Effects of China's Manufacturing Exports on Firm Innovation in the US

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Abstract: *Based on the market segmentation theory, this paper employed data on China-US trade and firm R&D, innovation and TFP to investigate the long-term effects of China's manufacturing exports on firm innovation in the US from an heterogeneity perspective, and tested the underlying mechanism. The authors found that in the long run, China's manufacturing exports had to some extent increased manufacturing firm innovation in the US. The effect is highly heterogeneous across various manufacturing sectors. While Chinese exports affect the innovation output of non-core manufacturing firms in the US, they did little on the innovation of core manufacturing firms in the US. In the long run, the cumulative R&D input of core manufacturing firms in the US has not decreased significantly, and factors of production had migrated from non-core to core manufacturing sectors. Such a reallocation of production factors has increased specialization and overall innovation output from US manufacturing firms. By demonstrating that the rise of developing countries is consistent with the theory of comparative advantages, this paper refutes the "China threat" narrative touted by some developed countries, and provides scientific basis for rational resource allocation and international division of labor.*

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1. Introduction

Since the 1990s, developing countries led by China have been rising to prominence in the world economy, transforming global industrial, trade and economic landscapes with their labor-intensive exports. Over the past two decades, China's manufacturing exports have been growing at an annual average pace of 18% (Chakravorty *et al*., 2017), accounting for close to 20% of world total exports in 2016, up from 2.3% in 1991 (Dorn *et al*., 2016). In this context, China's manufacturing prowess has sparked broad discussions and controversies, including the "China threat theory," at the dawn of the 21st century.[1] The United Nations, international media, and domestic academics have all expressed a keen interest in China's manufacturing industry (Zeng, 2006). As China's biggest trading partner, the United States has seen rapid increase in manufacturing imports from China. Widening China-US trade deficits have fueled the "China threat" narrative in the developed world led by the US. Over the years, the US government has attempted to address trade deficits with China by restricting manufacturing imports from China.

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[1] The first wave of "China threat" narrative after the Cold War occurred in the early 1990s, sparked by a World Bank report in 1993 that ranked China as the third largest economy in the world by GDP in purchasing power parity (PPP) terms and William Overholt's assertion that China could become a new superpower in the future. After the turn of the 21st century, the "China threat" narrative mainly refers to Made in China's global expansion and the crowding-out effect of China's economic development on other trading powers (Zhu, 2005).

Academics have paid close attention to surging manufacturing exports from developing countries led by China since the late 1990s. Numerous studies have been carried out to investigate the effects, especially income and employment effects, of manufacturing exports from low-income countries on developed countries. It is widely considered that manufacturing exports from low-income countries have intensified competition in the product market, chipping away at the market shares of firms in the US and Europe. In the developed world, numerous factories became closed (Bernard *et al*., 2006), jobs were shed (Pierce and Schott, 2016; Acemoglu *et al*., 2016), and wage inequality widened (Autor *et al*., 2014). Yet little attention has been paid to the effects on innovation - a key driver of economic growth (Romer, 1990; Aghion and Howitt, 1992) and core indicator of a country's manufacturing development in the long run. As a traditional powerhouse of innovation, the United States derived over two thirds of its patents from the manufacturing industry (Dorn *et al*., 2016). China's manufacturing exports to the US, therefore, may affect firm innovation in the US.

To date, there has been a paucity of research on Chinese manufacturing exports' effects on firm innovation in the US - a topic on which academics have yet to reach consistent conclusions. Liu and Rosell (2013) and Dorn *et al.* (2016) believed that Chinese manufacturing exports had increased R&D uncertainties for US firms, worsened their business performance, and undercut their innovation output. Chakravorty *et al*. (2017) argued that China's manufacturing exports had led to an increase in US innovation. Dorn *et al*. (2016) and others conducted an overall assessment of how Chinese exports had influenced US manufacturing firms' innovation capacity without delving into sectoral heterogeneity and transmission mechanism. Considering that most exports from low-income countries like China are low-end and high-income countries like the US boast comparative advantages in more sophisticated manufacturing, such an impact is likely to be asymmetrical and may affect the allocation and migration of production factors across sectors in the US.

Based on the market segmentation theory, this paper performs a theoretical analysis to explain the heterogeneous effects of China's manufacturing exports on firm innovation in the US. Then, firm- and sector-level trade, R&D and patent data are employed for an empirical test of such heterogeneous effects, thus enriching the empirical evidence for this type of research. Lastly, this study explained how China's manufacturing exports helped boost innovation for US manufacturing sectors at the high end. Our findings have deepened previous research on this topic.

2. Theoretical Framework and Hypotheses

Manufacturing exports from low-income countries influence firm innovation in the developed world by increasing product market competition. Yet academics offered opposing opinions on such effects. Based on the market segmentation theory[2], this paper investigates the effects of manufacturing exports from low-income countries on firm innovation in developed countries from a sectoral heterogeneity perspective.

According to the market segmentation theory, the relationship between product competition and firm innovation is not strictly linear, and is subject to the level of competition and firm characteristics such as product quality, market range, and sectoral type. Some academics considered that the relationship between product competition and firm innovation is subject to the level of competition. Aghion *et al.* (2005) found an inverted U-shaped relationship between product competition and firm innovation. When firm competition is minimal, an increase in competition will nudge firms to increase R&D spending and ease competitive pressures. In this stage, innovation will increase with product competition until a

[2] "Market segmentation theory" was collectively put forth by numerous academics with similar views, and summarized in this paper based on relevant literature.

certain optimal point is reached. Others believed that the relationship between product competition and firm innovation has to do with firm characteristics, including product quality, market range, and sectoral type. While some firms suffer from imports from low-income countries, others stay immune. Khandelwal (2010) and Sutton (2012) considered that firms with superior product quality lost smaller market shares to exports from low-income countries. Iacovone *et al.* (2013) found that more productive Mexican firms were less capable of scaling down production when faced with manufacturing exports from China. Holmes and Stevens (2014) believed that compared with global manufacturers, firms serving local markets were less affected by manufacturing exports from low-income countries. According to Bernard *et al*. (2006), US labor-intensive firms were more vulnerable to imports from low-income countries than more innovative capital and technology-intensive firms.

According to the market segmentation theory, manufacturing exports from low-income countries may create differentiated effects on firm innovation in developed countries depending on the latter's product quality and sectors. With a mathematical model, this paper will examine the sectoral heterogeneity of such effects, putting forth three hypotheses for empirical analysis.

It is assumed that numerous risk-neutral firms exist in a developed country and face competition from exports from low-income countries. This paper divides this country's manufacturing sectors by the level of technology into high-end sectors with comparative advantages and low-end sectors without comparative advantages. Their difference is then simplified into product quality difference arising from uneven firm innovations.

First, we introduce the impact of manufacturing exports. Around the turn of the century, China remained at the initial stage of industrial development and boasted advantages mainly in labor-intensive sectors. Back then, China's industrial output was dominated by low-tech and low-value goods. Hence, we consider that exports from low-income countries such as China are dominated by low-end manufacturing goods with modest quality.

Then, we examine the effects of exports from low-income countries on low-end manufacturing sectors in the developed country. The imported product from low-income countries is y[3], which is a complete replacement for domestic product x in the developed country. The output of product x is an increasing function of factor input, and requires ordinary production factor I and high-end production factors, including capital spending K and human capital H, for quality improvement, as shown in equation (1). Hence, the amount of high-end factor input can be expressed as a reverse function of product output and the input of other factors, as shown in equation (2) and equation (3):

$$x = f(I_1, K_1, H_1) \tag{1}$$

$$H_1 = f_H^{-1}(x, I_1, K_1) \tag{2}$$

$$K_1 = f_K^{-1}(x, I_1, H_1) \tag{3}$$

In this paper, we consider a representative consumer in this country, whose utility function is defined as $U(\mathrm{x})=\mathrm{x}^a, 0 < a < 1$, and the prices of the two types of commodities are p_x and p_y, respectively. Since both x and y are low-end products and complete replacements for each other, there is no difference in their utility to consumers; given the lower cost of labor and other factors in low-income countries, commodity y should be less expensive than x, i.e. $p_x > p_y$. Thus, the decision-making problem for consumer utility maximization can be expressed as:

$$\max_{x,y} (x+y)^a - p_x x - p_y y \tag{4}$$

[3] The symbol also denotes the output of y, and the same is true for x and z.

The first-order condition for consumer utility maximization is:

$$y = (\frac{p_y}{a})^{1/(a-1)}$$
$$x = 0 \quad (5)$$

Provided that all consumers are rational, the developed country's decision to maximize performance under the given impact of imports (y) is to suspend the production of x (equilibrium output of x is zero).

Then, we investigate the effects of manufacturing exports from low-income countries on the high-end manufacturing industry, and use z to denote high-end manufacturing goods in the developed country. Consumers obtain utility from consumer goods. With better quality, high-end goods will bring about higher utility to consumers. Relative to low-end goods, this paper assumes that high-end goods increase consumer utility by $q(q>1)$. Where, q is the innovation capacity of high-end manufacturing firms, which is a function of R&D input, capital spending, and human capital, as shown in equation (6). Similarly, the output of product z is a function of factor input, and high-end factor input can be expressed as a reverse function of product output and other factors, as shown in equations (7) through (9).

$$q = g(RD(\pi), K, H) \quad (6)$$

$$z = h(I_2, K_2, H_2) \quad (7)$$

$$H_2 = h_H^{-1}(z, I_2, K_2) \quad (8)$$

$$K_2 = h_K^{-1}(z, I_2, H_2) \quad (9)$$

Hence, the decision-making problem of consumer utility maximization can be expressed as:

$$\max_{z,y} (qz + y)^a - p_z z - p_y y \quad (10)$$

At this moment, P_z denotes the price of domestic high-end manufacturing goods, and the first-order condition of consumer utility maximization can be expressed as:

$$qa(qz + y)^{a-1} = p_z \quad (11)$$

$$a(qz + y)^{a-1} = p_y \quad (12)$$

It can be learned from equations (11) and (12) that when consumer utility is maximized, $p_z = qp_y$ holds true. c is the unit cost of manufactured goods, i.e. the cost of ordinary factor. $F = f(t, s(K, H))$ is the fixed cost additionally required to improve product quality, i.e. the cost of high-end factors, and is an increasing function of technology content t and a decreasing function of high-end factor supply $s(K,H)$. We assume the marginal cost of production to be the same for high-end and low-end manufactured goods, i.e. c. Assuming factor supply conditions to be constant, high-tech goods require a higher amount of fixed cost ($F_1 < F_2$), and at this moment, the decision-making expression for firm performance maximization is as follows:

$$\max_z \pi(z) = zp_z(z, y) - cz - F_2(t_2, s_2) \qquad \pi(z) \ge F_2 \quad (13)$$

The first-order condition for firm profit maximization is as follows:

$$zp_z'(z, y) + p_z = c \quad (14)$$

If the firm is able to pay the fixed cost of R&D, equation (11) is further substituted, and equation (14) can be rewritten as:

$$qa(qz + y)^{a-2}(qaz + y) = c \quad (15)$$

Since $p_z = qp_y$ holds true when consumer utility is maximized, both products will be available in the market, and the equilibrium output of equation (15) z is greater than zero. It can be seen that due to the existence of q, high-end manufacturing sectors generate a higher equilibrium output, i.e. since high-end manufacturing sectors offer better product quality, they are less vulnerable to the impact of export from low-income countries . However, domestic low-end manufacturing sectors face competition from domestic high-end manufacturing sectors and overseas low-end manufacturing sectors. As shown in equations (2), (3), (8) and (9), with other conditions held constant, difference in the equilibrium output will bring about change in factor demand across sectors and induce the intersectoral flow of production factors.

Shrinking low-end manufacturing sectors will spend less on R&D and suffer an outflow of capital spending and human capital. Some production factors will migrate to high-end manufacturing sectors that ramp up R&D to cope with competition. Based on equation (6), the inflow of production factors, especially high-end factors, will increase the innovation capacity q of high-end manufacturing firms; on the other hand, as shown in equations (13) and (6), the inflow of production factors will reduce R&D cost F_2 by increasing the supply of high-end factors. With higher equilibrium profits, high-end manufacturing firms will spend more on R&D and boost innovation capacity q. Hence, this paper considers that the effects of export from China on manufacturing firms in the developed world are heterogenous across sectors. In the long run, exports from China have optimized domestic resource allocation in the US, encouraged the inflow of production factors into high-end sectors in US, and thus helped boost innovation in the manufacturing industry as a whole. Based on the above theoretical analysis, we arrive at Hypotheses 1-3:

H1: Manufacturing exports from China significantly boosted innovation output from US manufacturing firms.

H2: The effects of Chinese exports on US manufacturing firms, including the effects on their innovation output, R&D spending and size of production factors, are significantly heterogenous across sectors.

H3: China's manufacturing exports have encouraged the migration of some production factors from low-end to high-end manufacturing sectors, thus contributing to an increase in the innovation output of US manufacturing firms.

3. Research Design

3.1 Model Specification

(I) Basic regression model: Referencing Autor *et al.* (2013), we created the following fixed-effect model to examine the effects of China's manufacturing exports on firm innovation in the US:

$$innov_{i(j),t} = \alpha + \beta us\_ratio_{j,t} + \gamma X_{i,j,t} + \theta X_{j,t} + \delta_t + \delta_i + \varepsilon_{i,j,t} \qquad (16)$$

Where, explained variable $innov_{i(j),t}$ is the innovation output of each manufacturing firm or sector, including the number of patent applications, the number of patent citations, and sectoral total factor productivity. The core explanatory variable $us\_ratio_{j,t}$ is the effect of exports on each manufacturing sector. $X_{i,j,t}$ is firm-level control variables, including firm profitability, employment, and capital spending. $X_{j,t}$ is sector-level control variables, including sectoral value-added, employment, and capital spending. δ_t is the fixed effect of time; δ_i is individual effect, including the individual effect of firm or sector; $\varepsilon_{i,j,t}$ is residual error.

(2) Instrumental variable model: More US imports from China reflect both an increase in China's exports and a greater US demand for manufacturing goods. Hence, an endogeneity problem may exist between the core explanatory variable in this paper - a rising share of US imports from China - and

firm innovation. Referencing Autor *et al.* (2013), we created an export index comprising eight other high-income countries' imports from China as the instrumental variable for the export impact. This instrumental variable offsets US domestic sectoral demand factor. Given the disparate socio-economic conditions in these eight countries, it can be assumed that the industry demand shocks in various countries are unrelated, so that this instrumental variable satisfies the exclusivity requirement.

3.2 Data Source

This paper employs international trade data from the UN Comtrade database. Given our focus on manufacturing sectors, we retained sectors with SIC codes in the range of 2000-3999. Finally, we obtained trade data for 397 manufacturing sectors in the US and eight other high-income countries over the period 1991-2016. We employed patent data from the NBER database, other firm-level data from Compustat database, and sector-level data from the NBER-CES database for manufacturing sectors. Finally, we consolidated the trade, firm and sector data of 1991-2011 for an analysis of the effects of exports on R&D input, patent applications, patent references, and TFP.[4]

3.3 Variable Selection and Explanation

(1) Core explanatory variable. Referencing Bernard *et al.*'s (2006) proportion method, we use each sector's imports from China as a share of the sector's total imports as a basic variable to measure the sector-level export impact. The method of variable creation as shown in equation (17):

$$us\_ratio_{j,t} = \frac{imp_{j,t}^{us\_china}}{imp_{j,t}^{us\_world}} \tag{17}$$

Table 1: Description of Core and Non-Core Manufacturing Variables

Variable description	Variable	Mean value		Standard error	
		Non-core manufacturing	Core manufacturing	Non-core manufacturing	Core manufacturing
Five-digit TFP	tfp5_w	0.9287	4.0965	0.1892	9.0911
Total sector output	vship_w	42749.1800	28585.5391	47487.2048	30022.0833
Sectoral value-added	vadd_w	25763.5475	16810.4919	28892.9295	17253.1447
Sectoral employment	emp_w	105.5527	88.5705	114.9529	59.1564
Sectoral human capital	hcap_w	37.8604	43.4344	30.6182	28.8201
Sectoral capital spending	cap_w	14929.1316	15044.1151	15303.1121	21573.3482
Sectoral total assets	ass_w	1723.8146	1390.1434	6124.2408	5705.3485
Firm profit before interest and tax	ebit_w	156.0476	112.6480	620.6127	525.2018
Firm employment	emp_fir_w	6.0802	4.6252	17.3533	14.9097
Firm capital spending	capx_w	84.7863	79.0000	315.1047	341.2712
Firm sales revenue	sale_w	1445.4445	1214.3694	4971.8129	4915.3185
Firm R&D spending	rd_w	75.2598	53.6808	269.7198	198.5037
Number of firm patent applications	pat_w	8.2339	9.4535	29.3109	32.6240
Number of firm patent citations	cite_w	789.9710	1156.3676	3151.5868	4173.0513

Source: Compiled by authors.

Where, $imp_{j,t}^{us\_china}$ is the imports of sector j in the US from China in year t; $imp_{j,t}^{us\_world}$ is the total imports of sector j in the US since year t.

(2) Explained variable: Firm-level innovation data includes the logarithmic forms of the number of patent applications and patent citations. Sector-level innovation data is each sector's five-digit TFP.[5]

(3) Control variables: Innovation is a high-risk investment activity, and requires a significant upfront investment. Hence, firm profitability is vital to innovation input and output. In addition, labor and capital are the most important factors of production as each sector's or firm's size and nature are reflected by employment and capital spending . Hence, we introduced the logarithmic forms of sector-level value-added, employment, and capital spending and the logarithmic forms of firm-level profit, employment, and capital spending as control variables. All variables are Winsorized at 1 and 99 percentiles to eliminate outliers. Descriptive analyses of key variables are shown in Table 1.

4. Analysis of Empirical Results

4.1 Impact of China's Manufacturing Exports on Firm Innovation in the US

First, this paper investigates the overall effect of China's manufacturing exports on the innovation output of manufacturing firms in the US. As shown in Tables 2 through 4,[6] an increase in US imports from China as a share of total US imports significantly increased the cumulative numbers of patent applications and patent citations, as well as industry average TFP, resulting in an increase in the innovation output of manufacturing firms in the US in the long run. Instrumental variables employed in the model have passed such effective tests as under-identification and weak instrumental variable.

Table 2: Impact of Export Shocks on Firm Patent Applications

	Cumulative patent applications by firms in the subsequent 1-5 years									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Fe	Iv	Fe	Iv	Fe	Iv	Fe	Iv	Fe	Iv
us_ratio	0.5364*	0.6868*	1.2685**	1.7323**	2.0823**	3.3533**	2.9220*	5.8844**	2.6681	8.0603**
	(1.9253)	(1.7585)	(2.2226)	(2.1038)	(2.1084)	(2.2618)	(1.9042)	(2.3588)	(1.3919)	(2.0605)
Firm effect	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Time effect	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Chi_sq P value		0.0000		0.0000		0.0000		0.0000		0.0000
Wald F value		1.7e+04		1.1e+04		6265.2550		3244.1430		1803.8330
N	20,268	20,058	17,601	17,362	15,152	14,908	12,959	12,743	10,987	10,795

Notes: ***, ** and * denote significance at 1%, 5% and 10% levels, respectively.

Source: Calculated by authors with Stata.

[4] Although the latest firms' patent data is dated 2006, this paper's conclusions are still valid and of practical significance. First, the sample period of most international studies on the effects of exports from low-income countries is generally between 1991 and 2006. A main reason is that the impact of export from China is the most significant and representative during this stage. Second, this paper arrived at similar conclusions by introducing sector-level TFP data to extend the sample period to 2011.. Lastly, this paper estimated the TFP data of sample firms during the period 1991-2016 for a supplementary analysis, and obtained relatively robust results.

[5] Five-digit total factor productivity (TFP5) includes capital, working hours of production workers, working hours of non-production workers, energy raw materials, and non-energy raw materials.

[6] In the interest of space, the regression results of control variables will not be separately listed, and are available upon request. The same below.

Table 3: Effect of Export Shocks on Firm Patent Citations[7]

	Cumulative patent citations in the subsequent 1-5 years									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Fe	Iv	Fe	Iv	Fe	Iv	Fe	Iv	Fe	Iv
us_ratio	1.3926**	1.4434*	3.2693***	3.3971*	5.3010**	7.5984**	6.4902*	11.3648**	5.5894	12.6705
	(2.3968)	(1.9142)	(2.6925)	(1.9463)	(2.4806)	(2.2823)	(1.9190)	(1.9671)	(1.2998)	(1.4729)
Chi_sq P value		0.0000		0.0000		0.0000		0.0000		0.0000
Wald F value		2.3e+04		1.4e+04		7660.8680		3736.5860		1967.5900
N	20,268	20,058	17,601	17,362	15,152	14,908	12,959	12,743	10,987	10,795

Notes: ***, ** and * denote significance at 1%, 5% and 10% levels, respectively.
Source: Calculated by authors with Stata.

Table 4: Impact of Export Shocks on Sector TFP

	Sector TFP in the subsequent 1-5 years									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Fe	Iv	Fe	Iv	Fe	Iv	Fe	Iv	Fe	Iv
us_ratio	1.1179***	3.7052***	0.9713***	3.1363***	0.8300***	2.4335***	0.6938***	1.5559***	0.5689**	1.0159**
	(4.4699)	(8.9564)	(3.8697)	(7.5840)	(3.2864)	(5.8147)	(2.6969)	(3.5749)	(2.1773)	(2.2354)
Chi_sq P value		0.0000		0.0000		0.0000		0.0000		0.0000
Wald F value		4160.3220		3946.5370		3621.0440		3163.6080		2713.4670
N	7,504	7,503	7,097	7,096	6,704	6,703	6,314	6,311	5,925	5,919

Notes: ***, ** and * denote significance at 1%, 5% and 10% levels, respectively.
Source: Calculated by authors with Stata.

4.2 Heterogeneous Effects of China's Manufacturing Exports on US Firms' Innovation Output

We further performed a grouped regression analysis to verify Hypothesis 2, dividing total samples into core (high-end) and non-core (low-end) manufacturing firm samples.[8] Results of grouped regression are shown in Tables 5 through 7. In the long run, the effects of China's manufacturing exports on

[7] All estimations have controlled for the time and individual effects (firm or sector effect), and will not be separately listed in the interest of length.

[8] There have been no clear criteria for the classification of high-end and low-end manufacturing sectors. Given the imperfection of individual criteria, this paper classified manufacturing sectors based on literature and relevant information. High-end manufacturing sectors, which by definition, developed in the late stage of industrialization, had the features of high value addition and sophisticated technology. Referencing Chandler's (1994) criteria for the classification of high-technology sectors, Zhang and Liu's (2017) discussions on the advantageous manufacturing sectors of China and the US, and the Brookings Institute's classification of high-end sectors in the US, we identified commercial aircraft, semiconductors, bio-robots, special chemical engineering, and system software as the US's advantageous industries. We also tried to ensure a balanced sample size when classifying industrial sectors. Finally, we defined core US manufacturing sectors as: 2911 (petroleum refining) of 29 (petroleum refining and relevant industries), 3571 (computers) and subsequent sectors of 35 (business machines and computer equipment), 36 (computer and other electrical components), 38 (measurement, analysis, control devices, photography, medical and people products, clocks), as well as 3721 (aircraft), 3724 (aircraft engines and engine components), 3728 (aircraft components and auxiliary equipment), 3761 (guided missiles and spacecraft), 3764 (guided missiles and spacecraft propellers and propeller components), and 3769 (guided missiles and spacecraft components and auxiliary equipment). Other manufacturing sectors are defined as non-core manufacturing sectors of the US. In addition, we attempted to adjust the criteria of industry classification by excluding sectors where technology levels or Chinese or US advantages are hard to assess.

Table 5: Heterogeneous Effects of Export Shocks on Patent Applications in Various Sectors

	Cumulative patent applications in the subsequent 1-5 years									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end
	Fixed effect model									
us_ratio	0.4184	0.4920	1.3328*	0.4300	2.5227*	0.2725	4.0121*	0.4057	3.8725	0.5596
	(1.1388)	(0.8941)	(1.7258)	(0.4131)	(1.8721)	(0.1770)	(1.8804)	(0.1984)	(1.3599)	(0.2329)
N	11,079	9,189	9,630	7,971	8,294	6,858	7,091	5,868	6,005	4,982
	Instrumental variable model									
us_ratio	0.7662	-0.4878	1.4891	0.3602	3.5934*	-0.3225	6.3099*	1.4768	10.9289*	0.8167
	(1.5954)	(-0.4723)	(1.4440)	(0.1773)	(1.8402)	(-0.0966)	(1.7729)	(0.3066)	(1.7829)	(0.1268)
Chi_sq P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wald F value	1.4e+04	2457.2080	9560.4740	1692.4620	5774.7990	1064.5770	2923.8010	666.0560	1544.4980	473.9170
N	10,973	9,085	9,504	7,858	8,170	6,738	6,977	5,766	5,904	4,891

Notes: ***, ** and * denote significance at 1%, 5% and 10%, respectively.
Source: Calculated by authors with Stata.

Table 6: Heterogeneous Effects of Export Shocks on Patent Citations in Various Sectors

	Cumulative patent citations in the subsequent 1-5 years									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end
	Fixed-effect model									
us_ratio	1.5340**	0.9101	3.9307**	1.1053	6.8901**	0.6743	9.7741**	0.0230	9.2221	-0.1401
	(2.0638)	(0.7124)	(2.3712)	(0.5138)	(2.3293)	(0.2391)	(2.0961)	(0.0060)	(1.5096)	(-0.0307)
N	11,079	9,189	9,630	7,971	8,294	6,858	7,091	5,868	6,005	4,982
	Instrumental variable model									
us_ratio	2.2931**	-2.2095	4.7100**	-1.8080	10.7590**	-2.3300	15.9025**	0.4025	22.2748*	-3.6385
	(2.4197)	(-1.1175)	(2.1239)	(-0.4344)	(2.4487)	(-0.3434)	(1.9780)	(0.0393)	(1.7531)	(-0.2733)
Chi_sq P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wald F value	1.8e+04	2886.2940	1.2e+04	1951.7090	6709.3760	1203.3330	3251.0160	736.3580	1666.1420	510.8510
N	10,973	9,085	9,504	7,858	8,170	6,738	6,977	5,766	5,904	4,891

Notes: ***, ** and * denote significance at 1%, 5% and 10%, respectively.
Source: Calculated by authors with Stata.

Table 7: Heterogeneous Effects of Export Shocks on TFP in Various Sectors

	Sectoral average TFP in the subsequent 1-5 years									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end
	Fixed-effect model									
us_ratio	8.5529***	-0.1330***	7.4173***	-0.1606***	6.4552***	-0.1811***	5.5958***	-0.1853***	4.5160***	-0.1840***
	(5.6730)	(-7.0721)	(4.9778)	(-8.5810)	(4.3094)	(-9.6922)	(3.6094)	(-9.9359)	(2.8225)	(-9.7382)
N	1,352	6,151	1,284	5,812	1,216	5,487	1,148	5,163	1,080	4,839
	Instrumental variable model									
us_ratio	18.2306***	-0.2062***	15.5086***	-0.2605***	12.3182***	-0.3211***	8.2903***	-0.3478***	5.3392**	-0.3959***
	(8.8563)	(-6.3913)	(7.7874)	(-8.0824)	(6.2220)	(-9.8377)	(4.0637)	(-10.3884)	(2.5445)	(-11.1991)
Chi_sq P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wald F value	1504.5110	2984.9650	1539.9520	2787.4620	1491.5850	2533.6330	1396.1540	2207.4240	1319.8830	1861.8730
N	1,352	6,151	1,284	5,812	1,216	5,487	1,148	5,163	1,080	4,839

Notes: ***, ** and * denote significance at 1%, 5% and 10%, respectively.
Source: Calculated by authors with Stata.

firm innovation in the US are significantly heterogenous within the manufacturing industry. China's manufacturing exports have sharply increased cumulative patent applications, patent citations and industry average TFP for high-end manufacturing firms in the US in the subsequent one to five years, but the effect was insignificant for low-end manufacturing firms and even significantly negative for their TFP. The effect is more prominent under the instrumental variable model free from the endogeneity problem.

4.3 Mechanism Test for China's Manufacturing Exports' Effects on US Manufacturing Specialization

Based on the previous two sections, we believe that China's manufacturing exports spurred innovation among US manufacturing firms probably by increasing specialization and innovation among core US manufacturing firms. In the section, this paper tests the mechanism through which China's manufacturing exports contributed to the innovation outputs of core manufacturing firms in the US, and thus verify Hypotheses 2 and 3.

Given that R&D input is a key factor of firm innovation output (Scherer, 1965), the first step we took was to consider the impact of China's manufacturing exports on the R&D input of US manufacturing firms. Based on our theoretical analysis, we believe that export should have significantly heterogeneous effects on manufacturing firm R&D input across sectors. Results of grouped regression are shown in Table 8. China's manufacturing exports created significantly negative effects on the cumulative R&D input of low-end US manufacturing firms, and such negative effects appeared in the subsequent phase, reflecting the latter's vulnerabilities to export shocks. In the first three phases, exports had no significant impact on the cumulative R&D input of high-end US manufacturing firms, and only started to generate a slightly negative impact since the fourth phase. Low-end manufacturing firms curtailed R&D input much more than high-end firms did, reflecting the latter's strong resilience to external shocks. Hence, we conclude that the positive effects of China's manufacturing exports on the innovation output of high-end manufacturing firms in the US may have to do with the fact that exports did not cause high-end manufacturing firms to slash R&D spending.

Aside from R&D input, innovation output is also subject to the magnitude of such production factors as capital spending and human capital, which is generally stable in the short run. After controlling for the existing production factors, R&D input can be deemed as the most important factor of firm innovation

Table 8: Heterogeneous Effects of Export Shocks on R&D Input in Various Sectors

	Cumulative R&D input in the subsequent 1-5 years									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end
	Fixed-effect model									
us_ratio	-0.0830	-0.5051**	-0.3039	-1.0051**	-0.7803**	-1.5903**	-1.5729***	-2.0921**	-2.3060***	-2.5387**
	(-0.8025)	(-2.0724)	(-1.3971)	(-2.0247)	(-2.3038)	(-1.9962)	(-2.9848)	(-2.0348)	(-3.2019)	(-2.0161)
N	18,525	12,974	16,345	11,377	14,371	9,932	12,596	8,639	10,978	7,470
	Instrumental variable model									
us_ratio	0.1081	-1.4933***	0.0378	-3.1526***	-0.4380	-5.0166***	-1.3104*	-6.7914***	-1.9387**	-9.1914***
	(0.8370)	(-4.0338)	(0.1403)	(-4.1057)	(-1.0478)	(-4.1673)	(-1.9071)	(-3.9672)	(-2.0483)	(-3.8386)
Chi_sq P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wald F value	3.2e+04	5195.5230	2.6e+04	4179.6100	2.5e+04	3289.0410	2.4e+04	2478.8000	2.1e+04	1674.9490
N	18,324	12,819	16,142	11,230	14,188	9,802	12,411	8,499	10,813	7,338

Notes: ***, ** and * denote significance at 1%, 5% and 10%, respectively.
Source: Calculated by authors with Stata.

output. Yet in the long run, since the factors of production migrate between sectors, such migration will also influence firm innovation output. From the perspective of long-term resource allocation, we attempt to explain the positive effects of China's manufacturing exports on the long-term innovation output of high-end manufacturing firms in the US from the three pathways of employment, capital spending, and human capital and test the mediating effect. Given that low-end manufacturing is more vulnerable to competition from imports, we consider that while Chinese exports may cause US employment to shrink, such a negative impact is heterogeneous across sectors. Job losses, for instance, mainly occurred in less resilient low-end manufacturing sectors.Skilled workers laid off from low-end sectors are likely to migrate from low-end to high-end sectors, thus boosting R&D and innovation in high-end sectors. Similarly, the reduction of capital spending mainly occurred in low-end sectors while high-end sectors saw little reduction in capital spending. In the long run, capital spending in high-end sectors could increase.

Table 9 reports the heterogeneous effects of China's manufacturing exports on the factors of production in US manufacturing sectors. Chinese exports slashed jobs and human capital in low-end sectors, but increased jobs, capital spending and human capital in high-end sectors. Hypothesis 2 is thus verified. Specifically, the sectoral heterogeneous effects on employment appeared in phase 1, the sectoral heterogeneous effects on capital spending appeared in phase 3, and the sectoral heterogeneous effects on human capital appeared in phase 4. A possible reason is that due to "trapped factors", low-end manufacturing firms would initially maintain or increase capital spending and human capital to offset the impact before the migration of production factors occurs. According to our analysis, this could take about two or three years. Hence, we believe that high-end manufacturing firms in the US are likely to benefit from an increase in innovation output due to an influx of labor and especially capital spending and human capital.

Table 9: Heterogeneous Effects of Export Shocks on Production Factors in Various Sectors[9]

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end	High-end	Low-end
Sectoral employment in the subsequent 1-5 years										
us_ratio	0.1736***	-0.5099***	0.2110***	-0.3942***	0.2614***	-0.4338***	0.2405***	-1.1168***	0.3580***	-1.4475***
	(5.8353)	(-9.1280)	(5.9916)	(-8.9548)	(5.5964)	(-8.6885)	(3.3304)	(-6.5637)	(3.8618)	(-5.7706)
N	12,865	10,660	11,088	9,168	9,507	7,830	8,118	6,685	6,875	5,661
Cumulative capital spending in the subsequent 1-5 years										
us_ratio	0.0684	0.1777	0.2266	0.3688	0.5273*	0.5742	1.1570**	0.7650	2.4770**	0.6097
	(1.1646)	(1.5473)	(1.6271)	(1.2303)	(1.7810)	(1.0572)	(2.0500)	(1.0053)	(2.4403)	(0.8695)
N	12,814	10,628	10,974	9,076	9,338	7,685	7,900	6,503	6,640	5,441
Sectoral human capital in the subsequent 1-5 years										
us_ratio	0.0784***	0.0549***	0.1193***	0.0860***	0.1652***	0.1245***	0.1995***	-0.2521***	0.3246***	-0.3840***
	(5.2070)	(3.6130)	(6.7786)	(5.3465)	(6.7090)	(5.9012)	(5.4709)	(-3.5637)	(7.5685)	(-3.6052)
Chi_sq P value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wald F value	1.7e+04	2479.5080	1.2e+04	1608.9180	6892.6340	987.2460	3472.2020	559.6370	1768.7330	362.6420
N	12,865	10,660	11,088	9,168	9,507	7,830	8,118	6,685	6,875	5,661

Notes: ***, ** and * denote significance at 1%, 5% and 10%, respectively.

Source: Calculated by authors with Stata.

[9] Since the results of the effectiveness test of the instrumental variable for the three explained variables are the same, only one is listed here.

Tables 10 through 12 further tested and verified the above-mentioned mechanism of long-term innovation output growth for high-end manufacturing firms under the mediating effect. With a three-variable mediating effect model, this paper created regression equations of the explained variable on the explanatory variable, the mediating variable on explanatory variable, and the explained variable on the explanatory variable and mediating variable.[10] As shown by the test results in Tables 10 through 12, employment, capital spending and human capital all constituted mechanisms through which exports influenced innovation output in the US, but demonstrated heterogeneity with respect to different methods for measuring innovation output and during different periods of time. In the long run, the inflow of production factors boosted the innovation output of high-end manufacturing firms in the US. In addition, it took a long time for the migration of production factors to stimulate innovation. In most cases, employment,, capital spending and human capital did little to spur innovation output in high-end manufacturing sectors in phase 1, and the effect did not become manifest until around phase 3. Hence,

Table 10: Mechanism Test for the Effect of Export Shocks on Firm Patent Applications[11,12]

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Patent applications	Employment	Patent applications	Patent applications	Capital spending	Patent applications	Patent applications	Human capital	Patent applications
Cumulative patent applications in the subsequent 3 years									
us_ratio	3.6189*	0.2614***	3.4674*	3.6189*	0.5273*	3.3063*	3.6189*	0.1652***	3.3387*
	(1.8532)	(5.5964)	(1.7538)	(1.8532)	(1.7810)	(1.6513)	(1.8532)	(6.7090)	(1.7166)
Mediating variable			0.6279			0.6210***			1.7944*
			(0.6893)			(2.7400)			(1.6482)
N	8,170	9,507	8,170	8,170	9,338	8,090	8,170	9,507	8,170
Cumulative patent applications in the subsequent 4 years									
us_ratio	6.3925*	0.2405***	6.1599*	6.3925*	1.1570**	5.6615	6.3925*	0.1995***	5.9508*
	(1.7961)	(3.3304)	(1.7337)	(1.7961)	(2.0500)	(1.5569)	(1.7961)	(5.4709)	(1.6902)
Mediating variable			1.2752[13]			0.7130***			2.5848*
			(1.0447)			(3.4783)			(1.6798)
N	6,977	8,118	6,977	6,977	7,900	6,887	6,977	8,118	6,977
Cumulative patent applications in the subsequent 5 years									
us_ratio	11.1437*	0.3580***	10.8484*	11.1437*	2.4770**	9.3521	11.1437*	0.3246***	10.6208*
	(1.8164)	(3.8618)	(1.7514)	(1.8164)	(2.4403)	(1.5088)	(1.8164)	(7.5685)	(1.7325)
Mediating variable			1.0365			0.7803***			1.8219
			(0.6632)			(3.9789)			(0.9238)
N	5,904	6,875	5,904	5,904	6,640	5,817	5,904	6,875	5,904

Notes: ***, ** and * denote significance at 1%, 5% and 10%, respectively.
Source: Calculated by authors with Stata.

[10] When the impact of the explanatory variable is significant for the explained variable, the complete mediating effect exists if the coefficient of the explanatory variable in the second equation is significant, and the coefficient of the mediating variable in the third equation is significant while the coefficient of the explanatory variable is insignificant; the partial mediating effect exists if the coefficient of the explanatory variable in the second equation is significant while the coefficients of the mediating variable and explanatory variable are both significant; whether the mediating effect exists needs to be determined by performing a Sobel test if either the coefficient of the explanatory variable in the second equation or the coefficient of the mediating variable in the third equation is significant. Sobel statistic greater than the critical value (0.97) at 5% significance level suggests the existence of the mediating effect.

[11] Tables 11 through 13 have all controlled for the fixed effects of firm (sector) and time, and all instrumental variables have passed the effectiveness test.

[12] Since the impact of exports on patent applications did not appear until phase 3, we have only conducted the mediating effect tests in 3-5 years after export impact.

Table 11: Mechanism Test for the Impact of Export Shocks on Firm Patent Citations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Patent citations	Employment	Patent citations	Patent citations	Capital spending	Patent citations	Patent citations	Human capital	Patent citations
Cumulative patent citations in the subsequent 1 year									
us_ratio	2.3055**	0.2097***	2.3827**	2.3055**	0.1233**	2.2959**	2.3055**	0.1149***	2.2376**
	(2.4310)	(7.4373)	(2.4954)	(2.4310)	(2.3975)	(2.4255)	(2.4310)	(6.8099)	(2.3615)
Mediating variable			-0.3573			0.2312			0.5701
			(-0.5529)			(0.5231)			(0.6139)
N	10,973	12,865	10,973	10,973	12,814	10,931	10,973	12,865	10,973
Cumulative patent citations in the subsequent 2 years									
us_ratio	4.7723**	0.2308***	4.4770**	4.7723**	0.3380**	4.6815**	4.7723**	0.1307***	4.3185**
	(2.1496)	(6.6705)	(2.0241)	(2.1496)	(2.5530)	(2.0993)	(2.1496)	(6.2613)	(1.9733)
Mediating variable			1.2753			0.4109			3.4761*
			(0.9531)			(0.9435)			(1.8363)
N	9,504	11,088	9,504	9,504	10,974	9,439	9,504	11,088	9,504
Cumulative patent citations in the subsequent 3 years									
us_ratio	10.8690**	0.2554***	10.0112**	10.8690**	0.7066**	10.6144**	10.8690**	0.1602***	9.8177**
	(2.4722)	(5.3513)	(2.2999)	(2.4722)	(2.5389)	(2.3951)	(2.4722)	(5.5073)	(2.2746)
Mediating variable			3.6319*			0.4955[14]			7.0479**
			(1.7470)			(1.1148)			(2.3872)
N	8,170	9,507	8,170	8,170	9,338	8,090	8,170	9,507	8,170
Cumulative patent citations in the subsequent 4 years									
us_ratio	16.2619**	0.2300***	15.2462*	16.2619**	1.4039**	15.5126*	16.2619**	0.1968***	14.6974*
	(2.0219)	(3.1883)	(1.9235)	(2.0219)	(2.5726)	(1.9036)	(2.0219)	(4.9823)	(1.8641)
Mediating variable			5.7153**			0.6449[15]			9.2749**
			(1.9643)			(1.5813)			(2.1364)
N	6,977	8,118	6,977	6,977	7,900	6,887	6,977	8,118	6,977
Cumulative patent citations in the subsequent 5 years									
us_ratio	23.0819*	0.3086***	21.8836*	23.0819*	2.5249***	21.2559*	23.0819*	0.3085***	21.2018*
	(1.8143)	(3.4022)	(1.7179)	(1.8143)	(2.6824)	(1.6490)	(1.8143)	(7.0331)	(1.6748)
Mediating variable			5.0261[16]			0.7760**			6.9093[17]
			(1.3624)			(2.0795)			(1.2433)
N	5,904	6,875	5,904	5,904	6,640	5,817	5,904	6,875	5,904

Notes: ***, ** and * denote significance at 1%, 5% and 10%, respectively.
Source: Calculated by authors with Stata.

we estimate that it takes about three years for the factors of production to migrate between sectors. Hence, Hypothesis 3 is verified.

5. Conclusions and Policy Advice

Through theoretical and empirical analyses, this paper found that China's manufacturing exports helped rather than hurt core US manufacturing sectors by spurring innovation. In the face of competition from low-tech exports, high-end manufacturing sectors were more resilient and less likely to reduce R&D spending. Meanwhile, some factors of production such as labor, capital and human capital migrated to high-end manufacturing sectors, thus increasing the latter's R&D capabilities. By optimizing resource allocation, China's manufacturing exports spurred US manufacturing firms to innovate.

Table 12: Mechanism Test for the Impact of Export Shocks on Sectoral TFP

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	TFP	Employment	TFP	TFP	Capital spending	TFP	TFP	Human capital	TFP
Sector average TFP in the subsequent 1 year									
us_ratio	18.2306***	0.1912***	17.3487***	18.2306***	0.0798	18.2828***	18.2306***	0.0418**	18.3389***
	(8.8563)	(4.9591)	(8.3981)	(8.8563)	(1.1377)	(8.8961)	(8.8563)	(2.1764)	(8.8824)
Mediating variable			4.6122***			-0.6537			-2.5941
			(3.0910)			(-0.7962)			(-0.8648)
N	1,352	1,352	1,352	1,352	1,352	1,352	1,352	1,352	1,352
Sector average TFP in the subsequent 2 years									
us_ratio	15.5086***	0.1735***	14.4798***	15.5086***	0.1942**	15.3480***	15.5086***	0.0413**	15.4863***
	(7.7874)	(4.5492)	(7.2800)	(7.7874)	(2.3978)	(7.7245)	(7.7874)	(2.1455)	(7.7615)
Mediating variable			5.9296***			0.8272[18]			0.5394
			(3.9709)			(1.1705)			(0.1816)
N	1,284	1,284	1,284	1,284	1,284	1,284	1,284	1,284	1,284
Sector average TFP in the subsequent 3 years									
us_ratio	12.3182***	0.1528***	11.2408***	12.3182***	0.2589***	11.8872***	12.3182***	0.0430**	12.1873***
	(6.2220)	(3.9554)	(5.7007)	(6.2220)	(2.8497)	(6.0298)	(6.2220)	(2.1892)	(6.1518)
Mediating variable			7.0516***			1.6650***			3.0470
			(4.6930)			(2.5886)			(1.0227)
N	1,216	1,216	1,216	1,216	1,216	1,216	1,216	1,216	1,216
Sector average TFP in the subsequent 4 years									
us_ratio	8.2903***	0.1388***	7.1702***	8.2903***	0.3585***	7.5522***	8.2903***	0.0458**	8.0499***
	(4.0637)	(3.4933)	(3.5341)	(4.0637)	(3.4884)	(3.7188)	(4.0637)	(2.3039)	(3.9435)
Mediating variable			8.0679***			2.0590***			5.2495*
			(5.2118)			(3.4117)			(1.6803)
N	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148	1,148
Sector average TFP in the subsequent 5 years TFP									
us_ratio	5.3392**	0.1516***	4.0865*	5.3392**	0.4376***	4.3683**	5.3392**	0.0615***	4.9303**
	(2.5445)	(3.6631)	(1.9532)	(2.5445)	(3.8202)	(2.0840)	(2.5445)	(3.0611)	(2.3446)
Mediating variable			8.2640***			2.2189***			6.6455**
			(5.2267)			(3.8612)			(2.0222)
N	1,080	1,080	1,080	1,080	1,080	1,080	1,080	1,080	1,080

Notes: ***, ** and * denote significance at 1%, 5% and 10%, respectively.
Source: Calculated by authors with Stata.

At the policy level, China must strive to develop core technologies for manufacturing sectors. Despite hefty R&D spending and numerous patent applications, China remains far less innovative compared with developed countries. China's manufacturing sectors are highly dependent on imports from developed countries, and mainly export low-end products. In the fourth global industrial relocation led by Southeast Asian countries, China must develop core technologies on a par with the US and create a complete domestic supply chain to stay competitive.

Over the years, China's robust export and economic growth has been driven chiefly by inter-industry upgrade strategy. Yet within each sector, progress towards higher value addition has been slow. Unlike

[13-18] The mediating effect is significant in sobel test.

the United States, China has been locked up at the bottom of the "smile curve." Going forward, China should emulate the US by moving from low-end activities such as the processing of primary goods and the manufacturing and assembly of parts and components to both ends of the smile curve, including R&D, design and core components at the upstream and marketing and branding at the downstream. China should take steps to replace low-value manufacturing goods with high-value ones to complete its manufacturing transition.

Based on its evolving comparative advantages, China should identify new dominant industries. As China's demographic dividends diminish, weakening labor cost advantage will put a break on low-end manufacturing. To avoid the comparative advantage trap, China must pursue a technology-driven growth path and foster new dominant industries in tandem with evolving comparative advantages through the implementation of selective trade and industrial policies.

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