent to which Chinese manufacturing enterprises are able to absorb green innovation factors in the course of their participation in the regional IEC. Secondly, the more industrialized countries and regions in East Asia are the major economies driving industrial gradients to China. The concomitant technology lock-in effect and high-end technology embargoes have reduced the efficacy of China's manufacturing industry's integration into the economic cycles of these economies in facilitating green innovation. Regression results in columns (7) to (9) of Table 10 demonstrate that Europe's IEC-driven demand pull significantly promotes green innovation among Chinese manufacturing enterprises, owing to the progress of China's "Belt and Road" Initiative. Extensive and in-depth economic cooperation with Europe—characterized by advanced industrial technology and robust green R&D capabilities—has significantly elevated the green innovation level of China's manufacturing industry. Notably, results in columns (10) to (21) of Table 10 reveal that IEC activities with Oceania and a large number of developing countries are emerging as a key driver of green innovation in Chinese manufacturing enterprises. This is attributable to the global widespread attention to environmental issues and the enormous market space derived from industrial complementarity, which jointly provide effective demand guidance and strong market support for green innovation in China's manufacturing sector. Furthermore, results in columns (22) to (24) of Table 10 indicate that despite the rapid development of economic exchanges between China and Africa, Africa's shortcomings in industrial structure, demand scale, and market environment weaken the impact of Sino-African economic cooperation on manufacturing enterprises' green innovation—even potentially exerting a negative effect on strategic green innovation activities. Therefore, China should further expand the areas of economic cooperation with African countries, facilitate the

upgrading of their industrial structures, and help them to establish an economic cycle that promotes green, sustainable, and high-quality development.

Table 10. Heterogeneity of external demand sources.

Variables	**(1) North America GI**	**(2) North America GI-S**	**(3) North America GI-T**	**(4) East Asia GI**	**(5) East Asia GI-S**	**(6) East Asia GI-T**
IEC	0.0045 (0.0093)	0.0055 (0.0109)	0.0064 (0.0112)	0.0038 (0.0097)	0.0052 (0.0114)	0.0052 (0.0121)
R-squared	0.0929	0.1079	0.1190	0.0918	0.1068	0.1190
Observations	15,484	15,484	15,484	15,484	15,484	15,484
Variables	**(1) Europe GI**	**(2) Europe GI-S**	**(3) Europe GI-T**	**(4) Oceania GI**	**(5) Oceania GI-S**	**(6) Oceania GI-T**
IEC	0.0145 *** (0.0027)	0.0128 *** (0.0032)	0.0199 *** (0.0034)	0.0341 * (0.0183)	0.0345 (0.0264)	0.0458 * (0.0277)
R-squared	0.0930	0.1080	0.1192	0.0912	0.1081	0.1192
Observations	7742	7742	7742	127,743	127,743	127,743
Variables	**(1) Southeast Asia GI**	**(2) Southeast Asia GI-S**	**(3) Southeast Asia GI-T**	**(4) South America GI**	**(5) South America GI-S**	**(6) South America GI-T**
IEC	0.0111 * (0.0061)	0.0106 (0.0072)	0.0154 ** (0.0075)	0.0343 ** (0.0135)	0.0317 ** (0.0158)	0.0477 *** (0.0168)
R-squared	0.0929	0.1028	0.1190	0.0948	0.1079	0.1193
Observations	38,710	38,710	38,710	19,355	19,355	19,355
R-squared	0.0828	0.0957	0.1070	0.0830	0.0958	0.1073
Variables	**(1) Central and South Asia GI**	**(2) Central and South Asia GI-S**	**(3) Central and South Asia GI-T**	**(4) Africa GI**	**(5) Africa GI-S**	**(6) Africa GI-T**
IEC	0.0111 * (0.0061)	0.0106 (0.0072)	0.0154 ** (0.0075)	−0.0263 (0.0211)	−0.0232 ** (0.0098)	−0.0345 (0.0256)
R-squared	0.0958	0.1025	0.1190	0.0922	0.1096	0.1195
Observations	38,710	38,710	38,710	11,613	11,613	11,613
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. * Regression coefficients significant at the 10% level. ** Regression coefficients significant at the 5% level. *** Regression coefficients significant at the 1% level.

5.4.2. Heterogeneity of Property Rights

To investigate the heterogeneous impacts of property rights on the IEC's promotion of green innovation in Chinese manufacturing enterprises, this research constructed a new dummy variable ("state-owned") by assigning a value of 1 to state-owned enterprises (SOEs) and 0 to non-SOEs in the sample. All regression results in columns (1) to (3) of

Table 11 are significantly positive at the 1% level, indicating that the IEC has a more pronounced promotional effect on green innovation in SOEs—particularly regarding strategic green innovation. This phenomenon is primarily attributed to two factors: first, the transformation of enterprises' green innovation strategies requires large-scale R&D investment, and SOEs face relatively looser financing constraints and possess stronger resource mobilization capabilities; second, the green transformation of SOEs constitutes a key vehicle for the country to implement its green development strategy, giving them greater impetus to carry out green innovation activities.

Table 11. Heterogeneity of property rights and industry technology attributes.

Variables	Property Rights			Technical Attributes		
	(1) GI	(2) GI-S	(3) GI-T	(4) GI	(5) GI-S	(6) GI-T
IEC·State-owned	0.3947 *** (0.0085)	0.5274 *** (0.0099)	0.2662 *** (0.0104)			
IEC·High-tech				0.0174 *** (0.0027)	0.0137 *** (0.0032)	0.0177 *** (0.0034)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.0972	0.1150	0.1213	0.0930	0.1080	0.1190
Observations	260,568	260,568	260,568	260,568	260,568	260,568

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

5.4.3. Heterogeneity of Industry Technical Attributes

Owing to differences in the types and complexity of technology applied in production across enterprises of various industries, enterprises with diverse industrial technology attributes may have varying incentives for green innovation. To further explore the heterogeneity of industrial technology attributes regarding the IEC's role in boosting green innovation in China's manufacturing sector, this study generated a new dummy variable ("high-tech") by coding high-tech enterprises as 1 and non-high-tech enterprises as 0, following the classification criteria of the National Bureau of Statistics. Columns (4) to (5) of Table 11 demonstrate that the IEC exerts a more pronounced facilitating effect on green innovation in high-tech enterprises. These enterprises tend to have superior innovation capacity, more agile and efficient production and management, and often act as pioneers in driving technological progress during socio-economic development. As a result, high-tech enterprises are better positioned to benefit from the IEC's green innovation-driven effect. It thus follows that the development of high-tech industries serves a fundamental leading function in promoting the green transformation of China's manufacturing industry via the IEC.

6. Further Analysis

6.1. The Potential Adverse Effects of Over-Reliance on the IEC

This section assesses the degree of China's economic dependence on the IEC from the perspective of labor productivity—measured as the ratio of operating income to the

number of employees. The regression result in column (1) of Table 12 indicates that IEC integration promotes labor productivity at the 1% significance level. Since the reform and opening-up, China's integration into the IEC has introduced advanced production technologies and management experience that were previously lacking in the country's modern industrial development, which has played a pivotal role in the rapid improvement of labor productivity in China's manufacturing sector. Thus, the result in column (1) of Table 12 aligns with practical realities.

Table 12. Non-linear effects of the IEC.

Variables	(1) Labor (Lag One Period)	(2) Labor (Lag One Period)	(3) Labor (Lag Two Periods)	(4) GI	(5) GI-S	(6) GI-T
IEC	0.0025 *** (0.0008)	0.0149 *** (0.0052)	0.0560 *** (0.0057)			
IEC^2		−0.0011 ** (0.0005)	0.0006 *** (0.0002)			
Labor				0.1345 *** (0.0041)	0.1450 *** (0.0048)	0.1658 *** (0.0045)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.1876	0.1877	0.2372	0.0978	0.1119	0.1281
Observations	260,568	260,568	260,568	3948	3948	3948

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

After further incorporating the quadratic term of the IEC into the model, results in column (2) of Table 12 reveal that the regression coefficient of the IEC's quadratic term is significantly negative. Regression results in column (3) of Table 12 demonstrate that the findings remain robust even when the independent variable is lagged by two periods—confirming that the impact of IEC integration on labor productivity in Chinese manufacturing enterprises exhibits an inverted "U"-shaped pattern. This indicates that in the initial stage of development, the IEC will bring relatively advanced production processes and organizational models to Chinese manufacturing enterprises, thereby posing new requirements for the quality of the labor force. Against this backdrop, industrial transfer and the introduction of technology will enhance labor productivity in enterprises. Nevertheless, as the domestic industrial structure upgrades and technological capabilities improve, an over-reliance on the IEC in the development model will hinder the further enhancement of labor productivity. In addition, under the globalized industrial division of labor system, developing countries' excessive reliance on the IEC can easily trap them in "technology lock-in," making it difficult to improve their industrial and employment structures, which will lead to a decline in labor productivity under conditions of surplus labor supply. For the research sample employed herein, Figure 2 demonstrates that the inflection point for IEC integration is at a value of 6.77. As evinced by the data distribution features in Table 13, approximately a quarter of the sample points are situated on the right side of the inflection point, which signifies a certain level of over-reliance on the IEC in the Chinese economy. Columns (3) to (5) of Table 12 yield results confirming that excessive

dependence on the IEC has a detrimental effect on green innovation in the manufacturing sector. However, overall, this negative impact is masked by the positive effects of the shift in economic growth drivers.

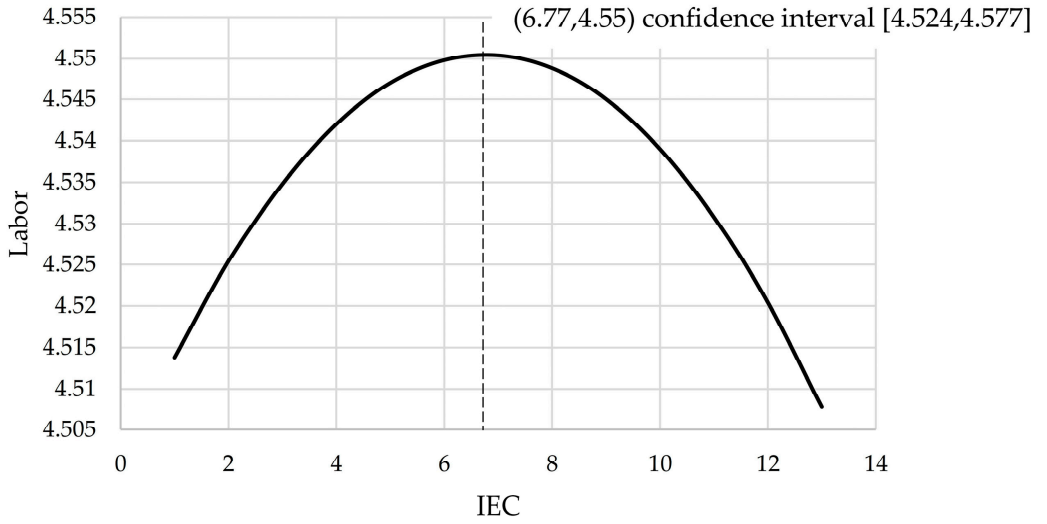

Figure 2. The impact of integrating into the IEC on labor productivity.

Table 13. Distribution of sample points.

Sample Points	P5	P10	P25	P50	P75	P90	P95
IEC	1.2360	1.9179	3.2699	4.8282	6.3721	7.7160	8.5088

6.2. The Key Role of Effective Regulation by Government Departments

Table 14 presents regression results confirming that government environmental regulation and macroeconomic guidance both exert a significant moderating role in the IEC's facilitation of green innovation among Chinese manufacturing enterprises. When these moderating effects are included, the significance and magnitude of the IEC's impact decrease, and in some cases, the effect becomes negative. This demonstrates that government macro guidance on environmental and economic development is crucial for promoting green innovation through the IEC. In the absence of effective government regulation, IEC integration would likely lead enterprises to prioritize short-term profit, undermining green innovation and resulting in market failure. Since 2006, China has integrated economic growth and environmental governance into the performance evaluations of local government officials, allowing for a stronger emphasis on ecological and environmental priorities. This regulatory framework is fundamental to the successful promotion of green innovation in Chinese manufacturing enterprises through the IEC. Effective government regulation is therefore indispensable for overcoming market failure and ensuring that the IEC drives the transformation of economic growth drivers toward green innovation.

The analysis results in Sections 6.1 and 6.2 also partially explain the research conclusions in the existing literature regarding the notion that engaging in international economic and trade activities would inhibit green innovation.

Table 14. The regulatory role of government departments.

Variables	(1) GI	(2) GI	(3) GI
IEC	0.0005 (0.0026)	0.0076 (0.0068)	−0.0661 *** (0.0094)
IEC·ER-Intensity	1.5149 *** (0.5320)		
IEC·ER-Index		−0.0059 *** (0.0020)	
IEC·EG-Target			0.0088 *** (0.0012)
Control variables	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes
Province–time fixed effects	Yes	Yes	Yes
R-squared	0.0956	0.0949	0.0957
Observations	260,568	260,568	260,568

Note: The regression coefficients are shown in the table, with the corresponding robust standard errors in parentheses. *** Regression coefficients significant at the 1% level.

7. Conclusions and Policy Recommendations

7.1. Research Conclusions

Since the reform and opening up, active integration into the IEC has injected a strong impetus into China's rapid economic growth. The IEC has consistently played a critical role in China's industrial restructuring and technological advancement. At present, China's economy has stepped into a new development stage: the impetus for economic growth is transitioning from factor-driven to innovation-driven, and the harmonious coexistence between humans and nature is a core characteristic of China's modernization endeavors. Furthermore, industrialization represents an unavoidable route for developing countries' economic development. As a major developing country, China has promoted industrialization by actively integrating into the IEC, providing important references for many developing countries. In the modern era of strong advocacy for sustainable development, China's integration into the IEC also offers valuable experience for other emerging economies that are rapidly industrializing, highlighting the impacts of green innovation on manufacturing enterprises. Thus, there is a need for a thorough examination of the IEC's impacts on green innovation in China's manufacturing sector. This research empirically verifies the impact and mechanism of IEC integration on green innovation among Chinese manufacturing enterprises, utilizing a constructed world multi-regional input–output table that includes China's provinces and data from listed Chinese manufacturing companies.

The research findings are summarized as follows: ① IEC integration can drive green innovation in manufacturing enterprises by advancing the transformation of China's economic growth drivers. ② As China's economic growth momentum continues to shift, economic cooperation with Europe and numerous developing countries has significantly promoted green innovation in Chinese manufacturing enterprises. Furthermore, the vast market space generated by industrial complementarity with developing countries has exerted a strong impetus for green innovation in these enterprises, effectively offsetting the negative impacts of technological lock-in from developed economies. ③ In the process of IEC integration, green innovation activities of state-owned enterprises (SOEs) and high-tech industry enterprises have become the fundamental driving force behind the green trans-

formation of China's manufacturing industry. ④ Notably, when the domestic economic cycle is relatively underdeveloped and labor supply is excessive, the impact of the IEC on labor productivity in China's manufacturing industry exhibits an inverted "U"-shaped pattern. Excessive reliance on the IEC will hinder the improvement of manufacturing labor productivity and the sound operation of the economic cycle, which is detrimental to enterprises' green innovation. China's economy has already shown a certain degree of over-reliance on the IEC, though this adverse effect is obscured by the positive impact of economic growth driver transformation. ⑤ Effective government regulation can address market failures and plays an indispensable role in facilitating green innovation among Chinese manufacturing enterprises within the IEC.

7.2. Policy Implications

Based on the above findings, this research offers the following policy implications:

(1) It has been confirmed that integrating into the IEC promotes green innovation in Chinese manufacturing enterprises by advancing the transformation of economic growth drivers. Efforts should be made to further enhance the level of opening-up, motivate enterprises to proactively participate in global market competition, and cultivate independent green innovation capacity.

(2) China should steer clear of over-reliance on the IEC by establishing a new development pattern centered on domestic circulation with mutual reinforcement between domestic and international circulations. Speeding up the development of domestic large-scale circulation and the establishment of a unified national market can stimulate domestic demand, facilitate the continuous optimization and upgrading of the industrial structure, and attain the steady improvement of labor productivity. This is conducive to increasing residents' income, promoting employment, and fully leveraging the driving force of consumption on economic growth. Ultimately, a higher-quality IEC based on the domestic economic cycle should be established and, through the IEC, continuous innovative impetus should be injected into the domestic economic cycle, thereby achieving beneficial interaction.

(3) Investment in the construction of digital information infrastructure should be expanded to support and foster the growth of the digital industry. Enterprises should be encouraged and guided to undertake digital transformation, which is crucial for them to better participate in the IEC, absorb external innovation resources, and drive the transformation of economic growth drivers in the rapidly developing digital economy.

(4) Amid the reconstruction of global value chains, we should proactively engage in economic and trade cooperation with developing countries, leverage complementary advantages, and pursue win-win cooperation to provide broad market space for the green transformation of China's manufacturing industry.

(5) Efforts should be made to consolidate the foundational function of SOEs in the strategic green transformation of China's manufacturing sector. With appropriate policy inclinations, the strategic leading role of high-tech industries in green transformation should be fully exerted, and these enterprises should be encouraged to extend their overseas business layout while improving their own development quality via international cooperation.

(6) It is imperative to fully acknowledge the significant role of government authorities in overcoming market failures and their guiding role in promoting economic green transformation, which is crucial for effectively utilizing the IEC to facilitate green innovation in China's manufacturing industry. Environmental regulations should be appropriately designed in light of specific circumstances, and blind pursuit of environmental assessment indicators while neglecting reality must be avoided. The

government-market relationship should be correctly understood, with increased application of market-based environmental regulation measures. Environmental costs should be internalized through market mechanisms to drive enterprises to strengthen their independent green innovation capacity. Ultimately, the performance evaluation mechanism for local governments needs to be further improved, and supervision and inspection efforts enhanced to boost the efficiency of environmental investment and crackdown on corruption.

7.3. Limitations of This Study

Owing to the long time span and low update frequency of China's multi-regional input–output tables, the sample period of this study has been significantly constrained. Furthermore, although small and medium-sized enterprises (SMEs) also play a vital role in green innovation, data accessibility challenges have precluded empirical analysis of these enterprises in the current research. As data quality continues to improve, we will conduct more in-depth investigations into the relationship between the IEC and corporate green innovation in future studies.

Author Contributions: Conceptualization, Z.L. and Q.Z.; methodology, Z.L.; software, Z.L.; validation, Z.L.; formal analysis, Z.L.; investigation, Z.L. and Q.Z.; resources, Z.L. and Q.Z.; data curation, Z.L. and Q.Z.; writing—original draft preparation, Z.L.; writing—review and editing, Z.L.; visualization, Z.L.; supervision, Q.Z.; project administration, Q.Z.; funding acquisition, Q.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Social Science Foundation Youth Project (20CJY028); Natural Science Foundation Project of Xinjiang Uygur Autonomous Region (2022D01C368); 2024 Annual Basic Research Funding Project for Universities in Xinjiang Uyghur Autonomous Region (XJEDU2024P004); Research Project on the Theoretical and Practical Aspects of the Party's Governance Strategy for Xinjiang in the New Era in 2025 (2023SJYB0277).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Magat, W.A. Pollution control and technological advance: A dynamic model of the firm. *J. Environ. Econ. Manag.* **1978**, *5*, 1–25. [CrossRef]
2. Clarke, R.A.; Stavins, R.N.; Greeno, J.L.; Bavaria, J.L.; Cairncross, F.; Esty, D.C.; Smart, B.; Piet, J.; Wells, R.P.; Gray, R.; et al. The challenge of going green. *Harv. Bus Rev.* **1994**, *72*, 37–48.
3. Wang, L.H.; Wang, H.; Dong, Z.Q. Economic growth and environmental quality compatibility policy conditions: A test of policy bias effects from the perspective of the direction of environmental technology progress. *Manag. World* **2020**, *3*, 39–60. [CrossRef]
4. Grossman, G.M.; Helpman, E. Trade, Innovation, and Growth. *Am. Econ. Rev.* **1990**, *80*, 86–91.
5. Copeland, B.R.; Taylor, M.S. North-south trade and the environment. *Q. J. Econ.* **1994**, *109*, 755–787. [CrossRef]
6. Antweiler, W.; Copeland, B.R.; Taylor, M.S. Is free trade good for the environment. *Am. Econ. Rev.* **2001**, *91*, 877–908. [CrossRef]
7. Su, L.J.; Liang, J.S. Understanding China's new dual circulation development strategy: A Marxian input-output analysis. *Rev. Radical. Pol. Econ.* **2021**, *53*, 590–599. [CrossRef]
8. Jiang, X.J.; Meng, L.J. Domestic circulation as the mainstay, external circulation as the empowerment, and a higher level of dual circulation: International experience and Chinese practice. *Manag. World* **2021**, *5*, 1–19. [CrossRef]
9. Wang, Y.; Pan, W.J.; Dong, W.H. Can a new infrastructure plan really promote the dual circulation strategy in China? *Singap. Econ. Rev.* **2024**, *69*, 61–79. [CrossRef]
10. Zhu, J.S.; Qu, D.D. Research on the impact of "Dual Circulation" on high-quality full employment in China. *World Surv. Res.* **2025**, *9*, 41–54. [CrossRef]

11. Dai, X.; Liu, C.P. Unimpeded dual circulation in manufacturing and enhanced innovation efficiency from the perspective of factor input. *China Bus. Mark.* **2024**, *12*, 58–70. [CrossRef]
12. Zhang, X.Y.; Dong, F. Temporal and spatial evolution of embodied carbon transfer network in the context of the domestic economic cycle. *Carbon Manag.* **2023**, *14*, 1–21. [CrossRef]
13. Dangelico, R.M. Green product innovation: Where we are and where we are going? *Bus. Strategy Environ.* **2016**, *25*, 560–576. [CrossRef]
14. Yang, B.; Li, B. The Belt and Road initiative and the green transformation and upgrading of enterprises. *Int. Econ. Trade Explor.* **2021**, *6*, 20–36. [CrossRef]
15. She, W.; Mabrouk, F. Impact of natural resources and globalization on green economic recovery: Role of FDI and green innovations in BRICS economies. *Resour. Policy* **2023**, *82*, 103479. [CrossRef]
16. Torrecillas, C.; Fernandez, S. Exports and outward FDI as drivers of eco-innovations: An analysis based on Spanish manufacturing firms. *J. Clean Prod.* **2022**, *349*, 131243. [CrossRef]
17. Qin, B.; Gao, Y.; Ge, L. The influence mechanism of outward fdi reverse technology spillovers on China's green innovation. *Technol. Econ. Dev. Econ.* **2023**, *29*, 468–499. [CrossRef]
18. Yang, L.; Zeng, H.; Xu, P. A comparative study of service trade competitiveness for green innovation development using the WWYZ model—Based on China and the 26 countries along 'the Belt and Road'. *Int. J. Technol. Manag.* **2021**, *85*, 165–189. [CrossRef]
19. Pan, H.; Yang, J.; Zhou, H. Global value chain embeddedness, digital economy and green innovation-Evidence from provincial-level regions in China. *Front. Environ. Sci.* **2022**, *10*, 1027130. [CrossRef]
20. Chiarvesio, M.; Marchi, V.D.; Maria, E. Environmental innovations and internationalization: Theory and practices. *Bus. Strategy Environ.* **2015**, *24*, 790–801. [CrossRef]
21. Szalavetz, A. Impact of greening on the upgrading of manufacturing subsidiaries' technological capabilities—A Hungarian perspective. *J. East Eur. Manag. Stud.* **2018**, *23*, 426–446. [CrossRef]
22. Zhang, D. Environmental regulation, green innovation, and export product quality: What is the role of greenwashing. *Int. Rev. Financ. Anal.* **2022**, *83*, 102311. [CrossRef]
23. Greenstone, M.; List, J.A.; Syverson, C. The effects of environmental regulation on the competitiveness of US manufacturing. *NBER Work. Pap.* **2012**, w18392. [CrossRef]
24. Popp, D. International innovation and diffusion of air pollution control technologies: The effects of NOx and SO_2 regulation in the US, Japan, and Germany. *J. Environ. Econ. Manag.* **2006**, *51*, 46–71. [CrossRef]
25. Li, Y.; Gao, D.; Wei, P. Can central environmental inspections induce green innovation in enterprises? *Stud. Sci. Sci.* **2021**, *8*, 1504–1516. [CrossRef]
26. Bai, Y.; Song, S.; Jiao, J. The impacts of government r&d subsidies on green innovation: Evidence from Chinese energy-intensive firms. *J. Clean Prod.* **2019**, *233*, 819–829. [CrossRef]
27. Xiang, X.; Liu, C.; Yang, M. Who is financing corporate green innovation? *Int. Rev. Econ. Financ.* **2022**, *78*, 321–337. [CrossRef]
28. Wang, X.; Wang, Y. Research on green credit policy promoting green innovation. *Manag. World.* **2021**, *6*, 173–188+11. [CrossRef]
29. Xia, L.; Gao, S.; Wei, J. Government subsidy and corporate green innovation—Does board governance play a role. *Energ. Policy* **2022**, *161*, 112720. [CrossRef]
30. Goetz, M. Financing conditions and toxic emissions. *Safe Work Pap.* **2019**, *254*. [CrossRef]
31. He, L.; Zhang, L.; Zhong, Z. Green credit, renewable energy investment and green economy development. *J. Clean Prod.* **2019**, *208*, 363–372. [CrossRef]
32. Liu, J.K.; Xiao, Y.Y. China's environmental protection tax and green innovation. leverage or crowding-out? *Econ. Res. J.* **2022**, *1*, 72–88.
33. Luo, S.; Yimamu, N.; Li, Y. Digitalization and sustainable development: How could digital economy development improve green innovation in China. *Bus. Strategy Environ.* **2022**, *32*, 1847–1871. [CrossRef]
34. Zhang, Z.N.; Qian, X.Y.; Cao, X.W. Research on the green innovation effects of enterprise digital transformation: Substantive innovation or strategic innovation? *Ind. Econ. Res.* **2023**, *1*, 86–100. [CrossRef]
35. Cao, Y.; Li, X.; Hu, H.L. How does digitalization drive the green transformation of manufacturing enterprises? An exploratory case study from the perspective of resource orchestration theory. *Manag. World* **2023**, *3*, 96–112+126+113. [CrossRef]
36. Xiao, J.; Zeng, P. Can digitalization achieve "quality improvement and quantity increase" of green innovation in enterprises? From the perspective of resources. *Stud. Sci. Sci.* **2023**, *5*, 925–935+960. [CrossRef]
37. Wang, F.Z.; Liu, X.L.; Zhang, L. Does digitalization promote green technology innovation in resource-based enterprises? *Stud. Sci. Sci.* **2022**, *2*, 332–344. [CrossRef]
38. Kong, F.X.; Liu, X.Z. Research on the impact of digital economy development on industrial green transformation: Empirical evidence based on Chinese cities. *Soft Sci.* **2023**, *4*, 27–35. [CrossRef]
39. Zhu, Q.Q.; Sun, J.W. The Belt and Road initiative and green innovation of Chinese enterprises. *Nanjing Soc. Sci.* **2020**, *11*, 33–40. [CrossRef]

40. Hu, D.; Jiao, J.; Tang, Y. How global value chain participation affects green technology innovation processes: A moderated mediation model. *Technol. Soc.* **2022**, *68*, 101916. [CrossRef]
41. Wu, L.C.; Cong, S.; Lin, L. A theoretical and empirical study on the impact of exports on green technological innovation in enterprises. *South China J. Econ.* **2022**, *8*, 52–72. [CrossRef]
42. Robert, H.A.; Ram, D.S. The role of standards in innovation. *Technol. Forecast. Soc.* **2000**, *64*, 171–181. [CrossRef]
43. Bowen, F.E.; Rostami, M.; Steel, P. Timing is everything: A meta-analysis of the relationships between organizational performance and innovation. *J. Bus. Res.* **2010**, *11*, 1179–1185. [CrossRef]
44. Pan, C.C.; Wang, F. How does digital empowerment affect the green transformation of enterprises? Analysis of the dual impact of green innovation capacity and organizational inertia. *J. Nanjing Tech Univ.* **2022**, *4*, 89–100+116.
45. Awan, U.; Nauman, S.; Sroufe, R. Exploring the effect of buyer engagement on green product innovation: Empirical evidence from manufacturers. *Bus. Strategy Environ.* **2021**, *30*, 463–477. [CrossRef]
46. Wang, J.; Xue, Y.; Yang, J. Boundary-spanning search and firms' green innovation: The moderating role of resource orchestration capability. *Bus. Strategy Environ.* **2020**, *29*, 361–374. [CrossRef]
47. Tao, F.; Zhao, J.Y.; Zhou, H. Does environmental regulation achieve "incremental and quality improvement" in green technology innovation? Evidence from environmental target responsibility. *Chin. Ind. Econ.* **2021**, *2*, 136–154. [CrossRef]
48. Baron, R.M.; Kenny, D. The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* **1986**, *51*, 1173–1182. [CrossRef]
49. Li, W.J.; Zheng, M.N. Substantive innovation or strategic innovation? The impact of macro industrial policies on micro enterprise innovation. *Econ. Res. J.* **2016**, *4*, 60–73.
50. Ley, M.; Stucki, T.; Woerter, M. The impact of energy prices on green innovation. *Energ. J.* **2016**, *37*, 41–76. [CrossRef]
51. Mi, Z.; Zheng, J.; Meng, J.; Ou, J.M.; Hubacek, K.; Liu, Z.; Coffman, D.; Stern, N.; Liang, S.; We, Y.-M. Economic development and converging household carbon footprints in China. *Nat. Sustain.* **2020**, *3*, 529–537. [CrossRef]
52. Wang, Y.Q.; Dong, W. How does the rise of robots affect China's labor market? Evidence from manufacturing listed companies. *Econ. Res. J.* **2020**, *10*, 159–175.
53. Acemoglu, D.; Restrepo, P. Robots and jobs: Evidence from Us labor markets. *J. Polit. Econ.* **2020**, *128*, 2188–2244. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.