

Article

A Catalyst for China's High-Tech Export Competitiveness: Perspective of Technological Innovation

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Abstract: This study investigates the pivotal role of technological innovation in enhancing the export competitiveness of high-tech products in China, analyzing its interplay with industrial upgrading. Theoretically, it contributes to the understanding of how technological innovation affects high-tech product markets, offering a novel product-centric perspective distinct from traditional industry-focused views. Set against China's shift toward a dual circulation development paradigm, the research utilizes a panel regression model to analyze data from 30 Chinese provinces, cities, and autonomous regions from 2011 to 2021. The findings underscore the significant positive impact of technological innovation on export competitiveness, with variances noted across Eastern, Central, and Western regions. The study reveals that technological innovation primarily influences the global competitiveness of high-tech products through industrial upgrading. Policy recommendations emphasize strengthening technological innovation, enhancing education and government support, leveraging regional strengths, and achieving a balance between internal innovation capabilities and market openness. The findings suggest these strategies are crucial for enhancing export performance in the global market for high-tech products.

Keywords: high-tech industry; technological innovation; industrial upgrading; export competitiveness; intermediary effect



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1. Introduction

China's transition toward a dual circulation development paradigm, integrating domestic and international economic flows, marks a pivotal step in its modernization journey. This paradigm shift emphasizes seamless economic integration and industrial linkages, underpinned by an enhanced, innovative supply system that addresses critical challenges and bolsters national economic fluidity [1,2]. Transitioning from rapid growth to a focus on high-quality development, China is deepening reforms and expanding openness [3,4]. This shift emphasizes scientific innovation and industrial upgrading as key drivers of this quality-focused growth phase [5]. The decline in China's demographic dividend, characterized by an aging population and shrinking labor force, coupled with diminishing export price advantages, underscores the imperative shift toward enhancing product quality. This transition from a 'Made in China' to a 'Created in China' ethos is not just a strategic realignment but a necessary evolution to sustain economic growth. China is pivoting to a model that prioritizes innovation and high-value manufacturing to maintain its competitive edge on the global stage [6,7]. The COVID-19 pandemic has further underscored the importance of sustaining and improving the international competitiveness of Chinese exports, a foundational aspect of China's stance in global competition [8].

In this context, high-tech products, those that embody advanced technologies and high value-added [9], such as aerospace, biotechnology, electronics, information technology, and pharmaceuticals, play a crucial role in the economic development and international competitiveness of China [10], as they generate higher returns, create more jobs, and foster

innovation and spillovers [11]. However, the capability to produce and export high-tech products varies significantly across different regions within China [12–14], a disparity attributed to the varying degrees of technological innovation and the pace of industrial upgrading [15].

Previous studies concentrate on how technological innovation serves as a key driver of economic development, enhancing labor productivity and catalyzing the optimization of industrial structure [16]. Although existing empirical studies confirm the role of technological innovation in improving product quality [17]; diversifying product ranges, and thus fostering industrial upgrading [18]; and emphasize that this innovation-centric approach not only supports industrial upgrading but also significantly enhances product export competitiveness [19,20], most existing research focuses on the impact of technological innovation on the export competitiveness of the high-tech industry; that is, from an overall industrial perspective [21,22].

However, few studies have specifically focused on the impact of technological innovation on the export competitiveness of high-tech products; that is, from a product perspective. This approach has unique advantages as it can more specifically reveal how technological innovation directly affects the competitive positioning of individual products [23]. The export competitiveness of high-tech products is an important component of national competitiveness [24], influenced by a variety of factors including research and development investments [25,26], human capital [27], and government policies [28].

Recent research underscores the complexity of global trade dynamics in the high-tech sector. Srholec (2007) [29] highlights that a significant portion of exports in high-tech products is driven by the fragmentation of international production, a phenomenon especially notable in the electronics trade. This fragmentation reflects the global distribution of manufacturing processes, where different stages of production are spread across countries to optimize efficiency and costs.

In addition to production dynamics, the maturity of financial markets emerges as a critical factor influencing export competitiveness in the high-tech industry, as identified by Gong, Zhang, and Lin (2014) [30]. Their findings suggest that well-developed financial systems, which are more prevalent in developed nations [6], provide the necessary support for innovation and international trade.

Furthermore, the capability of a nation to harness and effectively apply technological advancements is paramount for securing a competitive edge in the export of high-tech goods, according to Pan, He, and Liu (2022) [31]. This capability is not only about access to technology but also about the integration of technological innovations into the production process, enhancing the quality and value of exports.

At the heart of these dynamics is the role of independent technological innovation by enterprises, as emphasized by Guo, Guo, and Wei (2018) [32]. They argue that sustained export competitiveness in the high-tech sector relies on continuous innovation within firms. Such innovation is essential for maintaining and strengthening a country's position in the international high-tech export market.

Therefore, this study fills a gap in the existing literature by analyzing the impact of technological innovation on the export competitiveness of high-tech products from a product perspective. It provides a more detailed and direct view, helping to understand how technological innovation promotes the competitiveness of high-tech products at a micro level. This study examines not only the direct effects of technological innovation on the export competitiveness of high-tech products, but also the mediating role of industrial upgrading in this process. Additionally, the study delves into the regional variations in the export competitiveness of high-tech products, offering a nuanced understanding of its heterogeneous nature across different geographical contexts.

This study is dedicated to examining the influence of technological innovation and industrial upgrading on the export competitiveness of high-tech products in China. We delve into the nuanced ways these factors interact within diverse regional contexts, thereby contributing to or impeding the nation's prowess in the international high-tech market.

This exploration is timely and essential, considering China's strategic pivot toward a dual circulation development model that seeks to harmonize domestic economic activities with global economic integration. By adopting a product-centric approach—rather than the conventional industry-focused analysis—this research offers a novel perspective on the dynamics at play in enhancing the export competitiveness of high-tech products through technological innovation. This perspective not only broadens the understanding of the technological innovation–export nexus but also illuminates the varied regional capacities within China to engage in this competitive arena.

The subsequent sections of this paper are organized to systematically explore the topic. Section 2 presents the theoretical mechanism and research questions. Section 3 delineates the models and criteria for variable selection pertinent to our study. Section 4 offers a detailed analysis of the empirical results, providing insights into the implications of our findings. Section 5 summarizes the key findings and offers policy recommendations based on our research. Finally, Section 6 concludes the paper.

2. Theoretical Analysis and Research Questions

In general, the competitiveness of high-tech products manifests in two primary aspects: the product's inherent advantages and its price [33]. Comprehensive consideration of both aspects is necessary to enhance the competitive edge of export products. With technological innovation, the competitive advantage of the product itself is significantly highlighted by substantially reducing production costs [34,35]. Technological innovation enables enterprises to autonomously analyze, develop, and process products, thus independently determining product quality and aiding in its enhancement [36–38]. It allows for product refinement according to diverse consumer needs, increasing market recognition and brand influence, thereby elevating brand value and opening international markets to enhance global market competitiveness [39]. Furthermore, as high-tech products are knowledge- and technology-intensive, technological innovation can change the intensity of product elements, enhancing export competitiveness [40,41]. The intensity of elements reflects the quality of high-tech products, as the incorporation of substantial scientific and technological content continuously raises the intensity of knowledge and technology elements [33]. This increase in element intensity elevates the export price of the product, thereby generating higher profits and enhancing the product's value and revenue [42].

Hosan et al. (2022) [43] report a decline in China's working-age population since its peak in 2011, signaling a diminishing demographic dividend, a trend previously highlighted by Mason (2007) [44]. This shift underscores the imperative to examine labor capital inputs and export price advantages within China's high-tech sectors. Presently, these industries encounter significant technological bottlenecks and display regional development disparities. Our analysis reveals that technological innovation is pivotal in bolstering the competitiveness of high-tech exports. While numerous factors influence this competitiveness, innovation emerges as a critical catalyst for enhancing export competitiveness. This study offers a novel lens on the impact of technological innovation on the competitiveness of China's high-tech exports, incorporating a statistical exploration of this effect. Furthermore, we delve into the regional diversity of innovation's role in improving the export competitiveness of these products.

This study further investigates the impact of industrial upgrading on the role of technological innovation in bolstering the competitiveness of high-tech products within China's market. Empirical studies have shown that the shift from labor-intensive to knowledge-based and technology-oriented industries signifies a radical change in the industrial landscape [45,46]. This shift not only redefines the industrial structure [41], but also provides a solid foundation for the technological support necessary for exporting high-tech products [47].

In reality, technological innovation plays a dual role in this transformation [48]. It not only optimizes the industrial structure by moving away from traditional labor-intensive models [49], but also paves the way for enhanced participation in international trade [50].

In high-tech industries, technological innovation is crucial for improving product quality and reorganizing industrial chains [45,51]. It enables the identification and either the restructuring or elimination of enterprises lacking in innovation, thereby optimizing resource utilization and strengthening international market competitiveness [47].

With the advent of economic globalization, high-tech products are increasingly able to enhance their position in the value chain through continuous development and innovation [36,45]. Technological innovation facilitates effective control over various stages of product life, from design and development to production and sales [47]. This leads to substantial growth in related industries, accumulation of knowledge wealth, and technical expertise, thus creating higher value [50].

Central to this process is the concept of self-driven innovative branding and the continuous enhancement of the industrial structure [49]. By adopting a path of technological innovation, industries can gradually break free from low-end industrial chains, improve their positioning in the global market, and effectively open up new international markets [47]. This strategy is instrumental in elevating the overall competitiveness of high-tech products on the global stage [45].

Technological innovation is a critical driver of high-tech product competitiveness, often facilitated by industrial upgrading. Yet, the impact of industrial upgrading as a mediating factor in this dynamic could vary significantly between developed and emerging economies. Given China's status as the world's largest emerging economy, characterized by diverse geographical contexts, the mediating role of industrial upgrading in enhancing technological innovation's impact on competitiveness may exhibit notable heterogeneity. This study aims to quantitatively analyze the mediating effect of industrial upgrading on the competitiveness of high-tech products within China's unique economic landscape.

3. Model Setting and Variable Selection

3.1. Model Setting

Balestra and Nerlov (1966) [52] pioneered the integration of panel data into econometrics, marking a significant advancement in the field. Panel regression models stand out for their ability to control for individual heterogeneity, enabling the analysis to distinguish between subjects and to track these entities over various time points. This approach effectively mitigates individual-level heterogeneity, enhancing the reliability and accuracy of the findings by increasing the effective sample size. Compared to cross-sectional data, panel data enrich the analysis by offering more comprehensive insights into individual behaviors, thereby increasing the diversity and depth of information. Additionally, panel regression analysis incorporates individual fixed effects to refine the control over inter-individual differences, thus improving the precision in estimating the influence of explanatory variables on the dependent variable. However, the efficacy of panel regression models is contingent upon the quality of the data, with the reliance on a singular data source posing a significant constraint on the econometric analysis of panel data. The selection of an appropriate model (a critical step in the process), is often guided by the Hausman test, which aids in deciding between random effects and fixed-effects models, as noted by Hu et al. (2010) [53]. This methodological choice is pivotal as it hinges on differing assumptions and approaches inherent to each model.

Fixed-effects regression models are characterized by their ability to account for inherent individual heterogeneity, thereby mitigating sample selection bias and omitted variable bias. Conversely, random effects models presume that individual differences are stochastic and uncorrelated with the independent variables. This assumption renders random effects models more appropriate for assessing the extent to which independent variables impact individual outcomes.

This study aims to quantitatively assess the impact of technological innovation on the export competitiveness of high-tech products. Based on the Hausman test in empirical study, we construct a fixed-effects panel regression model. This model is specifically

designed to isolate and analyze the influence of technological innovation, controlling for other variables that may also affect export competitiveness.

$$\text{LnECI}_{it} = \alpha_0 + \alpha_1 \text{LnTi}_{it} + \alpha_2 \text{LnX}_{it} + \varepsilon_{it} \quad (1)$$

In our regression model, the dependent variable LnECI_{it} represents the logarithm of the export competitiveness of high-tech products for a given region i in year t . The variable LnTi_{it} denotes the logarithm of the core explanatory variable R&D funding in the same region and year. Additionally, the variable LnX_{it} indicates the logarithm of control variables, encompassing a range of factors that could influence export competitiveness. The term ε_{it} represents the random error, capturing unobserved influences on the dependent variable.

To investigate the potential mediating effect of industrial upgrading in the relationship between technological innovation and the export competitiveness of high-tech products, we employ a stepwise regression approach proposed by Wen and Ye (2014) [54]. This method is designed to rigorously test the hypothesized mechanism wherein technological innovation enhances the export competitiveness of products via the pathway of industrial upgrading. The models deployed for this analysis are outlined below.

$$\text{LnUpgra}_{it} = \beta_0 + \beta_1 \text{LnTi}_{it} + \beta_2 \text{LnX}_{it} + \varepsilon_{it} \quad (2)$$

$$\text{LnECI}_{it} = \varnothing_0 + \varnothing_1 \text{LnTi}_{it} + \varnothing_2 \text{LnUpgra}_{it} + \varnothing_3 \text{X}_{it} + \varepsilon_{it} \quad (3)$$

In the presented models, the variable LnUpgra_{it} denotes the logarithm of industrial upgrading. This transformation into logarithmic form allows for a more nuanced interpretation of the variable's impact within the regression analysis.

The mediation effect is calculated using the following formula:

$$\beta_1 \varnothing_2 = \alpha_1 - \varnothing_1 \quad (4)$$

where $\beta_1 \varnothing_2$ is the indirect effect of technological innovation on export competitiveness through industrial upgrading, and $\alpha_1 - \varnothing_1$ is the total effect of technological innovation on export competitiveness minus the direct effect.

Our approach to detecting this mediation effect follows a systematic process. Firstly, test the regression coefficient α_1 ; if significant, proceed to step two. Secondly, conduct the Baron and Kenny (1986) [55] partial mediation test, which involves sequentially testing the significance of coefficients β_1 , \varnothing_2 ; if both are significant, it means that the effect of technological innovation on export competitiveness is at least partially mediated by industrial upgrading, with a Type I error rate less than or equal to 0.05; then proceed to step three. Thirdly, perform the Judd and Kenny (1981) [56] complete mediation test (since the first two were completed in the previous step), which involves testing the coefficient \varnothing_1 . If not significant, it indicates a complete mediation process, i.e., the effect of technological innovation on export competitiveness is entirely through the mediator industrial upgrading; if significant, it indicates a partial mediation process, i.e., only a part of the effect of technological innovation on export competitiveness is mediated by industrial upgrading. The test ends. Finally, conduct the Sobel (1982) test [57]; if significant, it means the mediation effect of industrial upgrading is significant.

3.2. Variable Selection

(1) Explained Variable: Export Competitiveness

The assessment of export competitiveness can be approached through various established methods, each with its own set of evaluation indicators. Commonly used metrics include the Trade Competitiveness Index (TC), Revealed Comparative Advantage Index (RCA), Export Competitiveness Index (ECI), International Market Share Index (MSI), and Intra-industry Trade Index (IiT).

① Trade Competitiveness Index (TC)

The Comparative Advantage Index, a widely utilized metric for evaluating international trade competitiveness, assesses whether a country's products hold comparative advantages or disadvantages within global markets, alongside the extent of their competitive edge. This index is calculated based on the ratio of the net difference between a country's exports and imports to its total trade volume, offering a nuanced understanding of trade dynamics. Notably, the index is resilient to macroeconomic fluctuations, providing a relative measure of trade performance. The formula for calculating the Comparative Advantage Index is

$$TC = \frac{|X_{ij} - M_{ij}|}{(X_{ij} + M_{ij})} \quad (5)$$

In this model, X_{ij} represents the total export value of product j by country i , while M_{ij} denotes the total import value of the same product by the same country. The Trade Competitiveness (TC) index, ranging from -1 to 1 , serves as a quantitative measure of a country's comparative advantage in producing product j . A TC value greater than 0 signifies that country i possesses a comparative advantage in producing j , with values approaching 1 indicating a stronger comparative advantage and higher international competitiveness. Conversely, a TC value less than 0 suggests a comparative disadvantage, or a lesser degree of competitiveness, in producing j . A TC value near 0 implies that the comparative advantage of country i in product j aligns closely with the international average, indicating neither a significant advantage nor disadvantage.

② Revealed Comparative Advantage Index (RCA)

The Revealed Comparative Advantage (RCA) Index, introduced by Balassa (1965) [58], offers a methodological approach to assessing comparative advantage. This index is calculated as the ratio of a country's export share of a specific commodity or service to its total exports, relative to the global export share of that commodity or service against total global exports. As a relative measure, the RCA remains invariant to fluctuations in the aggregate export volumes of both the country in question and the world, thereby accurately reflecting the competitive standing of a specific product or service in international markets. The underlying formula for the RCA is

$$RCA = (X_{ij}/Y_i) / (X_{wj}/Y_w) \quad (6)$$

In the RCA framework, X_{ij} denotes the export value of commodity j from country i , and Y_i signifies the total export value of country i . Similarly, X_{wj} and Y_w represent the global export values for commodity j and the total global export value, respectively. The ratio X_{wj}/Y_w quantifies the global average competitiveness of commodity j . An RCA value exceeding 2.5 suggests that the country's products are significantly more competitive on the global stage, indicating a strong comparative advantage. Conversely, an RCA value below 0.8 reflects a comparative disadvantage, highlighting weaker international competitiveness for the product in question.

③ International market share (MSI)

This metric is defined as the ratio of a country's exports of goods or services to the total global exports, serving as a critical indicator of the international competitiveness and market position of a country's products. The formula for calculating this ratio is

$$MSI = \frac{X_{ai}}{X_{wi}} \quad (7)$$

In this context, X_{ai} denotes the export value of product i from country a , whereas X_{wi} represents the global export volume of product i . A higher market share ratio signifies enhanced competitiveness of the product on an international scale. Conversely, a lower ratio indicates diminished competitiveness.

④ Intra-industry Trade Index (IiT)

Although the Trade Competitiveness (TC) and Revealed Comparative Advantage (RCA) indices are widely employed to analyze inter-industry trade dynamics, the landscape of international trade is evolving, with a growing share of intra-industry trade, particularly in high-tech manufacturing sectors characterized by significant importation of intermediate inputs. Traditional metrics, including the Market Share Index (MSI), RCA, and TC, fail to account for the role of imported intermediate inputs within exported products. To bridge this gap, Grubel and Lloyd (1975) [59] introduced the Intra-industry Trade Index (IiT), designed to quantify the extent to which trading nations or regions import and export similar products within identical industries. The formula for calculating the IiT is

$$IiT_{ij} = 1 - |X_{ij} - M_{ij}| / (X_{ij} + M_{ij}) \quad (8)$$

In this framework, X_{ij} denotes the export volume of product j from region i , while M_{ij} indicates the import volume of the same product within the region. The Intra-industry Trade (IiT) Index approaches 1 as the regional interdependence of products, in terms of production specialization, increases. This reflects a higher level of intra-industry specialization and the development of intra-industry trade, which, in turn, may signal the international competitiveness of the industries and products involved. However, the precise origins of intermediate inputs are typically discernible only through input–output tables, where the categorization of goods is often too generalized to facilitate a detailed analysis of foreign trade structures.

⑤ Export Competitiveness Index (ECI)

Selecting metrics such as the Comparative Advantage Index or International Market Share inherently involves data biases stemming from their calculation methodologies. Industry competitiveness is intricately linked not only to the sector itself but also to its overall scale. Therefore, an objective assessment of export competitiveness necessitates more than just import and export volumes. The Export Competitiveness Index (ECI) addresses this by incorporating regional disparities, offering a comprehensive measure of export competitiveness across different regions. It calculates the ratio of an industry's export share to the national industrial export share, alongside the ratio of its sales revenue to the national industrial sales revenue share. This index captures the influence of the total scale of industrial exports, facilitating a nuanced evaluation of export competitiveness across provinces and sub-sectors.

Taking into account the constraints of data accessibility and the imperative to address regional variations, this study aligns with the methodologies proposed by Yan (2006) and Cai et al. (2018) [60,61] by employing the Export Competitiveness Index (ECI) as the chosen metric. This approach facilitates a detailed assessment of regional export competitiveness, particularly in the high-tech sector, underscoring the ECI's utility in capturing nuanced economic dynamics [60]. The ECI is calculated as a ratio, representing the export value of high-tech products from a specific region relative to the total export value of that region, normalized against the proportion of the region's GDP in the total regional GDP. The formulation of the ECI is as follows:

$$ECI_i = \frac{export_i / \sum_{i=1}^n export_i}{gdp_i / \sum_{i=1}^n gdp_i} \quad (9)$$

In our analysis, the variable ECI_i is designated to represent the Regional Export Competitiveness Index, a measure quantifying a region's competitive stance in international export markets. The variable $export_i$ denotes the export volume of high-tech products from the region, capturing the magnitude of its high-tech export activity. Finally, the variable gdp_i corresponds to the region's Gross Domestic Product (GDP), reflecting the overall economic scale and output of the region.

(2) Core Explanatory Variable: Technological Innovation

To quantify the level of technological innovation, two measurements can be considered, i.e., internal R&D expenditure and patent application volume [62,63]. Internal R&D expenditure, represented as Ti1, serves as the primary explanatory variable, reflecting the financial investment dedicated to research and development within the region. This measurement is from the perspective of technology input to measure technological innovation. Meanwhile, patent application volume, denoted as Ti2, is utilized as an alternative explanatory variable for robustness checks. It measures the technological innovation from the perspective of technology output. In our empirical analysis, both these variables are transformed into logarithmic form to enable a more nuanced interpretation of their effects.

Despite the input and output perspectives provided by these two metrics, biases arise from constraints in capital utilization rates and technological efficiency. Nevertheless, this study incorporates insights from Xie and Liao (2017) and Zhang et al. (2011) [62,63] to mitigate these limitations. Accordingly, it adopts the aforementioned proxy variables to capture a more nuanced understanding of the subject matter.

(3) Mediating Variable: Industrial Upgrading

Industrial upgrading is typically quantified by the proportion of tertiary industry output relative to the total industrial output, or by the ratio of tertiary to secondary industry output. According to Zhen and Yang (2022) [64], in this study we use the logarithm of the ratio of high-tech industry output to the total industrial output as a proxy for industrial upgrading, denoted as Upgra. Due to data constraints, comprehensive data on the total output of high-tech manufacturing are only available for the year 2011, sourced from the China High-tech Industry Statistical Yearbook and China Statistical Yearbook on Science and Technology. Subsequent years have seen changes in statistical categorizations within these yearbooks. Consequently, to maintain data consistency, the total industrial output of high-tech enterprises, as reported in China Torch Statistical Yearbook, is utilized as a proxy for the output of high-tech industries. This substitution is necessitated by the limitations of data availability and aims to provide the most accurate representation possible within these constraints.

(4) Control Variables: Government Support, Education Level, and Market Openness

Beyond technological innovation, a range of additional factors significantly influence the export competitiveness of high-tech products. Referencing the approach of Zhang et al. (2016) [65], this study incorporates several control variables to comprehensively account for external influences.

The sustainability of high-tech industry development extends beyond market dynamics, necessitating substantial governmental intervention. Governmental funding plays a pivotal role not only in bolstering research and innovation within high-tech enterprises, enhancing product quality and performance, but also in marketing and market expansion efforts for high-tech products. Such strategies are instrumental in elevating the global competitiveness of these products. Echoing the methodology of Zhang et al. (2016) [65], this study incorporates a measure of government support, quantified by the ratio of government technology spending to total fiscal outlays, to assess the impact of governmental backing on the sector.

The high-tech sector, pivotal to the national economy's strategic framework, increasingly depends on skilled high-tech professionals. Enhanced human capital levels not only facilitate the alignment of workers with roles that correspond to their skills and experience, thereby improving job performance and technological advancement, but also bolster research and development (R&D) capabilities. This, in turn, drives enterprise R&D enhancement and supports export sophistication [66]. In line with Yu and Fan (2022) [67], this study incorporates educational attainment as a control variable to gauge human capital's impact. The education level, denoted as Edu, is assessed through the ratio of university students to teachers, providing an indicator of educational resource availability and quality in the region.

China's foundational policy of international openness plays a pivotal role in shaping its export competitiveness. Echoing the methodology of Han et al. (2023) [68], this study controls for market openness by employing the ratio of total trade volume (imports plus exports) to GDP as an indicator of economic integration and global market engagement. This metric serves as a critical determinant in assessing the nuances of regional export competitiveness.

4. Empirical Studies

4.1. Data Description

Owing to data constraints, this study omits Xizang, Hong Kong, Macao, and Taiwan from its scope, concentrating instead on panel data from 30 provinces, municipalities, and autonomous regions within China for the period 2011 to 2021. This analysis primarily utilizes data from authoritative sources including the China Statistical Yearbook, China Industrial Statistical Yearbook, Statistical Yearbooks of 30 Provinces and Municipalities, China High-Tech Industry Statistical Yearbook, China Statistical Yearbook on Science and Technology, and China Torch Statistical Yearbook (the bulk of the data originate from yearbooks published by the National Bureau of Statistics of China (NBSC). This source is widely regarded as authoritative in the study of China's socioeconomic conditions. It provides a comprehensive reflection of the macroeconomic landscape of China), supplemented by data from the EPS database. Table 1 presents an exhaustive account of the variables selected and the corresponding data sources. In our empirical analysis, we have applied a logarithmic transformation to the data to normalize distributions and stabilize the variance. Furthermore, to address the issue of missing values, interpolation techniques have been employed to estimate these gaps, ensuring the integrity and continuity of our dataset.

Table 1. Variable Selection and Data Sources.

Variables	Measurement	Literature	Data Sources
Export Competitiveness (Eci)	$\frac{\text{export}_i / \sum_{i=1}^n \text{export}_i}{\text{gdp}_i / \sum_{i=1}^n \text{gdp}_i}$	Yan (2006) [60]	China Statistical Yearbook, National Bureau of Statistics of China (NBSC), China High-Tech Industry Statistical Yearbook, Statistical Yearbooks of 30 Provinces and Municipalities, EPS Database.
Technological Innovation (Ti)	Internal R&D expenditure (Ti1), Patent application volume (Ti2)	Zhang et al. (2011) [63], Xie and Liao (2017) [62]	China High-Tech Industry Statistical Yearbook, China Statistical Yearbook, National Bureau of Statistics of China (NBSC).
Industrial Upgrading (Upgra)	Ratio of high-tech industry output to total industrial output	Zhen and Yang (2022) [64]	China High-Tech Industry Statistical Yearbook, China Statistical Yearbook on Science and Technology, China Torch Statistical Yearbook, China Industrial Statistical Yearbook, Statistical Yearbooks of 30 Provinces and Municipalities.
Government Support (Gov)	Ratio of government technology expenditure to total fiscal expenditure	Zhang et al. (2016) [63]	China Statistical Yearbook, National Bureau of Statistics of China (NBSC).
Education Level (Edu)	Student-to-teacher ratio at universities	Yu and Fan (2022) [67]	China Statistical Yearbook, National Bureau of Statistics of China (NBSC).
Market Openness (Open)	Ratio of total trade (imports plus exports) to GDP	Han et al. (2023) [68]	China Statistical Yearbook, National Bureau of Statistics of China (NBSC), Statistical Yearbooks of 30 Provinces and Municipalities.

4.2. Analysis of Benchmark Regression

(1) Endogeneity Tests

Endogeneity is a common problem in causal inference, arising from measurement errors, omitted variables, and bidirectional causality. This paper attempts to control for endogeneity in the model specification. The data are obtained from official statistical year-books, reducing the likelihood of measurement errors. To examine the relationship between technological innovation and export competitiveness, the regression analysis includes three control variables: educational level, government support, and market openness. Since the panel data may have individual effects, a Hausman test was used to select the appropriate model, and a fixed-effects model was chosen based on the test results.

Furthermore, endogeneity may also manifest in reverse causality between variables; for instance, while technological innovation enhances the competitiveness of high-tech product exports, an increase in the competitiveness of high-tech product exports may, in turn, elevate the level of technological innovation. Thus, drawing on the method for testing endogeneity proposed by Geng and Bai (2019) [69], this study opts to use the lagged one period of the explanatory variable as an instrumental variable, and employs panel 2SLS (Two-Stage Least Squares) regression to address the issue of endogeneity. In the model examining the impact of technological innovation on the competitiveness of high-tech product exports, the lagged one period of technological innovation (L.Ti) is tested as the explanatory variable, where L.Ti represents the data of LnTi lagged by one period. Table 2 reports the regression results of the endogeneity test. It is evident that, even when considering endogeneity, the level of technological innovation significantly enhances the competitiveness of high-tech product exports.

Table 2. Results of Endogeneity Tests.

	(1) Stage 1	(2) Stage 2
L.Ti	0.9438 *** (62.74)	
LnTi		0.3786 *** (8.48)
LnEdu	0.1384 (0.54)	4.6096 *** (6.46)
LnGov	0.1260 *** (2.62)	0.2137 (1.55)
LnOpen	−0.0284 (−1.05)	0.7520 *** (9.97)
Cons	0.9234 (1.24)	−17.2408 *** (−8.25)
N	300	300
R ²	0.972	0.725

Note: *** $p < 0.01$, with t-statistics in parentheses.

(2) Parameter Estimation Results

Utilizing Equation (1), a Hausman test was conducted, yielding a chi-square value of 16.11 and a p -value of 0.0001. This result substantiated the selection of a fixed-effects model for our analysis. Table 3 presents the parameter estimation results regarding the impact of technological innovation on the export competitiveness of high-tech products. The first column of Table 3 details the parameter estimation results without the inclusion of control variables. The subsequent columns (second to fourth) incorporate the control variables: education level, government support, and market openness, respectively. These results elucidate that technological innovation substantially boosts export competitiveness, as evidenced by a coefficient of 0.3267 in the absence of control variables. This finding underscores that increased R&D funding in high-tech industries significantly elevates export competitiveness.

Table 3. Estimation of the Benchmark Regression Model.

	(1) <i>LnECI</i> Fixed Effects			
LnTi1	0.3267 *** (6.67)	0.2652 *** (5.22)	0.1947 *** (3.40)	0.3218 *** (5.51)
LnEdu		2.7251 *** (3.69)	2.9526 *** (4.01)	2.6568 *** (3.79)
LnGov			0.3744 *** (2.59)	0.2041 (1.46)
LnOpen				0.7084 *** (5.88)
Constant	−5.5729 *** (−9.03)	−12.6290 *** (−6.29)	−10.8756 *** (−5.18)	−11.0494 *** (−5.55)
Observations	330	330	330	330
R ²	0.13	0.17	0.19	0.27

Note: T-values associated with the variables are presented in parentheses. *** indicates significance at the 1% level.

Moreover, the study reveals that education level, government support, and market openness each significantly contribute to enhancing export competitiveness. Notably, the education level exhibits the most pronounced positive effect on export competitiveness. The increase in government technology expenditure is observed to invigorate enterprise innovation, further amplifying the competitiveness of product exports.

(3) Robustness Testing

To validate the robustness of our initial findings, this study conducts an additional robustness test. In this test, the number of patent applications, previously used as a proxy for technological innovation, is replaced with internal R&D expenditure. This substitution serves to further examine the consistency of the relationship between technological innovation and the export competitiveness of high-tech products. The detailed results of this robustness check are presented in Table 4. In Table 4, columns one to four display the parameter estimation results, reflecting the impact of technological innovation on high-tech export competitiveness after substituting the core explanatory variable and sequentially incorporating control variables, such as education level, government support, and market openness. The empirical results reveal that the coefficients for the level of technological innovation remain positive and significant at the 1% level across all models. This consistency with the benchmark regression model's results affirms the robustness of our conclusions. Moreover, the findings underscore that the education level and marketization level significantly boost the competitiveness of high-tech product exports. However, the positive relationship between government support and the export competitiveness of China's high-tech products is not as pronounced. These observations suggest that while government investment in enterprises can foster the development of high-tech industries to a certain extent, relying solely on this is not a sustainable strategy for long-term competitiveness in the international market. Crucially, it is the enhancement of independent innovation capabilities and the development of distinct brand competitiveness that are fundamental for enterprises to achieve a strong position in global competition.

(4) Heterogeneity Analysis

This study further delves into regional disparities by dividing the samples into three subgroups: Eastern, Central, and Western regions of China. We conduct heterogeneity tests on model (1) for these regions, with the specific results presented in Table 5. The empirical findings reveal nuanced regional variations in the impact of technological innovation on export competitiveness. In the Eastern region, technological innovation exhibits a minimal and statistically insignificant effect on improving export competitiveness. Here, an inverted U-shaped relationship emerges, suggesting that beyond a certain point, the marginal contribution of R&D investment diminishes. Conversely, in the Central region, technological innovation significantly bolsters the export competitiveness of high-tech products, with

a notable coefficient of 0.7132 at the 1% significance level. The Western region, however, demonstrates a weaker link between technological innovation and export competitiveness. This could be attributed to several developmental challenges and a relatively weaker foundation in technological innovation compared to the Eastern and Central regions. As a result, increased R&D funding in the Western region does not effectively translate into enhanced export competitiveness of high-tech products. Notably, the level of education significantly enhances export competitiveness in the Western region, a trend not observed in the Eastern and Central regions. This may be due to the high demand for top-tier innovative talent in China's high-tech sector. Investment in education, particularly in the talent-scarce Western region, can foster the cultivation of innovative talent and elevate the overall educational standard, thereby significantly improving the region's high-tech export competitiveness. Government support plays a distinctive role across regions. In the less developed Western region, government support markedly improves export competitiveness. In contrast, it appears to have a somewhat inhibitory effect in the Central region and shows no significant impact in the Eastern region. Moreover, the degree of openness has a positive and significant association with high-tech export competitiveness, underscoring the importance of an open economic environment in facilitating these outcomes.

Table 4. Robustness Test Results.

(1) <i>LnECI</i>				
Fixed Effects				
LnTi2	0.5289 *** (8.36)	0.4556 *** (6.50)	0.3865 *** (4.58)	0.5538 *** (6.57)
LnEdu		1.7892 ** (2.35)	2.0589 *** (2.63)	1.5663 ** (2.11)
LnGov			0.2211 (1.46)	0.0360 (0.25)
LnOpen				0.7100 *** (6.12)
Constant	−6.3542 *** (−10.83)	−10.8177 *** (−5.44)	−10.0554 *** (−4.90)	−9.6695 *** (−4.99)
Observations	330	330	330	330
R ²	0.19	0.20	0.21	0.30

Note: Significance levels are denoted as follows: ** indicates significance at the 5% level, and *** at the 1% level.

Table 5. Results of the Heterogeneity Test.

	Eastern Region	Central Region	Western Region
Fixed Effects			
LnTi1	0.04436 (0.61)	0.7132 *** (6.37)	0.2555 ** (2.52)
LnEdu	−0.5123 (−0.97)	1.4478 (1.19)	5.0655 *** (3.38)
LnGov	0.0539 (0.43)	−0.3672 * (−1.78)	0.6236 * (1.94)
LnOpen	0.7963 *** (5.51)	0.2715 (1.16)	0.7425 *** (3.52)
Constant	1.2057 (0.70)	−15.8905 *** (−4.37)	−15.0948 *** (−3.62)
Observations	121	88	121
R ²	0.30	0.54	0.28

Note: Significance levels are denoted as follows: * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

4.3. Analysis of Mediation Effects

(1) Impact of Technological Innovation on Industrial Upgrading

Table 6 presents the parameter estimation results examining the impact of technological innovation on industrial upgrading. The first column of the table details the results without the inclusion of control variables, while the subsequent columns (second to fourth) incorporate these variables sequentially. The empirical analysis reveals a significant positive relationship between technological innovation and industrial upgrading, with the coefficient being significant at the 1% level. This finding underscores that technological innovation serves as a driving force for the upgrading of high-tech industries. Additionally, the level of education is observed to positively contribute to industrial upgrading. On the other hand, the government's role, while important in macro coordination and policy optimization, shows a non-significant negative correlation with industrial upgrading. This suggests that the government's influence may be more indirect in this context. Interestingly, a significant negative correlation is found between the degree of openness and industrial upgrading. This indicates that the process of upgrading high-tech industries may rely more heavily on internal technological innovation rather than external market factors. In this study, we adopted the approach of Qu (2022) [70], utilizing the ratio of sales values between high-technology and low-technology industries as a proxy variable for industrial upgrading in our robustness tests. The results, as shown in Table 7, indicate that the levels of technological innovation are positive and pass the significance test at the 1% level. This suggests that technological innovation significantly promotes the upgrading of high-technology industries, confirming the robustness of our conclusion.

Table 6. Results of Parameter Estimation on Industrial Upgrading.

	(2) LnUpgra Fixed Effects			
LnTi1	0.5316 *** (12.02)	0.4759 *** (10.38)	0.5050 *** (9.69)	0.4988 *** (8.88)
LnEdu		2.4643 *** (3.69)	2.3704 *** (3.53)	2.3847 *** (3.54)
LnGov			−0.1544 (−1.17)	−0.1462 (−1.08)
LnOpen				−0.0342 (−0.29)
Constant	−8.5235 *** (−15.29)	−14.9042 *** (−8.23)	−15.6274 *** (−8.17)	−15.6190 *** (−8.15)
Observations	330	330	330	330
R ²	0.33	0.35	0.36	0.36

Note: *** indicates significance at the 1% level.

(2) Mediation Effect Test

Table 7. Parameter Estimation Results after Substituting for Industrial Upgrading.

	(2) LnUpgra1 Fixed Effects			
LnTi1	0.2543 *** (4.47)	0.2778 *** (4.61)	0.2892 *** (4.21)	0.3367 *** (4.57)
LnEdu		−1.0257 (−1.17)	−1.0632 (−1.20)	−1.1750 (−1.33)
LnGov			−0.0604 (−0.35)	−0.1240 (−0.70)
LnOpen				0.2642 * (1.74)
Constant	−4.8080 *** (−6.71)	−2.1564 (−0.91)	−2.4378 (−0.97)	−2.4988 (−1.00)
Observations	329	329	329	329
R ²	0.07	0.06	0.07	0.08

Note: Significance levels are denoted as follows: * indicates significance at the 10% level, and *** at the 1% level.

Table 8 delineates the results of testing the mediating effect of industrial upgrading on the relationship between technological innovation and the export competitiveness of high-tech products. Columns one and two of the table present the parameter estimation results of the impact of technological innovation on export competitiveness, before and after the inclusion of control variables, respectively. Columns three and four display the parameter estimation results illustrating the mediating role of industrial upgrading in this relationship, respectively with and without the inclusion of mediating variables. The test results reveal that both the coefficients of technological innovation and the mediating variable of industrial upgrading are significantly positive. This finding substantiates that industrial upgrading exerts a considerable mediating effect on how technological innovation influences the competitiveness of high-tech products. Moreover, the analysis suggests that the mediating effect of industrial upgrading is more pronounced in the absence of control variables. This indicates that, in scenarios where control variables are not considered, the impact of technological innovation on high-tech product export competitiveness primarily manifests through the influence of industrial upgrading. Consequently, this underlines the critical role of technological innovation in fostering industrial upgrading, thereby enhancing the export competitiveness of high-tech products.

Table 8. Results of Mediation Effect Test.

	(1) <i>LnECI</i> Fixed Effects		(3) <i>LnECI</i> Fixed Effects	
LnUpgra			0.3188 *** (5.19)	0.3015 *** (5.21)
LnTi1	0.3267 *** (6.67)	0.3218 *** (5.51)	0.1572 *** (2.75)	0.1714 *** (2.72)
LnEdu		2.6568 *** (3.79)		1.9378 *** (2.83)
LnGov		0.2041 (1.46)		0.2482 * (1.84)
LnOpen		0.7084 *** (5.88)		0.7187 *** (6.22)
Constant	−5.5729 *** (−9.03)	−11.0494 *** (−5.55)	−2.8553 *** (−3.61)	−6.3405 *** (−3.00)
Observations	300	330	330	330
R ²	0.13	0.27	0.20	0.33

Note: Significance levels are denoted as follows: * indicates significance at the 10% level, and *** at the 1% level.

To further test the robustness of the aforementioned conclusions, we replaced the index of industrial upgrading with the ratio of sales values between high-technology industries and low-technology industries for robustness testing. Considering that the effect of industrial upgrading may have a certain lag and cannot immediately enhance the export competitiveness of products, we included the lagged data of industrial upgrading (one period behind) in the model. Table 9 presents the test results of the mediating effect of technological innovation on the export competitiveness of high-tech products, where L.LnUpgra represents the data of industrial upgrading lagged by one period. Specifically, the first and second columns show the parameter estimation results of the impact of technological innovation on the competitiveness of high-tech product exports without and with control variables, respectively; the third and fourth columns, respectively, present the parameter estimation results of the mediating effect of industrial upgrading on the competitiveness of high-tech product exports, with and without control variables, after introducing the mediating variable. The test results indicate that the coefficients of technological innovation and the lagged industrial upgrading variable are both significantly positive, suggesting that industrial upgrading plays a partial mediating role in the impact of technological innovation on the competitiveness of high-tech products, and this effect is lagged. A possible reason is that the collected data are from the end of the statistical

year, so the current data on industrial upgrading can have an impact on future periods and definitely will not affect the competitiveness of the same period (current period).

Table 9. Robustness Test Results of the Mediating Effect after Substituting Variables.

	(1) <i>LnECI</i> Fixed Effects		(3) <i>LnECI</i>	
L.LnUpgra1			0.1524 ** (2.52)	0.1279 ** (2.27)
LnUpgra1			−0.1083 * (−1.74)	−0.1268 ** (−2.20)
LnTi1	0.3267 *** (6.67)	0.3218 *** (5.51)	0.2522 *** (4.68)	0.2820 *** (4.37)
LnEdu		2.6568 *** (3.79)		2.0927 *** (2.98)
LnGov		0.2041 (1.46)		0.1371 (0.98)
LnOpen		0.7084 *** (5.88)		0.6937 *** (5.67)
Constant	−5.5729 *** (−9.03)	−11.0494 *** (−5.55)	−4.5167 *** (−6.41)	−9.1708 *** (−4.72)
Observations	300	330	298	298
R ²	0.13	0.27	0.11	0.25

Note: Significance levels are denoted as follows: * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

5. Discussion

5.1. Research Findings

This study, set against the backdrop of the “new development pattern”, employs a panel regression model to analyze data from 30 provinces, cities, and autonomous regions of China (excluding Xizang, Hong Kong, Macao, and Taiwan) spanning from 2011 to 2021. The research focuses on the impact of technological innovation on the export competitiveness of high-tech products, examining the mediating role of industrial upgrading, and exploring regional heterogeneity in export competitiveness across China’s three main regions. The findings illuminate the critical role of technological innovation in shaping the export competitiveness of high-tech products in China, a key element in the nation’s “new development pattern”. This pattern emphasizes shifting from export-led growth to a more balanced model focusing on high-quality development, technological self-reliance, and sustainable economic progress. These findings are particularly relevant in the context of China’s ambitions to become a global leader in innovation and technology by 2050. By identifying the key drivers of export competitiveness in high-tech products, this research supports the strategic priorities outlined in China’s Five-Year Plans and its long-term development goals. It provides empirical evidence to guide the allocation of resources toward sectors and regions with the highest potential for contributing to these goals. Specifically:

First, the empirical studies conducted in this research provide compelling evidence of the significant impact of technological innovation on the export competitiveness of high-tech products in China. A Hausman test led to the selection of a fixed-effects model for analysis. Technological innovation positively influences export competitiveness, with a coefficient of 0.3267, indicating that increased R&D funding in high-tech industries elevates export competitiveness. Education level, government support, and market openness each significantly contribute to enhancing export competitiveness, with education level showing the most pronounced positive effect. It underscores the necessity for policies that support R&D investment, education, and government backing. For policymakers, this evidence advocates for a continued push toward increasing R&D expenditure, not just in quantity but also in the quality and relevance of research to high-tech industries. It also calls for reforming educational policies to better align with industry needs, particularly in fostering a

strong foundation in science, technology, engineering, and mathematics (STEM) disciplines and encouraging innovative thinking from an early age.

Second, substituting patent applications with internal R&D expenditure in the model confirmed the positive, significant impact of technological innovation on high-tech export competitiveness. Regional analysis revealed distinct differences. The Eastern region showed a minimal impact of technological innovation on export competitiveness, while the Central region exhibited a significant positive effect. The Western region demonstrated a weaker link, highlighting the need for investment in education and government support to foster competitiveness. The Eastern region's minimal impact suggests it may already be operating at a high level of innovation efficiency, whereas the Central and Western regions' varying impacts point to the need for targeted investment and support. This has implications for China's internal economic balance and stability, as well as for its strategy in engaging with different global regions in trade and investment.

Third, the study found a significant positive relationship between technological innovation and industrial upgrading, emphasizing the role of technological innovation as a driving force in the upgrading of high-tech industries. As China moves up the value chain, it is likely to reshape global trade patterns, potentially leading to increased competition in high-tech sectors. This could encourage other countries to also invest in technological innovation, possibly leading to a global shift toward more knowledge-intensive economies. While the government's role is more indirect in industrial upgrading, the degree of openness showed a significant negative correlation, suggesting a reliance on internal innovation over external market factors. It suggests a nuanced challenge in balancing global integration with domestic innovation. This is a crucial consideration as China seeks to position itself as a leader in sustainable development and green technology. The findings advocate for a strategic approach to opening up, one that selectively leverages foreign expertise and investment while fostering a conducive environment for domestic innovation.

Fourth, our findings reveal that industrial upgrading plays a significant mediating role in the relationship between technological innovation and the export competitiveness of high-tech products. The study suggests that technological innovation primarily influences export competitiveness through industrial upgrading, especially in scenarios where control variables are not considered. This insight is invaluable for businesses and industry stakeholders, indicating that investments in new technologies and processes can lead to significant gains in global market share. It also highlights the importance of government and private sector collaboration in facilitating an environment where such upgrading can occur, through subsidies, tax incentives, and infrastructure improvements.

The research findings offer valuable insights into the dynamics of technological innovation, industrial upgrading, and regional disparities in China's quest for high-tech export competitiveness. By situating these findings within the broader context of China's economic and industrial development strategies, this study highlights their significance for economic and political stakeholders. It underscores the necessity of strategic investments in innovation and education, the importance of regional development strategies, and the need for a balanced approach to international engagement and self-reliance. As China continues to navigate its path toward becoming a global technological superpower, these findings provide a crucial empirical foundation for informed decision-making and strategic planning.

5.2. Generalization of Findings

In considering the broader applicability of our findings beyond the specific context of China's high-tech industries, it is imperative to reflect on the generalizability of these results to different geographical and economic environments. The robust relationship identified between technological innovation and the export competitiveness of high-tech products, underpinned by the mediating role of industrial upgrading, presents a compelling framework for understanding the dynamics in other economies with varying levels of

development and technological advancement. However, the distinct regional disparities observed within China caution against a one-size-fits-all application of these insights.

The nuanced regional analysis within China—highlighting the differential impacts of technological innovation across the Eastern, Central, and Western regions—underscores the importance of contextual factors such as government policy, market openness, and education systems in shaping the efficacy of technological innovation on export competitiveness. These findings suggest that, in other contexts, similar structural and regional heterogeneities could significantly influence the outcomes of technological innovation efforts. Therefore, when extrapolating these conclusions to other countries, it is essential to consider the specific socioeconomic and political landscapes, as well as the stage of technological development and industrial maturity.

Moreover, the significant role of government support and market openness in facilitating technological innovation and industrial upgrading within China points to the potential for policy-driven approaches to enhance export competitiveness in other nations. Yet, the observed negative correlation between the degree of openness and industrial upgrading raises intriguing questions about the balance between internal innovation and external market integration in different economic contexts. This indicates that countries seeking to replicate China's success in leveraging technological innovation for export growth must tailor their strategies to their unique developmental and institutional contexts.

5.3. Implications of Findings

Our research offers a comprehensive analysis of the factors influencing the export competitiveness of high-tech products in China, highlighting the critical role of technological innovation and industrial upgrading. The long-term implications of our findings span economic, industrial, and political dimensions.

Economic implications include sustained growth and diversification as well as increased investment in human capital. On the one hand, our research underscores the vital role of technological innovation in driving export competitiveness, indicating that continued investment in R&D can sustain economic growth. By bolstering high-tech exports, China can diversify its economy, reducing reliance on traditional manufacturing and mitigating vulnerabilities to global market fluctuations. On the other hand, the pronounced positive effect of education level on export competitiveness highlights the necessity for substantial investments in human capital, particularly in STEM fields. This implies a long-term economic shift toward more knowledge-intensive industries, requiring a workforce equipped with advanced skills and continuous learning capabilities.

Industrial implications include a shift toward high-value industries, and regional development and disparities. On the one hand, the significant relationship between technological innovation and industrial upgrading suggests an ongoing shift toward high-value, technologically advanced industries. This transition necessitates not only direct investment in technology but also the development of supportive ecosystems, including venture capital, incubators, and innovation hubs. On the other hand, the regional heterogeneity in the impact of technological innovation on export competitiveness points to the need for tailored industrial policies. Addressing regional disparities through targeted support can foster balanced economic development, ensuring that less advanced regions are not left behind in the shift toward high-tech industries.

Political implications include policy focus on innovation and education, as well as international collaboration and competition. On the one hand, the findings advocate for a policy focus on fostering innovation and enhancing education. Government support should be strategically directed toward creating an innovation-friendly environment, protecting intellectual property, and building a robust education system that can produce the talent required by high-tech industries. On the other hand, the negative correlation between market openness and industrial upgrading implies a nuanced approach to international trade and collaboration. While fostering internal innovation is crucial, China must also navigate

the complexities of global markets, protecting its industries from unfair competition while engaging in international R&D collaborations that benefit its high-tech sector.

By addressing these economic, industrial, and political implications, China can strategically navigate the complexities of technological innovation and export competitiveness, securing a leading position in the global high-tech industry.

5.4. Policy Recommendations

To bolster the export competitiveness of high-tech products, this study recommends several policy measures. Firstly, fortifying technological innovation is pivotal for increasing the global competitiveness of high-tech products. This necessitates increased investment in research and development by both government and private sectors, with a focus on emergent and strategic technologies. However, in an era of budget constraints and competing priorities, both government and private sectors may find it difficult to allocate additional resources toward R&D. To address this, a multi-faceted strategy involving public–private partnerships can be pursued to share the financial burden and risks associated with R&D investments. Additionally, creating more targeted funding programs that prioritize emergent and strategic technologies can help direct resources where they are most needed and can have the greatest impact.

Moreover, cultivating an innovation-friendly ecosystem is essential. This involves bolstering startups, supporting research institutions, and enhancing academia–industry collaboration. However, cultivating an innovation-friendly ecosystem presents its own set of challenges, particularly in terms of fostering effective academia–industry collaboration and supporting startups. These efforts often stumble due to cultural and communication gaps between academic researchers and industry practitioners, as well as the high failure rates associated with startups. To overcome these obstacles, policies could focus on establishing platforms and networks that facilitate interaction and cooperation between academia and industry. Furthermore, providing startups with access to mentorship, networks, and early-stage financing can mitigate some of the risks they face.

Additionally, policy incentives such as tax credits and grants should be implemented to encourage innovative activities within companies (although this may encounter challenges related to ensuring that these incentives are both accessible and appealing to a wide range of businesses). Complex application processes and stringent eligibility criteria can deter small and medium-sized enterprises from taking advantage of these incentives. Simplifying application procedures and broadening eligibility criteria can help to make these incentives more inclusive and effective.

Strengthening intellectual property laws is also crucial to protect and stimulate innovation efforts. The challenge lies in balancing the need to protect intellectual property rights to encourage innovation with the need to avoid overly restrictive practices that could hinder the sharing of knowledge and collaboration essential for technological advancement. Engaging in dialogue with stakeholders from various sectors, including industry, academia, and civil society, can help in crafting intellectual property laws that strike the right balance between protection and openness.

Overall, it is essential to adopt a holistic and adaptive approach to policymaking in addressing these challenges. This involves not only crafting policies that are sensitive to the nuances of the high-tech sector, but also being prepared to adjust strategies in response to feedback and changing conditions. By acknowledging and proactively addressing the practical and political obstacles to policy implementation, governments can enhance the likelihood of achieving the desired outcomes in boosting the export competitiveness of high-tech products.

Secondly, strategic investments in education and targeted government support are essential for augmenting the export competitiveness of high-tech products. Prioritizing STEM education at all educational levels is crucial to cultivating a skilled workforce. However, one of the primary challenges is the current educational infrastructure's capacity to support a significant shift toward STEM. This includes the availability of qualified

teachers, the adequacy of educational materials, and the infrastructure to support hands-on, experiential learning that is critical in STEM education. Overcoming these challenges requires not only increased funding but also a concerted effort to enhance teacher training and curriculum development. Additionally, there is a need to combat societal and cultural biases that may deter students from pursuing STEM fields.

It is also imperative to allocate significant funding to universities and public research institutes specializing in high-tech disciplines. However, securing significant funding for universities and public research institutes specializing in high-tech disciplines is another challenge. This requires navigating political and budgetary constraints, as resources are often limited and must be allocated across competing priorities. To address this, advocating for the long-term economic benefits of investing in high-tech research and education can help garner support. Additionally, exploring alternative funding models, such as public-private partnerships and industry-sponsored research programs, can provide supplementary financial resources.

Encouraging collaborations among government, industry, and academia for technology development and transfer is another vital step. However, fostering these partnerships can be challenging due to differing goals, expectations, and timelines. Building a cooperative framework requires establishing clear communication channels, aligning objectives, and creating incentives for collaboration. Policies designed to facilitate these partnerships should include mechanisms for intellectual property management and benefit-sharing that address the concerns of all parties involved.

Additionally, developing specialized training and skill development programs is key to keeping the workforce updated with the latest technological advancements. However, it encounters obstacles such as identifying the most relevant skills and technologies, ensuring access to training for all segments of the workforce, and securing funding for these initiatives. Strategies to overcome these challenges include conducting regular industry needs assessments to guide program development, leveraging online and modular training programs to increase accessibility, and establishing partnerships with industry to co-fund and co-design training initiatives.

In sum, to navigate these challenges effectively, it is imperative to adopt a holistic and integrated approach that involves stakeholders from various sectors. Engaging educators, industry leaders, policymakers, and community representatives in the planning and implementation process can help ensure that the initiatives are well targeted and supported. Additionally, continuous monitoring and evaluation of these initiatives are essential to assess their effectiveness and make necessary adjustments. By proactively addressing the practical and political obstacles to implementing these policy recommendations, governments can significantly enhance the export competitiveness of their high-tech products, fostering economic growth and innovation.

Thirdly, recognizing the distinct challenges and strengths in technological innovation across different regions is crucial. It necessitates conducting comprehensive assessments to pinpoint each region's specific technological strengths and weaknesses. This task faces potential obstacles such as limited access to reliable data, differences in regional reporting standards, and the complexity of accurately identifying technological strengths and weaknesses. To surmount these challenges, establishing standardized assessment criteria and methodologies is crucial. Collaboration with local governments, academic institutions, and industry stakeholders can also enhance the quality and availability of necessary data. Employing a mix of quantitative and qualitative research methods can provide a more nuanced understanding of each region's capabilities and needs.

While establishing innovation hubs or centers of excellence in regions with specific technological strengths is a promising approach, it requires substantial investment and strategic planning. Challenges here include securing funding, choosing optimal locations, and ensuring the participation of key stakeholders such as businesses, universities, and local governments. A strategy to overcome these obstacles could involve creating public-private partnership models to share the financial burden and benefits. Additionally, a clear

vision and objectives for each hub, aligned with regional and national economic goals, can help in rallying support and resources.

Tailoring incentives and support to stimulate local innovation and technology businesses is essential. However, it presents its own set of challenges, notably in designing programs that effectively address the unique needs of each region while avoiding the creation of unfair advantages. To navigate this, incentives and support programs should be flexible, allowing for adjustments based on ongoing evaluations of their effectiveness and the evolving needs of the local ecosystem. Engaging with local stakeholders in the design and implementation phases can ensure that the measures are well targeted and have the desired impact.

Additionally, prioritizing infrastructure development in less advanced regions is key to attracting high-tech industries and skilled professionals, thus balancing regional disparities in technological advancement. However, this can be hindered by limited resources, competing priorities, and the challenge of creating an attractive environment for high-tech investments. A multi-tiered strategy that combines immediate short-term initiatives with long-term infrastructure projects can provide gradual improvements while working toward comprehensive development. Leveraging federal or national funding, along with international development assistance, could also be pivotal in overcoming financial constraints.

In short, to effectively implement these policy recommendations, it is vital to adopt an integrated approach that considers the interdependencies between these initiatives. Continuous dialogue and partnership among all levels of government, industry, academia, and communities will be key to addressing the practical and political challenges that may arise. Furthermore, adopting an iterative process that allows for policy refinement based on feedback and changing conditions will enhance the resilience and effectiveness of these strategies. By acknowledging and proactively addressing these obstacles, policymakers can foster a more equitable and dynamic technological innovation landscape across regions.

Fourthly, industrial upgrading is a crucial conduit for leveraging technological innovation to boost export competitiveness. It is imperative to initiate efforts to modernize existing industries via technology integration. But it encounters several challenges. These include resistance to change from businesses accustomed to traditional operations, the high cost of adopting advanced technologies, and a potential skills gap within the workforce. Strategies to overcome these obstacles include offering financial incentives and subsidies to reduce the cost burden of technology adoption, as well as providing comprehensive training programs to upskill workers. Additionally, establishing a clear roadmap for technology integration that includes support services such as consultancy and technical assistance can help ease the transition for traditional industries.

Advanced technologies such as artificial intelligence and the Internet of Things should be employed to enhance supply chain efficiency and competitiveness. However, this presents challenges related to cybersecurity, data privacy, and the need for significant infrastructure investments. To address these concerns, governments should develop and enforce robust cybersecurity standards and data protection laws. Furthermore, public-private partnerships should be instrumental in mobilizing the necessary investments in infrastructure, while tax incentives could encourage private sector participation in these technology upgrades.

Promoting collaborative projects between established and burgeoning industries for technology transfer and advancement is also vital. But it can be hindered by intellectual property rights concerns and the divergent interests of different industry players. A framework that facilitates fair and equitable technology sharing and collaboration can mitigate these issues. This includes creating legal and regulatory frameworks that protect intellectual property rights while promoting innovation, and establishing platforms or consortia that encourage collaboration across industries.

Periodic assessments of the industrial landscape are recommended to identify sectors in need of upgrading and support. However, this recommendation faces challenges such

as ensuring the accuracy and objectivity of assessments, and the dynamic nature of technological advancement which can quickly alter industrial needs. Implementing a transparent and inclusive assessment process that involves stakeholders from government, industry, and academia can enhance the reliability of these evaluations. Leveraging real-time data analytics and forecasting tools can also help in keeping the assessments up to date with the latest industry trends and technological developments.

To sum up, addressing these challenges requires a coordinated approach that involves not only government intervention but also active participation from industry and academia. Policymakers need to be flexible and adaptive, ready to update strategies based on feedback and evolving circumstances. By acknowledging the practical and political obstacles to the effective implementation of industrial upgrading recommendations, and by considering strategies to overcome them, a more conducive environment for leveraging technological innovation to boost export competitiveness can be created.

Fifthly, while market openness is crucial, the primary focus should be on nurturing indigenous technological capabilities to ensure sustainable industrial growth. This approach involves prioritizing the development of internal R&D capabilities, rather than over-reliance on foreign technologies. But it poses several challenges, including the substantial financial investment required, the potential shortage of skilled R&D personnel, and the time needed to see tangible outcomes from these investments. Strategies to mitigate these challenges include leveraging fiscal policies to provide tax incentives and subsidies for R&D activities, investing in education and training programs to build a skilled workforce, and establishing partnerships with universities and research institutions to foster a culture of innovation.

Implementing selective market openness policies that facilitate foreign investment and partnerships can bolster internal innovation. But bolstering internal innovation requires a delicate balance. The challenges here include ensuring that such policies do not inadvertently stifle local innovation or lead to over-dependence on foreign technology. A strategic approach involves setting clear criteria for foreign partnerships that align with national innovation goals, enhancing regulatory frameworks to protect domestic industries and intellectual property rights, and promoting joint ventures that offer mutual benefits and knowledge exchange.

Engaging in global collaborations should aim at knowledge exchange that supports local technological expertise. However, these global collaborations face the challenge of ensuring that these exchanges are truly reciprocal and that local entities are not merely recipients but active contributors to the innovation process. To overcome this, it is vital to establish collaboration agreements that specify the terms of knowledge sharing, intellectual property rights, and capacity building. Additionally, fostering a global network of researchers and innovators can facilitate more equitable and productive collaborations.

Additionally, it is essential to encourage sustainable innovation practices, ensuring technological advancements are environmentally conscious and socially responsible. This recommendation confronts obstacles such as the potential increase in costs and the need for a shift in corporate and societal values. Addressing these challenges requires integrating sustainability into the core of innovation policies, offering incentives for green technologies, and raising awareness of the importance of sustainable practices. Regulatory measures can also be employed to ensure that companies adhere to sustainability standards.

Therefore, to effectively navigate these challenges, a multi-stakeholder approach that involves government, industry, academia, and civil society is essential. This approach ensures that policies are not only designed with a comprehensive understanding of the obstacles but are also adaptable to changing technological landscapes and societal needs. By acknowledging the practical and political hurdles to the effective implementation of these policy recommendations, and considering strategies to surmount them, policymakers can foster a more resilient and sustainable industrial growth model that balances market openness with the nurturing of indigenous technological capabilities.

In conclusion, these policy recommendations, derived from empirical findings, aim to create a dynamic, innovative, and competitive high-tech industry landscape. The emphasis is on creating an environment where technological innovation thrives, education and government play supportive roles, regional strengths are leveraged, industrial upgrading is continuous, and a balance is maintained between internal innovation capabilities and market openness. Implementing these policies effectively would be key to improving high-tech products' competitive edge in the international market.

5.5. Limitations and Future Research

While this study unveils compelling insights, it is imperative to consider its constraints comprehensively. Firstly, the data quality may be compromised by factors such as missing values, which could potentially skew the results. Future studies should prioritize the improvement of data quality by employing more rigorous data collection and cleaning methodologies. Secondly, potential biases in sampling methods, such as over-reliance on Chinese context, may not accurately represent the broader geographical or economic contexts, thus limiting the generalizability of the findings. Future research should aim to apply and test the established model in diverse geographical settings, encompassing both developing and developed economies. Lastly, the presence of uncontrolled variables—external factors not accounted for in the study design—can introduce unknown influences, complicating the interpretation of causal relationships. Further research could explore how external factors, such as international trade policies, global market dynamics, and foreign direct investment, influence the relationship between technological innovation and export competitiveness. In addition, in identifying the mediating variables that influence the relationship under study, this research has delineated a set of potential factors. Notably, aspects such as the firms' capacity for technological absorption and their supply chain management strategies merit further investigation as significant mediators. However, this study approaches the subject from an industry perspective rather than at the firm level, thus not accounting for micro-level variables. This delineation presents a limitation insofar as it precludes a granular analysis of firm-specific dynamics. Future research could address this gap by employing microdata at the firm level to explore these relationships in greater depth.

6. Conclusions

Our study into the dynamics of technological innovation and its impact on the export competitiveness of high-tech products in China offers significant insights with far-reaching implications. By employing a robust panel regression model to analyze data from 30 provinces, cities, and autonomous regions over a decade, we have illuminated the pivotal role of technological innovation in driving high-tech export competitiveness. This study not only underscores the critical importance of R&D investment, education, government support, and market openness but also highlights the mediating influence of industrial upgrading and the nuanced effects of regional heterogeneity.

The empirical evidence presented reinforces the necessity for strategic policy initiatives aimed at enhancing technological innovation, bolstering education, and fostering an environment conducive to high-tech industry growth. The findings advocate for a multi-faceted approach that addresses the unique challenges and leverages the distinct strengths of different regions, emphasizing the importance of tailored industrial policies and targeted investments.

Moreover, our research contributes to the broader discourse on the global shift toward knowledge-intensive economies, offering a framework for understanding the interplay between technological innovation, industrial upgrading, and export competitiveness. The significant positive relationship between technological innovation and industrial upgrading, coupled with the strategic role of government and market factors, provides a compelling narrative for economies navigating the complexities of technological advancement and global market integration.

The strategic priorities outlined in this study align with China’s ambitions to become a global leader in innovation and technology by 2050, supporting the nation’s “new development pattern” focused on high-quality development, technological self-reliance, and sustainable economic progress. By situating these findings within the global context, our research not only sheds light on China’s path to technological and economic prowess but also offers valuable lessons for other countries striving to enhance their competitive edge in the high-tech sector.

In conclusion, this study’s insights into the intricate relationship between technological innovation, industrial upgrading, and export competitiveness in China’s high-tech industry provide a crucial empirical foundation for informed policymaking and strategic planning. As the world moves toward more knowledge-intensive economic models, the lessons gleaned from China’s experience are instrumental in guiding the global quest for innovation-driven growth and sustainable development.

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