sustainability

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Technological Innovation, Product Quality and Upgrading of Manufacturing Value Chain: Empirical Evidence from China

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Abstract: The aim of this research is to investigate the relationship between enterprise technological innovation, export product quality, and the upgrading of the manufacturing value chain. The study is based on panel data from Chinese manufacturing enterprises between 2000 and 2013 and uses a multi-dimensional fixed-effect method to analyze the moderating effect of enterprise export product quality on the relationship between technological innovation and the upgrading of the manufacturing value chain. The results show that technological innovation significantly promotes the upgrading of the manufacturing value chain. The regression analysis indicates that a 1% increase in enterprise technological innovation leads to a 0.28% increase in the upgrading of the manufacturing value chain. Similarly, the study demonstrates that improving the quality of exported products significantly enhances the manufacturing industry's status in the global value chain. The regression analysis reveals that a 1% increase in the quality of exported products leads to a 0.14% increase in the upgrading of the manufacturing value chain. Moreover, the research identifies a threshold value of 0.4438 for the moderating effect of enterprise export product quality on the impact of technological innovation on the upgrading of the manufacturing value chain. When the quality of exported products is below the threshold value, it has a strong positive regulatory effect on technological innovation, promoting the upgrading of the manufacturing value chain. However, once the quality of exported products exceeds the threshold value, its regulatory effect becomes insignificant. The study's findings have important implications for enterprises looking to overcome the "dilemma of scientific and technological innovation" and promote the intelligent development of the manufacturing industry. The research conclusions have strong reference value for promoting the combination of technology innovation and business model innovation in manufacturing enterprises. This will allow for climbing the high-end links of the global value chain and achieving sustainable development.

Keywords: technological innovation; product quality; value chain; threshold effect; China

Citation: Gao, X.; Li, C.; Elahi, E.; Abro, M.I.; Cui, Z. Technological Innovation, Product Quality and Upgrading of Manufacturing Value Chain: Empirical Evidence from China. *Sustainability* **2023**, *15*, 7289. https://doi.org/10.3390/su15097289

Academic Editors: Francisco J. G. Silva, Carla M.A. Pinto and Raul D. S. G. Campilho

Received: 3 February 2023
Revised: 25 April 2023
Accepted: 25 April 2023
Published: 27 April 2023

1. Introduction

Developed countries have maintained a strong hold on the high-end links of the global value chain, while developing countries are more concentrated on the low-end links, leading to compressed profit margins [1]. As globalization deepens, developing countries increasingly rely on global production networks, which puts them in a double dilemma of being "locked" in low-end links and "blocked" in high-end links of global value chains [2]. Despite being a "big manufacturing country", China has mainly undertaken low value-added links in the labor-intensive and simple production process within the global value chain division system, although it has achieved a "growth miracle" by fully utilizing its advantages in factors such as demographic dividend and resource endowment since the reform and opening up [3,4]. Therefore, it is crucial for the government to address the key issue of how to effectively promote the manufacturing industry to adapt to the new pattern of international vertical specialization, actively climb the high-end links of the global value chain and achieve stable and sustainable economic growth.

In the era of Industry 4.0, for manufacturing enterprises, transformation and upgrading need to grasp the core competitiveness to be based on the market, and the core is innovation, including both technological innovation and business model innovation. Moreover, as the fundamental driving force and source of economic growth [5], technological innovation has become the driving force for economic change and economic structure adjustment and optimization in a country or region [6,7]. However, some scholars also pointed out that there is a "dilemma of scientific and technological innovation" in China at present [8,9], i.e., China's technological innovation activities have not promoted a good transformation of economic growth mode from factor-driven to innovation-driven, and even have a certain inhibitory effect [10]. Then, at the present stage, China's manufacturing industry is in a critical period of transformation and upgrading and actively climbing the high-end links of the global value chain, so it is particularly important to discuss whether there is a "dilemma of scientific and technological innovation". At present, more scholars emphasize that technological innovation is an important way for China's manufacturing industry to achieve successful transformation and upgrading and actively strive into the high-end links of the global value chain. For example, Jones et al. [11] pointed out that technological innovation can promote enterprises to participate better in the international division of labor within products, enhance the embedded position of global value chains, and narrow the gap between developing and developed countries.

In the new pattern of opening, China's economic growth has undergone a significant transformation. The production of value has shifted from relying on the middle and low ends of the value chain to the high-end [12]. There has been an iterative transformation between extensional expansion and endogenous growth, with the latter driven by technological innovation replacing the development model driven by resource consumption and cost dividends [13]. Therefore, it is of practical significance to explore the driving factors for the upgrading of China's manufacturing value chain from a technical perspective.

Expanding the export scale is a potential strategy for enterprises to improve total factor productivity and promote independent innovation [14,15]. However, overreliance on the international market can leave enterprises vulnerable to foreign trade protection policies, which can negatively impact their research and development and hinder technological upgrading [16]. As a result, enterprises may struggle to improve their position in the division of labor within the global value chain. This challenge leads enterprises to question how they can achieve the upgrading of the manufacturing value chain through their own technological innovation. The upgrading of the quality of exported products by enterprises reflects their technological innovation capabilities [17] and inevitably impacts their technological innovation behavior. Improving the quality of exported products can enhance the innovation effect brought by exports and alleviate the inhibitory effect of exports on innovation [18]. However, exporting high-quality products can weaken the momentum of technological upgrading and hinder the upgrading of the manufacturing value chain.

Since technological innovation is the main driving force for upgrading product quality in enterprises [19,20], the quality of exported products may have a moderating effect on the impact of technological innovation on the upgrading of the manufacturing value chain. Therefore, it is important to investigate whether the role of technological innovation and the quality of export products in promoting the manufacturing industry to climb the high-end links of the global value chain is "one thing and the other" or "advance and retreat together. In other words, under the heterogeneity of product quality, will there be heterogeneity in the mechanism and effect of enterprise technological innovation on upgrading the manufacturing global value chain? If so, what is the boundary of the role of technological innovation in product quality heterogeneity? To this end, this requires us to understand the quality level of enterprises' own products thoroughly and then upgrade the global value chain of the manufacturing industry through technological innovation, form a real innovation-driven sense, avoid falling into the "dilemma of scientific and technological innovation", and promote China's economy to achieve high-quality growth.

The article is divided into five main sections. Section 1 belongs to the introduction. Section 2 describes the theoretical mechanism and research hypotheses. Section 3 explains the research methods used to approach the study's objectives. Section 4 empirically estimates the results. Section 5 summarizes the main findings of the study.

2. Theoretical Mechanism and Research Hypotheses

According to the theory of global value chain upgrading, the upgrade of the manufacturing value chain can be divided into four stages: process upgrading, product upgrading, function upgrading, and chain upgrading [21]. Among them, process upgrading is driven by technological progress. Product upgrading is manifested as the improvement of product quality and added value. Functional upgrade means that the service capabilities of R&D, brand, marketing, and after-sales services of enterprises are improved. Chain upgrading indicates that the embedded degree and division of labor status of enterprises in the global value chain have been improved, and the transition from the low value-added industrial chain to the high value-added industrial chain has been realized [22]. Based on this, this paper will analyze the theoretical mechanism from the following aspects.

Firstly, the impact of the enterprise's technological innovation on upgrading the manufacturing value chain. According to the theory of global value chain upgrading, technological innovation has a significant role in promoting the upgrading of the manufacturing value chain. On the whole, innovation always runs through the process of industrial upgrading, providing impetus and creating necessary conditions for industrial upgrading [23] and, which is embodied in the following aspects: (1) From the perspective of factor allocation. Technological innovation can promote the recombination of production factors, enhance output capacity [24], improve industrial efficiency and operating profit, increase its added value in the international trade division of labor, and realize the upgrading of the global value chain. In recent years, the demographic dividend has decreased, and the labor force and labor costs have shown a reverse evolution trend. As a result, it is becoming increasingly challenging to sustain low-end processing and manufacturing industries. This has forced a transition from relying on the "demographic dividend" to the "talent dividend" and "technology dividend". To achieve this transition, it is necessary to accelerate industrial upgrading and technological innovation. Traditional processing and manufacturing industries must relocate to form an endogenous driving force for value chain upgrading. (2) From the perspective of technology spillovers. On the one hand, the new technologies and new knowledge brought by technological innovation have significant characteristics of externality, which also create a good atmosphere for other enterprises to actively carry out "learning by doing" [1,25], thus improving their technical level. An example of the positive impact of foreign investment on domestic enterprises' technological innovation and industrial upgrading is the entry of high-tech foreign-funded enterprises. This has provided spillover space for domestic enterprises to upgrade their technologies [13]. For instance, this has inspired emerging technology enterprises like Huawei and BYD to enter the global leading track and become pioneers in domestic market upgrading and industrial iteration. On the other hand, the collaborative innovation of enterprises within the same industry can effectively reduce the waste of resources caused by repeated R&D investment in the process of technological innovation of technology-related enterprises, indirectly enhance the capital adequacy of enterprises, promote the R&D department of enterprises to conduct more exploratory searches, and enhance technological innovation capabilities [26]. Therefore, technology spillovers can effectively improve the industry's overall technical level and production efficiency [27], increase the export-added value of enterprises' products, and enhance the embedded position of enterprises in the global value chain.

From the perspective of market demand. Technological innovation can promote the formation of new products and processes. According to the product life cycle theory, new products and methods will initially form a monopoly on the market and stimulate the internal industry to expand the production scale actively [28]. At the same time, to adapt to the market, the upstream and downstream industries matching with the new products will inevitably increase their technological innovation efforts and eventually form a new and complete industrial chain, which will drive the transformation and upgrading of industrial structure [29], and finally enhance the embedded position of industry in the global value chain. In addition, domestic enterprises have been enhancing their technological innovation level and market competitiveness. They have also entered the international market, established research and development centers and production bases in developed countries, and expanded their advanced production capacity. This has enabled them to challenge the market position of multinational enterprises in developed countries, seek leadership, and empower the transformation and upgrading of the value chain from the inside out [24]. Based on these observations, this paper proposes Research Hypothesis 1:

Hypothesis 1 (H1): *The upgrading of enterprise technology innovation level has a positive promoting effect on the upgrading of the global value chain of the manufacturing industry.*

Secondly, the impact of an enterprise's product quality upgrading on the upgrade of the manufacturing value chain is significant. Product quality is not only an essential manifestation of enterprise value chain upgrading, but it is also positively influenced by the service-oriented manufacturing industry. This can promote enterprise value chain upgrading [30] and enhance the international competitiveness of enterprises in the value chain division of labor system [31].

According to the theory of global value chain upgrading, product quality upgrading belongs to the second stage of value chain upgrading, and there is a specific positive correlation between them. The higher the quality of exported products, the stronger the export competitive advantage, and the easier it is to expand the market share, thereby increasing export profits [31]. With continuously increasing profits, enterprises are more capable of transforming into service functions such as brand, logistics, after-sales services, and marketing. This promotes the upgrading of the global value chain functions of enterprises, deepening the embedded degree of the global value chain, and ultimately achieving the climb of the global value chain [22].

Furthermore, to maximize the value-added capacity of the industrial production process, enterprises often invest in service-oriented to intermediate production processes. This means they will transfer their investment from the production process to service processes that can bring more value-added capacity [32].

From the perspective of trade value creation, the quality of export products can reflect the contribution of enterprises to domestic added value in the process of participating in the division of labor in the global value chain. The status of the global value chain often reflects the domestic added value content of export products of a country or region in the process of international trade. There is usually a positive correlation between them. The higher the quality of enterprises' export products, the higher the embedded position of enterprises in the global value chain, and the easier it is to promote its climb to the high-end value chain. Based on these observations, this paper proposes Research Hypothesis 2:

Hypothesis 2 (H2): *The upgrading of export products positively affects the manufacturing value chain.*

Finally, product quality plays a moderating role in the impact of technological innovation on the upgrading of the global value chain of the manufacturing industry. Wang et al. [33] and Zhu et al. [34] found that for exporting countries, the sum of the domestic added value rate and the foreign added value rate is 1. This means that with the promotion of the global value chain status of the industry, its domestic value-added rate will continue to increase, leading to the decline of the foreign value-added rate. Moreover, the domestic value-added rate can only vary between 0 and 1, so there is a specific constraint range in the global value chain status. Therefore, in the previous analysis, although this paper points out that technological innovation and product quality upgrading of enterprises can promote the upgrading of the global value chain of industries, however, because the domestic value-added rate can only vary between 0 and 1, it indicates that the promoting effect of the above two factors is not infinitely expanded. The upgrading of the quality of export products may have certain constraints on technological innovation's impact on upgrading the manufacturing value chain. Specifically, it can be analyzed from the following two aspects.

First, when the quality of enterprises' export products is relatively low, the improvement of the quality of enterprises' export products will help enterprises quickly gain market recognition, expand their market share and increase their profits. In order to obtain additional benefits, enterprises will actively conduct technological innovation and increase investment in research and development. Meanwhile, Huang [35] and Xu et al. [36] believed that the key to the high-quality development of the manufacturing industry is to build the core competence of China's manufacturing industry, and technological innovation capability is the key support. So this will better promote the upgrading of product quality, enhance the added value of export products, and thus enhance the embedded position of the manufacturing value chain. Therefore, to this aspect, product quality upgrading has a positive moderating effect on the impact of technological innovation on the upgrade of the manufacturing value chain.

Second, when the product quality reaches a specific value, the higher the quality of export products of enterprises, it usually means that the products themselves have higher market competitiveness and can obtain higher export profits for enterprises [37,38]. Due to the increased risks of technological innovation, enterprises will face a high possibility of making mistakes in the process of product development, which is easy to cause low returns on capital investment of enterprises. At this time, when the competitive advantage of high-quality export of products that enterprises already have can bring stable export profits for enterprises, the motivation or enthusiasm for technological innovation of enterprises will be seriously weakened, thus inhibiting the promotion effect of technological innovation on the upgrading of the global value chain of the manufacturing industry. Therefore, to this aspect, product quality upgrading has a negative moderating effect on the impact of technological innovation on the upgrading of the value chain of the manufacturing industry.

For example, Tesla, not General Motors, is the most outstanding startup company in the field of electric vehicles at present; Smartphones were made by Apple, not Nokia, the dominant mobile phone industry at that time. To sum up, when the export quality of products is low, the relationship between enterprise technological innovation and export quality is "complementary", but when the export quality of products is high, the relationship between enterprise technological innovation and export quality is more "substitution". So this paper puts forward the following research Hypothesis 3:

Hypothesis 3 (H3): *The advancement of technology in the manufacturing sector can enhance the value chain, but it may also have both positive and negative effects on the quality of exported products by enterprises.*

When the product quality reaches a certain level, with the continuous upgrading of the quality of export products, the role of enterprise technological innovation in promoting the upgrading of the global value chain of the manufacturing industry is gradually weakened.

3. Material and Methods

3.1. Measurement Model

Building on previous theoretical analysis, the paper investigates the relationship between technological innovation, export product quality, and the upgrading of the manufacturing value chain using unbalanced panel data of Chinese manufacturing enterprises from 2000 to 2013. To construct an econometric model (1), we referred to the specific approach of Gao et al. [39].

$$lnGVC_{kt} = \beta_0 + \beta_1 lnnew_{it} + \beta_2 lnquality_{it} + \beta_3 \ln X + \mu_i + \varphi_t + \varepsilon_{it} \tag{1}$$

Furthermore, this paper investigates the moderating effect of the quality of export products on the impact of technological innovation on the upgrade of the manufacturing value chain. To construct an econometric model (2), we referred to the approach introduced by Dong and Gao [40].

$$lnGVC_{kt} = \beta_0 + \beta_1 lnnew_{it} + \beta_2 lnquality_{it} + \beta_3 lnnew_{it} \times lnquality_{it} + \beta_4 \ln X + \mu_i + \varphi_t + \varepsilon_{it} \quad (2)$$

where i is the enterprise, k = the product industry, and t is the year. $\ln new_{it}$ is the indicator of technological innovation at the enterprise level, whose estimation coefficient β_1 depicts the causal impact of it on manufacturing GVC. If $\beta_1 > 0$, it means technological innovation has a positive impact on the upgrading of manufacturing GVC, and vice versa. $\ln quality_{it}$ is the quality of export products at the enterprise level, whose estimation coefficient β_2 depicts the causal impact of it on manufacturing GVC. If $\beta_2 > 0$, it means the quality of export products has a positive impact on the upgrading of manufacturing GVC, and vice versa. $\ln new_{it} \times \ln quality_{it}$ is the interaction between technological innovation and the quality of export products, whose estimation coefficient β_3 depicts the causal impact of their interaction on manufacturing GVC. If $\beta_3 > 0$, it means the impact of technological innovation on the manufacturing GVC will gradually increase with the improvement of the quality of the products exported by the enterprise. Otherwise, it will gradually decrease. Moreover, X is a series of control variables in this paper, including capital intensity ($klratio_{it}$), export intensity (exe_{it}), and enterprise size ($size_{it}$). μ_i is the fixed effect of the enterprise. λ_t is the fixed effect of the time. ε_{it} is the random disturbance term which is assumed to be normally distributed at zero mean value [41–43] and constant variance [44–46].

The following are the main steps involved in applying this method. Firstly, collect and organize the necessary data for this study and build the required data panel for empirical testing. Secondly, utilize the constructed model to test the data, including robustness and heterogeneity tests, to verify the research hypotheses. Figure 1 provides a visual representation of the methodology flowchart.

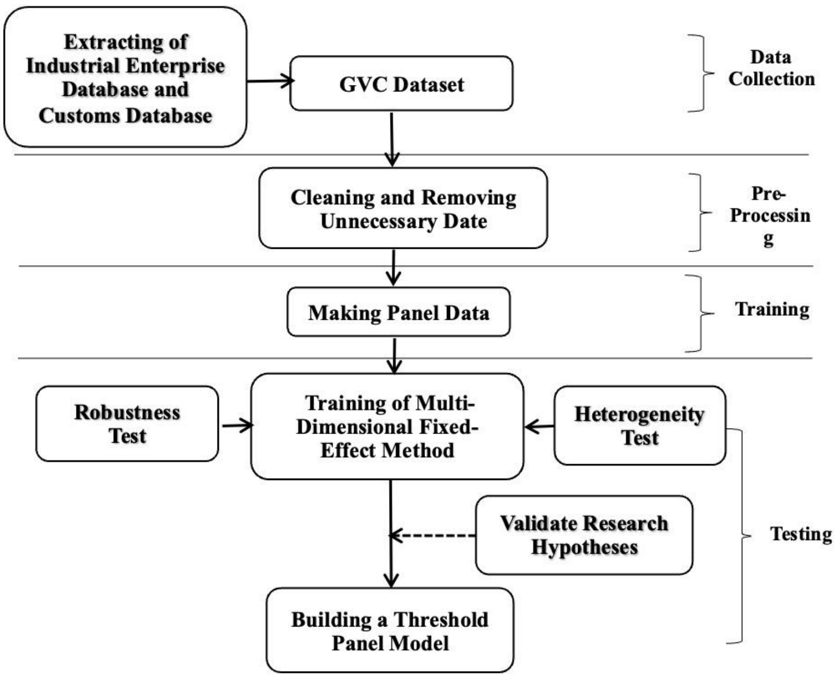

Figure 1. The flowchart of methodology.

3.2. Setting of Indicators

Explained variable (GVC): For the estimation of the status of GVCs, early scholars used Leontief's method to decompose the domestic added value in export trade of a single economy, but it could not determine the source of imports and the destination of exports, let alone reflect the phenomenon that domestic added value returned to the country through intermediate products. Therefore, the method of Wang et al. [47] was used to decompose the total export trade in this paper. Specifically, the intermediate trade at all levels was decomposed according to the origin and the final absorption destination to form each part absorbed by the final product production of different departments in different countries so as to decompose the domestic added value of export trade completely. In this study, we used the approach of Cheng and Yang [48] to illustrate the fundamental concepts of decomposing bilateral intermediate trade flows. Three countries were chosen randomly. Based on this approach, the authors developed an input-output model among the selected countries, which is presented in Table 1.

Table 1. Input-output model.

Input \ Output		Intermediate Use			Final Use			Total Output
		Country y^s	**Country y^r**	**Country y^t**	**Country y^s**	**Country y^r**	**Country y^t**	
Intermediate Input	Country y^s	Z^{ss}	Z^{sr}	Z^{st}	Y^{ss}	Y^{sr}	Y^{st}	X^s
	Country y^r	Z^{rs}	Z^{rr}	Z^{rt}	Y^{rs}	Y^{rr}	Y^{rt}	X^r
	Country y^t	Z^{ts}	Z^{tr}	Z^{tt}	Y^{ts}	Y^{tr}	Y^{tt}	X^t
Value Added		VA^s	VA^r	VA^t		…		
Total Input		$(X^s)'$	$(X^r)'$	$(X^t)'$				

where s, r, and t are three different countries, and Z and Y represent the parts of one country's products that are used as intermediate inputs and end-use products by other countries. VA^s and X^s, respectively, represent the added value and output of country S, and the rest is similar. The superscript indicates transposition. Assuming that the number of departments in each country is n, Z in the above table is $n \times n$ matrix, X and Y are $n \times 1$ column vectors, and V is $1 \times n$ row vector.

The input-output model in Table 1 was decomposed, and we used the measurement method of the GVC status index defined by Koompman [49] to construct a measurement model for the status index. This can be seen in Equation (3).

$$GVC_{kt} = ln(1+\frac{IV}{E}) - ln(1+\frac{IV}{E}) = ln(1+\frac{DVA\_INT + DVA\_REX}{E}) - ln(1+\frac{FVA\_FIN + FVA\_INT}{E}) \quad (3)$$

where IV is the domestic value added. FV is the foreign value added. E is total export. DVA_INT is the domestic value added in the form of direct intermediate exports (without third countries). DVA_REX is the domestic value added in the form of indirect intermediate exports (with third countries). FVA_FIN is the foreign value added realized by export of final products. FVA_INT is the foreign value added realized by export of intermediate products.

Explanatory variable: (1) new_{it}. This paper mainly refers to the practices of Pu Yanping and Gu Ran [50] and uses the annual output value of new products to measure enterprises' technological innovation capability. (2) $quality_{it}$. It is mainly measured by the counterfactual reasoning method of Hallak and Sivadasan [51].

Control variables: (1) $size_{it}$. Under the framework of the new trade theory, enterprises will gain an advantage in cost by their size. Because the larger the size of the enterprise, the stronger its ability to obtain economies of scale and, therefore, the more potent the ability of the industry to obtain profits. Thus, the greater the added value of the industry in the international division of labor and trade, the higher the status in the GVC. This paper used the total number of employees as an alternative indicator of this variable. (2) $klratio_{it}$. It is measured by the ratio of fixed assets to the total number of employees. Theoretically, the higher the capital intensity of an enterprise, the larger the fixed assets, the richer the capital elements and technical elements, the more perfect the production equipment and facilities, and the easier it is for the products produced by such enterprises to obtain higher domestic added value. Therefore, the capital intensity will enhance the industry's position in the GVC. (3) exe_{it}. It is measured by the ratio of export delivery value to sales. Previous studies have confirmed that export intensity positively impacts enterprise performance, and enterprises with high export intensity can gain more technology and management experience from overseas markets, thus increasing the domestic added value of their products. However, some scholars believe that exchange rate appreciation, loss of cost advantage, rising wages, etc., will significantly reduce the profits of export-intensive enterprises, thus inhibiting the upgrading of GVC. Therefore, considering the impact of export intensity on the GVC of the industry, the export intensity of enterprises was included in the study as a control variable.

3.3. Data Source

Although the National Bureau of Statistics collects statistics on the database of Chinese industrial enterprises every year, the disclosure of the micro-database of Chinese industrial enterprises by the state is delayed. Currently, most academic circles have only studied the period from 2000 to 2013. While a few universities and research institutes have obtained data for 2014 and 2015, the customs trade enterprise information is not disclosed because the customs database only provides industry data after 2014, which cannot be matched with the customs trade data. Therefore, we selected the research sample interval from 2000 to 2013. Specifically, the research data in this paper include: (1) The Chinese industrial enterprise database from 2000 to 2013. (2) Customs import and export trade data from 2000 to 2013, which is currently the available data span from 1995 to 2013. (3) The input-output data published in the WIOD database spans from 2000 to 2014. (4) Customs trade data spans from 2000 to 2016. The sample interval from 2000 to 2013 was selected after the intersection of the three sets of data.

Since China's industrial enterprise data is annual, and customs import and export trade data is monthly, the monthly data was first added to the annual level. Then the samples with missing enterprise names and missing indicators required in this paper were deleted so that the two databases could be matched according to enterprise names and telephone numbers. As the input-output data of various countries in the world are from the WIOD database, with a time span of 2000–2014, the data were first decomposed according to the method of Wang et al. [47] to get the trade value added of each stage of China's manufacturing industry. Secondly, the GVC status was calculated using the trade value added. Finally, the data of the GVC status were matched to the matching data of China's industrial enterprise data and the customs import and export trade database according to the industry code and time of China's manufacturing industry.

It should be noted that the data for 2004 was removed because of the missing of many core indicators required by this paper in the database of Chinese industrial enterprises in 2004. Descriptive statistical results are shown in Table 2.

The presented table shows the average values of seven variables utilized in an empirical investigation that explores the correlation between technological innovation within enterprises, export product quality, and the upgrading of the manufacturing value chain. The variables in the table include Global Value Chain, Quality, Technological Innovation, Capital Intensity, Sale, Export Intensity, Forward Vertical Specialization, and Backward Vertical Specialization. Specifically, the mean values of Global Value Chain, Quality, Technological Innovation, Capital Intensity, Sale, Export Intensity, Forward Vertical Specialization, and Backward Vertical Specialization are 0.2399, 0.4553, 0.905, 3.9970, 5.6500, 0.5935, 0.1903, and 0.2246, respectively.

Table 2. Descriptive statistics of variables.

Variables	Definitions	Observations	Mean	Std	Min	Max
Global value chain	$\ln GVC$	1,807,740	0.2399	0.2215	−0.5994	4.8442
Quality	$\ln quality_{it}$	1,887,752	0.4553	0.0239	0.0000	1.0000
Technological innovation	$\ln new_{it}$	1,889,490	0.9059	0.2175	0.0000	1.0000
Capital intensity	$\ln klratio_{it}$	1,885,613	3.9970	1.4358	−6.1159	13.8445
Sale	$\ln size_{it}$	1,888,125	5.6500	1.2776	0.0000	12.2009
Export intensity	$\ln exe_{it}$	1,882,347	0.5935	0.7832	−0.2048	11.8876
Forward vertical specialization	$For - vs$	1,807,741	0.1903	0.1241	−0.0056	5.6947
Backward vertical specialization	$Bac - vs$	1,807,741	0.2246	0.1509	0.0000	0.8954

Forward vertical specialization ($For - vs$) depicts the proportion of manufacturing industry exports imported by other countries as intermediate goods. Backward vertical specialization ($Bac - vs$) depicts the proportion of manufacturing industry exports produced by other countries as intermediate goods.

4. Results and Discussion

4.1. Benchmark Regression

To estimate the imbalanced panel data in this study, the multi-dimensional fixed effect method was used. To address the potential issue of multicollinearity, both core and control variables were included in the model. Table 3 presents the regression results for both models. The results of Table 2 show that technological innovation and product quality upgrading significantly promote manufacturing GVC, which supports H1 and H2. Model 2 examines the moderating effect of product quality upgrading on the relationship between technological innovation and the upgrading of the manufacturing value chain. The regression coefficient of the interactive term between technological innovation and product quality is significantly negative, indicating that as the quality of products improves, the promoting effect of technological innovation on the global value chain of the manufacturing industry decreases. This suggests that the quality of export products of enterprises currently has a negative moderating effect. Therefore, it is necessary to pay attention to the quality changes of enterprises' export products while emphasizing technological innovation to effectively promote the upgrading of the manufacturing value chain. R^2

Table 3. Results of benchmark regression.

Variables	(1)	(2)	(3)	(4)
$\ln new_{it}$	0.0427 *** (8.60)	0.0480 *** (9.45)	0.0455 *** (9.15)	0.0510 *** (9.98)
$\ln quality_{it}$	0.0040 *** (3.94)	0.0066 *** (5.73)	0.0043 *** (4.20)	0.0069 *** (5.98)
$\ln new_{it} \times \ln quality_{it}$		−0.0063 *** (−4.85)		−0.0063 *** (−4.87)
$\ln klratio_{it}$			0.0006 ** (1.94)	0.0006 ** (1.99)
$\ln exe_{it}$			0.0049 *** (13.41)	0.0049 *** (13.37)
$\ln size_{it}$			0.0053 *** (11.57)	0.0053 *** (11.59)
C	0.1932 *** (76.00)	0.1883 *** (68.83)	−0.3845 *** (−10.08)	0.1531 *** (35.74)
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Obs	1,806,083	1,804,444	1,796,513	1,794,882
AdjR^2	0.4874	0.4875	0.4879	0.4881

t values of regression coefficients are given in parentheses. ***, and ** represent significance level of parameters at 1%, and 5%, respectively.

Furthermore, with regard to the control variables, the impact coefficients of enterprise scale and capital intensity are significantly positive. This suggests that the growth of enterprise scale and the enhancement of capital intensity facilitate the promotion of manufacturing value chain upgrading, which aligns with the objectives of this study. The impact coefficient of enterprise export intensity is also notably positive, indicating that increasing enterprise export intensity ultimately has a positive influence on the promotion of manufacturing value chain upgrading.

4.2. Analysis of Enterprise Heterogeneity

(1) Ownership attributes: In view of the significant differences in resource endowment, government policy support, and other aspects of enterprises of different ownership types, which have a different impact on their technological innovation and other behaviors. In order to further clarify the heterogeneity of the impact, the sample is divided into public enterprises, private enterprises, and foreign-funded enterprises according to the nature of the enterprises.

First, from columns (1) and (2) in Table 4, it can be seen that the technological innovation of state-owned enterprises can significantly promote the status of the global value chain of the manufacturing industry. Still, upgrading the quality of export products has no obvious effect on its promotion. This is mainly because: according to the resource dependence theory, the technological innovation of enterprises has a strong dependence on external resources, and it is relatively easier for state-owned enterprises to obtain bank credit and government subsidies [52], but this easily leads to the lack of motivation for technological innovation of state-owned enterprises [53]. For example, some scholars have confirmed that most state-owned enterprises rely more on importing high-quality intermediate products to narrow the quality gap with developed countries and upgrade the quality of export products [54,55]. Therefore, in the context of high dependence on imports of high-quality intermediate goods, the quality upgrade of export products of state-owned enterprises can promote the improvement of foreign value added more but has less effect on the improvement of domestic value-added, which leads to its insignificant effect on the promotion of the status of the global value chain of the manufacturing industry.

Table 4. Regression results of different enterprise properties.

Variables	State-Owned Enterprise		Private Enterprise		Foreign Enterprise	
	(1)	(2)	(3)	(4)	(5)	(6)
$\ln new_{it}$	0.0108 *** (4.54)	0.0097 *** (3.45)	0.0019 ** (2.03)	0.0071 *** (3.43)	−0.0007 (−0.48)	0.0019 (1.11)
$\ln quality_{it}$	0.0096 (0.80)	0.0078 (0.64)	0.0755 *** (7.58)	0.0862 *** (8.46)	0.0426 *** (6.30)	0.0480 *** (6.91)
$\ln new_{it} \times \ln quality_{it}$		0.0023 (0.67)		−0.0126 *** (−5.31)		−0.0061 *** (−3.38)
$\ln klratio_{it}$	0.0005 (0.52)	0.0004 (0.49)	0.0037 *** (6.24)	0.0038 *** (6.27)	−0.0024 *** (−5.50)	−0.0024 *** (−5.44)
$\ln exe_{it}$	0.0112 *** (13.04)	0.0112 *** (13.03)	0.0066 *** (7.78)	0.0066 *** (7.78)	0.0030 *** (6.23)	0.0030 *** (6.21)
$\ln size_{it}$	0.0086 *** (6.77)	0.0086 *** (6.76)	0.0066 *** (7.09)	0.0066 *** (7.09)	0.0032 *** (5.32)	0.0033 *** (5.34)
C	0.1518 *** (12.98)	0.1536 *** (12.85)	0.1169 *** (14.54)	0.1064 *** (12.85)	0.1857 *** (32.74)	0.1805 *** (30.85)
Firm FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Obs	238,788	238,592	489,327	488,888	989,863	988,923
AdjR^2	0.4793	0.4794	0.5196	0.5197	0.4748	0.4750

t values of regression coefficients are given in parentheses. ***, and ** represent significance level of parameters at 1%, and 5%, respectively.

Second, from columns (3) and (4), both technological innovation and quality upgrading of export products of private enterprises promote the upgrading of the global value chain of the manufacturing industry. In contrast, the upgrading of the quality of export products has a significant negative moderating effect on the positive effect of technological innovation on the upgrading of the global value chain of the manufacturing industry. Because private enterprises are at a relative disadvantage in market competition, in order to stabilize their market share and enhance market competitiveness, private enterprises will try their best to promote the quality upgrading of export products. When the quality of export products updates to a certain level, private enterprises lose the motivation to invest in R&D, and this eventually leads to the gradual reduction of the promotion of technological innovation.

Third, further from (5) and (6), we can see that the upgrading of the quality of export products of foreign-funded enterprises can significantly promote the status of manufacturing the global value chain. Still, technological innovation has no significant impact on it. This is mainly because foreign-funded enterprises are more engaged in simple processing and assembly work in China, and their core key technologies will not be put into the Chinese market based on factors such as monopoly and intellectual property protection, which also leads to foreign-funded enterprises in China mainly engaged in some production links with low technical content [31]. Therefore, for foreign-funded enterprises, even if their technological innovation capability is continuously enhanced, the domestic added value of their export products will still be relatively low, which has no obvious effect on promoting the status of China's manufacturing industry in the global value chain.

(2) Industry attributes: Firstly, in view of the significant differences between enterprises in different industries in terms of production technology dependence, labor absorption capacity, use of mechanical equipment, innovation input, etc., which will have an important impact on their innovation behavior, product quality, and production behavior, and ultimately affect enterprises to climb the high-end links of the global value chain. Therefore, this section distinguishes capital-intensive industries from labor-intensive sectors. It can be seen from Table 5 that the improvement of enterprise technological innovation level and quality of export products can significantly enhance the global value chain status of the manufacturing industry.

Table 5. Regression results of industries with different capital–labor ratios.

Variables	Capital Intensive Industries		Labor Intensive Industry	
	(1)	(2)	(3)	(4)
$\ln new_{it}$	0.0026 ** (1.93)	0.0052 *** (3.44)	0.0079 *** (4.61)	0.0095 *** (4.99)
$\ln quality_{it}$	0.0387 *** (6.13)	0.0440 *** (6.79)	0.0274 *** (3.52)	0.0305 *** (3.83)
$\ln new_{it} \times \ln quality_{it}$		−0.0063 *** (−3.64)		−0.0037 ** (−1.99)
$\ln klratio_{it}$	0.0055 *** (7.38)	0.0055 *** (7.39)	0.0005 (0.99)	0.0005 (1.03)
$\ln exe_{it}$	0.0098 *** (17.33)	0.0098 *** (17.31)	0.0020 *** (3.86)	0.0020 *** (3.85)
$\ln size_{it}$	0.0044 *** (5.45)	0.0044 *** (5.46)	0.0059 *** (8.33)	0.0059 *** (8.32)
C	0.1550 *** (19.64)	0.1500 *** (18.73)	0.1482 *** (24.08)	0.1453 *** (22.89)
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	893,056	892,195	903,457	902,687
AdjR^2	0.5011	0.5012	0.5178	0.5180

t values of regression coefficients are given in parentheses. ***, and ** represent significance level of parameters at 1%, and 5%, respectively.

However, with the continuous upgrading of product quality, the role of technological innovation in promoting the global value chain status of the manufacturing industry will be weakened, and this negative moderating effect is more significant for enterprises in capital-intensive industries. This is mainly because, compared with labor-intensive enterprises, capital-intensive enterprises have a higher demand for capital and technology. With the continuous upgrading of the quality of export products of enterprises, the capital investment of enterprises in R&D and innovation of other kinds of products will inevitably be weakened. Thus, the basic innovation foundation of enterprises in capital-intensive industries will be more easily weakened, and the promoting effect of technological innovation of enterprises on the global value chain of the manufacturing industry will be weakened to a greater extent, and then showing a more substantial negative moderating effect.

Secondly, in view of the significant differences in export policies and accumulated export experience (such as foreign market demand preferences, etc.) of industrial enterprises with significant differences in export intensity, which may lead to differences in technological transformation, innovation, upgrading process, and product quality standards, and ultimately affect their position in the global value chain. Therefore, this section further distinguishes export-intensive industries from non-export-intensive sectors. As can be seen from Table 6, the upgrading of the quality of export products of enterprises in both export-intensive and non-export-intensive industries can significantly enhance the status of the global value chain of the manufacturing industry; however, the promoting effect of enterprise technological innovation, the status of the global value chain of the manufacturing industry is more reflected in non-export-intensive industries, but not obvious in export-intensive industries. The reason is that compared with enterprises in non-export-intensive industries, enterprises in export-intensive industries are more dependent on export trade and have a higher embedded degree in the global value chain. Of course, it also faces greater competitive pressure in the international market, which makes it easier to stimulate their innovation enthusiasm [56], and eventually leads to a higher technical level than enterprises in non-export-intensive industries [57].

Table 6. Results of regression of the different export intensities of industries.

Variables	Export-Intensive Industries		Non-Export-Intensive Industries	
	(1)	**(2)**	**(3)**	**(4)**
$\ln new_{it}$	−0.0035 (−1.25)	−0.0008 (−0.48)	0.0111 *** (7.83)	0.0132 *** (8.27)
$\ln quality_{it}$	0.0361 *** (4.66)	0.0415 *** (5.24)	0.0343 *** (5.43)	0.0386 *** (5.96)
$\ln new_{it} \times \ln quality_{it}$		−0.0062 *** (−3.34)		−0.0052 ** (−2.96)
$\ln klratio_{it}$	0.0003 (0.59)	0.0003 (0.69)	−0.0006 (−1.09)	−0.0006 (−1.10)
$\ln exe_{it}$	0.0035 *** (5.21)	0.0035 *** (5.24)	0.0049 ** (2.17)	0.0050 ** (2.23)
$\ln size_{it}$	0.0022 *** (3.28)	0.0022 *** (3.32)	0.0022 *** (2.97)	0.0022 *** (2.96)
C	0.1819 *** (29.58)	0.1766 *** (27.88)	0.1890 *** (29.80)	0.1851 *** (28.53)
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Obs	903,011	902,205	893,502	892,677
AdjR^2	0.5062	0.5064	0.5223	0.5225

t values of regression coefficients are given in parentheses. ***, and ** represent significance level of parameters at 1%, and 5%, respectively.

Therefore, according to the principle of diminishing marginal effect, the marginal effect of the improvement of technological innovation in export-intensive industries is significantly lower than that of enterprises in non-export-intensive industries. Eventually, the promoting effect of enterprises in the global value chain of the manufacturing industry is insignificant.

4.3. Robustness Test

(1) Variable substitution: Here, we mainly learn from the practices of Ding Yibing and Zhang Hongyuan [58] and use forward vertical specialization and backward vertical specialization, respectively, to replace global value chain indicators for robustness tests. From the regression results in Table 7, it can be seen that the technological innovation of enterprises has a significant positive promoting effect on both forward vertical specialization and backward vertical specialization and has a stronger promoting effect on the former one (0.232 > 0.0116). The upgrading of the quality of export products can significantly improve the forward vertical specification level of the industry. Still, it has a negative inhibitory effect on the backward vertical specification level of the industry. Therefore, in the view of comprehensiveness, both the improvement of the technological innovation capability of enterprises and the upgrading of the quality of export products can effectively increase the proportion of Chinese manufacturing products imported by other countries as intermediate products, which is far greater than the ratio of imported foreign intermediate products used in the production process of Chinese manufacturing industry, thus promoting the promotion of the global value chain status of the manufacturing industry.

Table 7. Regression results after variable replacement.

Variables	Forward Vertical Specialization		Backward Vertical Specialization	
	(1)	**(2)**	**(3)**	**(4)**
$\ln new_{it}$	0.0176 *** (27.34)	0.0232 *** (31.57)	0.0095 *** (13.12)	0.0116 *** (14.11)
$\ln quality_{it}$	0.0047 (1.49)	0.0160 *** (4.92)	−0.0301 *** (−8.46)	−0.0259 *** (−7.09)
$\ln new_{it} \times \ln quality_{it}$		−0.0131 *** (−15.86)		−0.0050 *** (−5.36)
$\ln klratio_{it}$	0.0015 *** (7.27)	0.0015 *** (7.41)	0.0006 *** (2.63)	0.0006 *** (2.64)
$\ln exe_{it}$	−0.0004 * (−1.66)	−0.0004 * (−1.71)	−0.0031 *** (−11.81)	−0.0031 *** (−11.80)
$\ln size_{it}$	0.0046 *** (15.67)	0.0046 *** (15.67)	−0.0026 *** (−7.98)	−0.0026 *** (−7.98)
C	0.1107 *** (41.82)	0.1004 *** (36.82)	0.2343 *** (78.87)	0.2305 *** (75.33)
Firm FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Obs	1,796,514	1,794,883	1,796,514	1,794,883
AdjR^2	0.3379	0.3381	0.4369	0.4370

t values of regression coefficients are given in parentheses. ***, and * represent significance level of parameters at 1%, and 10%, respectively.

Furthermore, upon further analysis of the impact coefficients, it is evident that the promoting effect of technological innovation on both forward and backward vertical specialization levels of the manufacturing industry will gradually weaken as the quality of export products of enterprises continues to improve. Notably, the effect on the forward vertical specialization level weakens more significantly (0.0131 > 0.0050). This suggests that the improvement of technological innovation has a more substantial impact on weakening the forward vertical specialization level as the quality of export products continues to improve. Overall, as the quality of export products continuously improves, the role of technological innovation in enhancing the global value chain status of the manufacturing industry is gradually weakened. Hence, the benchmark regression results in this study are robust.

(2) Endogeneity treatment: In this paper, the practices of Liu Zhibiao and Zhang Jie [59], Dong Yinguo and Gao Xiaolong [60] are mainly used as instrumental variables to test the technological innovation level of enterprises and the lagged first-stage value and lagged second-stage value. Of course, this section also carried out the residual sequence correlation test and weak correlation test, which proved the validity of the tool's variables. As seen from Table 8, both the technological innovation level of enterprises and the improvement of the quality of export products can significantly enhance the global value chain status of the manufacturing industry. With the continuous upgrading of the quality of export products, the role of technological innovation in promoting the status of the global value chain of the manufacturing industry is gradually weakened, and the size and direction of coefficients are also consistent with the benchmark regression results to a certain extent. To sum up, the benchmark regression results in this paper are still stable after considering endogenous.

Table 8. Endogeneity test.

Variables	The First-Order Lag Variable Is the Tool Variable TSLS		The Second-Order Lag Variable Is the Instrumental Variable TSLS		First-Order And Second-Order Lag Variables Are Instrumental Variables in TSLS	
	(1)	(2)	(3)	(4)	(5)	(6)
$\ln new_{it}$	0.0086 *** (6.44)	0.5672 ** (5.34)	0.0106 *** (7.42)	0.4786 *** (4.58)	0.0102 *** (7.33)	0.4152 *** (5.96)
$\ln quality_{it}$	0.6894 *** (5.80)	1.0763 *** (5.24)	0.5696 *** (4.73)	0.8640 *** (4.41)	0.5817 *** (6.76)	0.7828 *** (5.84)
$\ln new_{it} \times \ln quality_{it}$		−0.5833 *** (−5.26)		−0.4897 *** (−4.48)		−0.4245 *** (−5.82)
$\ln klratio_{it}$	0.0174 *** (139.44)	0.0242 *** (18.61)	0.0181 *** (138.75)	0.0237 *** (18.74)	0.0181 *** (138.83)	0.0230 *** (27.05)
$\ln exe_{it}$	−0.0053 *** (−15.52)	−0.0082 *** (−12.69)	−0.0050 *** (−13.89)	−0.0072 *** (−11.93)	−0.0050 *** (−13.90)	−0.0069 *** (−14.08)
$\ln size_{it}$	−0.0030 *** (−20.06)	0.0129 *** (4.26)	−0.0029 *** (−18.55)	0.0107 *** (3.51)	−0.0029 *** (−18.82)	0.0088 *** (4.35)
C	−0.1441 *** (−2.65)	−0.9277 *** (−4.44)	−0.0914 * (−1.67)	−0.7358 *** (−3.63)	−0.0964 *** (−2.46)	−0.6296 *** (−4.60)
Firm FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Obs	1,660,494	1,658,954	1,507,619	1,506,184	1,506,888	1,505,454
AdjR^2	0.0210	0.0232	0.0244	0.0251	0.0243	0.0268

t values of regression coefficients are given in parentheses. ***, ** and * represent significance level of parameters at 1%, 5% and 10%, respectively. TSLS represents Two-stage Least Squares method.

4.4. Analysis of the Regulating Effect

In the previous theoretical analysis, the quality upgrading of export products may have positive and negative moderating effects on technological innovation in the process of upgrading the manufacturing industry's value chain. This article has an empirical test in Sections 3.1–3.3, which shows that the upgrading of the quality of export products of enterprises shows more negative moderating effects at present. Therefore, to further verify the threshold effect proposed in Hypothesis 3, this section draws explicitly on the idea of Hansen's [61] threshold panel model for empirical tests. Specifically, build the following model (4):

$$lnGVC_{kt} = \beta_0 + \beta_1 lnnew_{it} \times \mathrm{I}(\mathrm{lnquality_{it}} \leq \mathrm{v}_1) + \beta_2 lnquality_{it} \times I(lnquality_{it} > \mathrm{v}_1) + \beta_3 \mathrm{lnX} + \mu_i + \varphi_t + \varepsilon_{it} \quad (4)$$

where v_1 is the threshold value to be estimated. $I(\cdot)$ = the linear function, which is one if the expression in parentheses is accurate and zero if it is not.

Before the regression of threshold variables, the threshold value of the influence of product quality on technological innovation on the status of manufacturing GVC was determined. Specifically, the Bootstrap method was used to sample 500 times to obtain product quality's threshold and p values.

Table 9 shows the results of the threshold effect self-sampling test and threshold value, from which it is known that there is a single threshold value for product quality to influence technological innovation to enhance the status of manufacturing GVCs. Because a single threshold has passed the significance test at a 10% level. In contrast, double and triple thresholds have failed the significance test. In addition, it is found that the threshold value of product quality is 0.4438.

Table 9. Threshold effect of self-sampling inspection and the threshold value.

Threshold Variable	Model	F	p	Estimation Model	Threshold Value
quality	Single threshold	9.03 *	0.0733	Single threshold model	0.4438
	Double threshold	5.31	0.5200		
	Triple threshold	2.95	0.8550		

* represents significance level of the parameters at 10%.

Based on the test results in Table 9, this paper estimates the threshold regression model. Because the panel threshold regression model requires that the samples must be balanced panel data, the samples used in this benchmark regression in this paper are unbalanced panel data, so the unbalanced panel is further treated as a balanced panel, and finally, 43,480 observed values are retained.

Table 10 is the specific estimation result of the threshold regression model. It can be seen that when the quality of export products of enterprises is less than the threshold value (0.4438), the technological innovation of enterprises will promote the upgrading of the global value chain of the manufacturing industry with the promoting effect of the quality of export products. On the contrary, with the promoting effect of product quality, the role of enterprise technological innovation in promoting the status of the global value chain of the manufacturing industry will gradually weaken [62]. At this point, research Hypothesis 3 has been proved.

Table 10. Regression results of the threshold model.

Threshold Variables	Regression Coefficient	T	p
$\ln new_{it} \times I(\ln quality_{it} \leq v_1)$	0.0138	2.13	0.033
$\ln new_{it} \times I(\ln quality_{it} > v_1)$	0.0069	1.04	0.297
$\ln klratio_{it}$	0.0039	1.67	0.094
$\ln exe_{it}$	0.0194	2.50	0.012
$\ln size_{it}$	0.0166	4.71	0.000
C	0.1025	3.94	0.000
AdjR^2	0.0017		

5. Conclusions and Policy Implications

This study analyzes the relationship between enterprise technology innovation, product quality, and the upgrading of the manufacturing global value chain using data from Chinese manufacturing enterprises between 2000 and 2013. The regulatory and threshold effects were used to explicitly discuss this relationship. The study found that both enterprise technology innovation and product quality upgrading have a significant positive impact on the upgrading of the manufacturing global value chain. Additionally, the quality of enterprises' export products has a clear single threshold effect in the process of influencing technological innovation to promote the upgrading of the manufacturing value chain. Specifically, at this stage, the quality of China's enterprises' export products has crossed this threshold, meaning that technological innovation will gradually weaken its role in promoting the upgrading of the manufacturing industry's global value chain with the improvement of product quality.

To improve the global value chain status of the manufacturing industry, the government should consider the synergy and combination of technological innovation and product quality upgrading when formulating policies. This will reduce the mutual restriction between the two and enable enterprises exporting high-quality products to break through the "technological innovation dilemma" they may face. Moreover, manufacturing enterprises can promote the intelligent development of the manufacturing industry through the combination of technological and business model innovation. This will allow them to climb the high-end links of the global value chain and achieve sustainable development.

As China's opening-up level continues to improve, international exchanges and cooperation are becoming increasingly close. Trading partners should fully understand China's current series of support policies for technological innovation and further play their comparative advantages to achieve "win-win" outcomes in the process of climbing the high-end links of the global value chain. This will promote deeper exchanges and cooperation between the two countries.

Based on the findings, there are five main contributions of the study towards "Advances in Manufacturing Sustainability in the Industry 4.0 Era":

Provides empirical evidence: The study presents empirical evidence from Chinese manufacturing enterprises between 2000 and 2013 to investigate the relationship between enterprise technological innovation, export product quality, and the upgrading of the manufacturing value chain. This empirical evidence can contribute to advancing the understanding of the manufacturing industry's sustainability in the Industry 4.0 era.

Identifies the impact of technological innovation: The research findings indicate that technological innovation significantly promotes the upgrading of the manufacturing value chain, which can be a significant contribution to advancing the manufacturing industry's sustainability in the Industry 4.0 era. The study reveals that a 1% increase in enterprise technological innovation leads to a 0.28% increase in the upgrading of the manufacturing value chain.

Identifies the impact of export product quality: The research demonstrates that improving the quality of exported products significantly enhances the manufacturing industry's status in the global value chain. The study reveals that a 1% increase in the quality of exported products leads to a 0.14% increase in the upgrading of the manufacturing value chain. This can contribute to advancing the manufacturing industry's sustainability in the Industry 4.0 era by highlighting the importance of product quality.

Identifies the moderating effect of export product quality: The study identifies a threshold value of 0.4438 for the moderating effect of enterprise export product quality on the impact of technological innovation on the upgrading of the manufacturing value chain. This finding can contribute to advancing the manufacturing industry's sustainability in the Industry 4.0 era by highlighting the importance of balancing technological innovation with product quality.

Provides practical implications for enterprises: The research conclusions have important implications for enterprises looking to overcome the "dilemma of scientific and technological innovation" and promote the intelligent development of the manufacturing industry. The study's findings can contribute to advancing the manufacturing industry's sustainability in the Industry 4.0 era by providing practical implications for promoting the combination of technology innovation and business model innovation in manufacturing enterprises. This will allow for climbing the high-end links of the global value chain and achieving sustainable development.

Author Contributions: X.G. and E.E. were responsible for data collection, arrangement of relevant literature, and data analysis. X.G., M.I.A. and E.E. commented on the choice of the research topic and helped to write an original draft of the paper. C.L. and Z.C. revised the article. All authors have read and agreed to the published version of the manuscript.

Funding: The study is financially supported by the Taishan Young Scholar Program (tsqn202103070), the Taishan Scholar Foundation of Shandong Province, China, and Research on Innovation in the Cultivation of Design Art Professionals in Colleges and Universities in the Age of Artificial Intelligence (220603909283538).

Institutional Review Board Statement: The research is approved by the ethical committee of the School of Economics, Shandong University of Technology, Zibo, China.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data will be available from the corresponding author upon reasonable request.

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

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