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The Impact of Imports, Technological Progress and Domestic Demand on the Growth of and Structural Changes in China's Steel Industry

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Abstract

The Chinese steel industry had a very small presence in the world until the early 1980s; however, in 2018, it became the number one producer and consumer of crude steel, occupying half of the world totals.
Why has China's steel industry grown so rapidly over such a short period? To explore the answer to this question, in this paper, we first constructed a comparative statics model. Then, we theoretically discussed how the supply and price volatility of raw materials, trade relations between countries, technological progress and demand for final goods impacted the production and trade of intermediate goods and the production of final goods, adopting the perspective of the vertical division of labor.
Based on the theoretical analysis, we focused on the Chinese steel industry and collated panel data by steel product to demonstrate how various factors (the price of iron ore, the domestic demand for final goods, the technological progress of the steel industry, accession to the WTO and the triggering of anti-dumping measures) affected imports from Japan and South Korea and the domestic production of steel products. We further estimated how these factors impacted the production of final goods that are closely related to steel products in China. The following results were obtained. First, although the rapid growth of China's steel industry is due to the improvement in its steel production technology, the effect of iron ore prices and imports from Japan and South Korea, the domestic demand for final goods has the greatest impact. In addition, these factors affect the production of different steel-related final goods differently. From this point of view, China's steel industry has not only expanded in scale but has also undergone significant structural changes.

Keywords: Vertically related markets, trade, iron-steel industry,
JEL Classification: F12, F14, L61, O13, O53

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1. Introduction

Since the industrial revolution, the steel industry in most developed countries has grown along with the national economy. In this sense, the analysis of the growth process of a country's iron and steel industry would promote understanding of characteristics of the country's economic growth. China is no exception; the steel industry has grown significantly in line with economic growth since the reform and opening-up that began in 1978.

In 1980, the world's total crude steel production was 715.6 million tons[1], and China (excluding Taiwan and Hong Kong) produced 157.1 million tons, accounting for approximately 22% of the world total. In addition, although the production of iron ore in China (112.58 million tons) accounted for as much as 12% of the world's total production (931.34 million tons), the iron content of the iron ore mined domestically was very poor, and the smelting technology for crude steel was not highly developed[2].

On the other hand, looking at the final consumption of finished steel products (apparent steel use), the total global consumption was 5.76 million tons, while the consumption of China was 33.68 million tons, accounting for only 6% of the world total. Additionally, looking at the export volume of steel products, China exported just 398 thousand tons, which was negligible as a percentage of the world's total export volume (140.72 million tons); for imports, China imported 5.01 million tons, which was 3.5% of the world total (141.21 million tons).

As indicated in the statistics above, the Chinese steel industry had a very small presence in the world until the early 1980s; however, by 2018, it had become the number one producer and consumer of crude steel, occupying half of the world totals. Moreover, its iron ore imports came to represent half of the world's production, and it exported a quarter of the world's production. China has become a superlarge steel-producing country.

Turning to the perspective of the East Asian region, after the end of World War II, Japan's steel industry grew significantly with the country's rapid economic growth, and in the 1970s, its production reached the top level in the world. Since then, however, production has been declining, and as of 2018, although production remained at a level of 100 million tons, it equaled only approximately one-ninth of China's production. However, continuous casting technology, which dramatically reduces costs through technological

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1 Unless otherwise noted, all statistics presented in this paper are adapted or calculated based on data from the World Steel Yearbook for each year.

2 The average Fe content of China's iron ore is only approximately 30%.

innovation, was adopted in Japan at the fastest pace in the world, and the resulting high-strength steel sheets made a significant contribution to the lightweighting of automobiles. The Korean steel industry also grew significantly from the 1980s to the 1990s in line with economic growth, and Korea has become a top steel producer in terms of both production scale and productivity.

Although it initially lagged behind the Japanese and South Korean industry, China's steel industry has grown rapidly since the mid-1980s, surpassing Japan in crude steel production to become the top producer in 1996. However, its production scale and productivity improved significantly only when the automotive and railway industries in China began to grow rapidly after 2000.

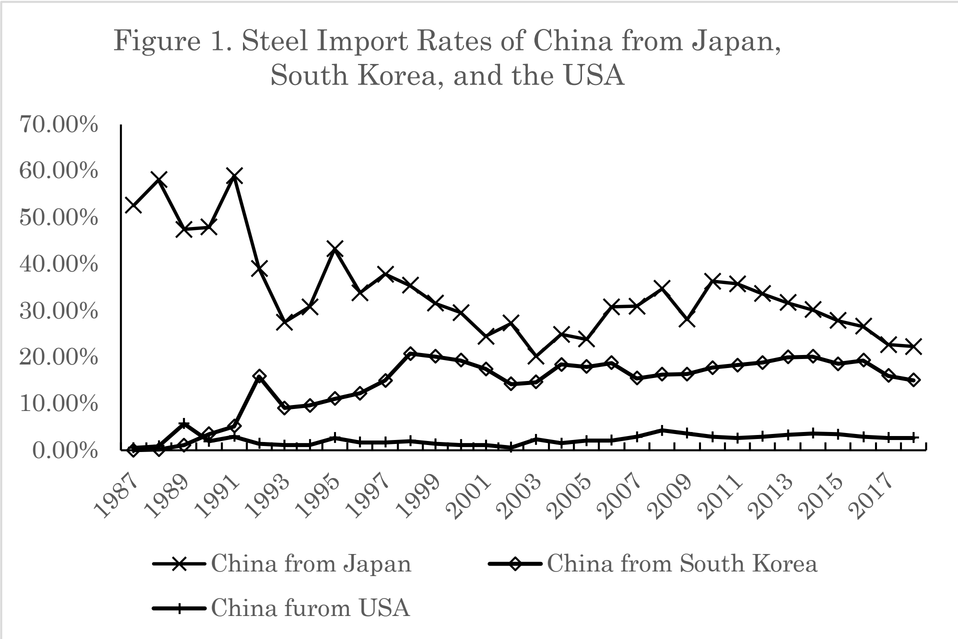
While the steel industries of the three East Asian countries have grown along with the countries' own economies, these countries currently hold the most important position in the world's steel industry, and the trade in steel products among them has become increasingly close.

In China, imports of steel products were mostly from Japan until the late 1980s, accounting for 60% of China's total imports. Since 2000, the amount of imports from Japan has been declining, and it currently stands at 20%, while imports from South Korea have gradually increased to approximately 20% of the total (see Figure 1 and 2).

The above facts suggest that the growth of China's steel industry has been largely driven by the expansion of demand due to domestic economic growth since 2000 but has also been influenced by the trade relations with Japan and South Korea. In addition, China's steel industry has shifted from emphasizing scale expansion to promoting structural change.

Steel products are a typical noncompetitive intermediate product. For analysis, we use a vertically related market model introduced by Bernhofen (1995), who showed that the price dumping of an intermediate good arises from technological differences in final good production. Recently, Kuo, Ping-Shin el al. (2016) analyzed the effects of not only antidumping duty but also price policies using a modified version of Bernhofen's model. We use a model similar to Kuo, but we assume that an upstream firm uses different technology for intermediate production.

Accordingly, there is a need to elucidate the mechanisms involved in the process of such growth, and the understanding of these mechanisms will contribute to understanding of the growth of the overall economy in China. Considering the above issues, this paper seeks to describe the mechanisms by analyzing the impact of factors such as global iron ore price fluctuations, technological progress in China's domestic steel production, changes in the demand for final goods, and changes in the trade relations with Japan and South Korea on the growth of China's steel industry.



(Source: UN Comtrade Database)

(Source: UN Comtrade Database)

2. Literature review

Movshuk (2004) used a stochastic frontier model with panel data to evaluate the impact of major reform initiatives on enterprise performance in China's iron and steel industry and obtained the following conclusions: while the production possibility frontier of the examined enterprises was shifting upward, their technical efficiency did not improve significantly and was even deteriorating in the mid-1990s. Moreover, the largest steel enterprises did not have a pronounced efficiency advantage over smaller enterprises, even though the Chinese authorities considers the former to be the core of ongoing centralized merger campaigns to create internationally competitive steel conglomerates.

Hernandez et al. (2018) analyzed the most recent and most comprehensive data on the global steel industry and quantified the savings associated with energy- and material-saving measures. They reported that a global shift from average ore-based production to the best available operation methods could save up to 6.4 EJ/year in 2010.

Li et al. (2018) analyzed the material and value flows of iron-containing commodities between China and other countries worldwide and revealed several facts. First, during the period from 2010 to 2016, the total amounts of iron materials imported to and exported from China increased by 224 million tons and 81 million tons, respectively. Second, 90% of the iron material imported by China consisted of iron ore and was imported from Australia and Brazil. More than 98% of the iron material exported from China consisted of rolled steel and IEPs (mainly engineering machinery and land vehicles) and was exported to Japan, South Korea, and the United States. Third, China had an international iron trade surplus, which increased from 31 billion USD in 2010 to 272 billion USD in 2016 at an average annual growth rate of 130%.

Sui et al. (2019) focused on steel products in different stages of the industrial chain. They revealed various features of price transmission, calculated the Granger causality relationship between different steel products in different markets and in the midstream industry chain, and analyzed the network indicators. First, emerging economies play a major role in international steel product price transmission. Second, billets and plates of middle thickness are the components with the greatest price transmission in the steel market. Third, China imposes the broadest price transmission impacts in most regions. Last, steel products at the end of the midstream steel industrial chain are "bridges" of price transmission activities.

However, previous studies, including those described above, have not analyzed the impact of global iron ore price fluctuations and technological advances in the steel industry on the production of steel products. This study will focus on these factors.

3. Theoretical model

Building on Kuo, Ping-Shin el al. (2016), we use the following theoretical model. There are two countries, Country 1 and Country 2, and each has an upstream firm and a downstream firm. Each upstream firm produces an identical intermediate good using a primary good imported from a world primary good market at a given price p_w. The upstream firm of Country 1 uses k units of the primary good to produce one unit of the intermediate good. On the other hand, the upstream firm of Country 2 uses one unit of the primary good to produce one unit of the intermediate good. Therefore, except for the case of $k = 1$, the production technologies of the upstream firms are different. If $k < 1$, then the upstream firm of Country 1 has a higher production technology than another firm, and vice versa. We assume that the upstream firm of Country 1 produces only for the domestic intermediate good market, but the upstream firm of Country 2 produces for both intermediate good markets. We assume that both upstream firms compete in Cournot fashion in the intermediate good market of Country 1. The profit functions of the upstream firms are as follows:

$$\pi_1 = (w_1 - kp_w)z_{11}, \quad (1)$$
$$\pi_2 = (w_1 - p_w)z_{21} + (w_2 - p_w)z_{22}, \quad (2)$$

where w_1 and w_2 are the prices of the intermediate good in Countries 1 and 2, z_{11} is the production of the intermediate good of the upstream firm in Country 1, and z_{21} and z_{22} represent the production of the upstream firm in Country 2 for each market.

For the final good, we assume that each country has one downstream firm that uses one unit of the intermediate good to produce one unit of an identical final good. Thus, there is no difference in production technology. Both downstream firms produce final goods only for the final good market in Country 1, and they compete in Cournot fashion. Thus, the downstream firm of Country 2 exports all production to Country 1. The linear inverse demand function of the final good in Country 1 is

$$p_1 = a - b(x_{11} + y_{21}), \quad (3)$$

where p_1 is the price of the final good, a is the consumers' highest willingness to pay, $b \in [0,1]$ is a constant slope of the inverse demand function in Country 1, and x_{11} and y_{21} represent the production of the downstream firm of Country 1 and Country 2, respectively.

The profit functions of the downstream firms are as follows:

$$\Pi_1 = (p_1 - w_1)x_{11}, \tag{4}$$
$$\Pi_2 = (p_1 - w_2)y_{21}, \tag{5}$$

where $x_{11} = z_{11} + z_{21}$, and $y_{21} = z_{22}$.

We assume there is a two-stage game: in the first stage, both upstream firms simultaneously choose their optimal output in the intermediate good markets, and in the second stage, both downstream firms simultaneously choose their output in the final good market. Hence, the subgame perfect Nash equilibrium is solved through backward induction.

In the second stage, the first-order conditions for profit maximizations of the downstream firms are:

$$\frac{\partial \Pi_1}{\partial x_{11}} = a - b(2x_{11} + y_{21}) - w_1 = 0, \tag{6}$$

$$\frac{\partial \Pi_2}{\partial y_{21}} = a - b(x_{11} + 2y_{21}) - w_2 = 0. \tag{7}$$

From these, we have solutions for the final good market in country 1:

$$\begin{bmatrix} x_{11} \\ y_{21} \end{bmatrix} = \frac{1}{3b} \begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix} \begin{bmatrix} a - w_1 \\ a - w_2 \end{bmatrix}. \tag{8}$$

Thus, considering $x_{11} = z_{11} + z_{21}$ and $y_{21} = z_{22}$, we have the inverse demand functions for intermediate goods:

$$\begin{bmatrix} w_1 \\ w_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} a - 3b(z_{11} + z_{21}) \\ a - 3bz_{22} \end{bmatrix}. \tag{9}$$

In the first stage, the first-order conditions for the profit maximizations of the upstream firms are

$$\frac{\partial \pi_1}{\partial z_{11}} = a - 2b(2z_{11} + z_{21}) - bz_{22} - kp_w = 0, \tag{10}$$

$$\frac{\partial \pi_2}{\partial z_{21}} = a - 2b(z_{11} + 4bz_{21}) - 2bz_{22} - p_w = 0, \tag{11}$$

$$\frac{\partial \pi_2}{\partial z_{22}} = a - \ b(z_{11} + 2z_{21}) - 4bz_{22} - p_w = 0. \tag{12}$$

Thus, we have the equilibrium production of the intermediate good:

$$\begin{bmatrix} z_{11} \\ z_{21} \\ z_{22} \end{bmatrix} = \frac{1}{12b}\begin{bmatrix} 2a - 2(2k-1)p_w \\ a + (2k-3)p_w \\ 2a - 2p_w \end{bmatrix}. \tag{13}$$

Then, considering $x_{11} = z_{11} + z_{21}$ and $y_{21} = z_{22}$, we have the equilibrium production of the final good:

$$x_{11} = \frac{1}{12b}\{3a - (2k+1)p_w\}, \tag{14}$$

$$y_{21} = \frac{1}{6b}(a - p_w), \tag{15}$$

and the equilibrium price of the final goods:

$$p_1 = \frac{1}{12}\{7a + (2k+3)p_w\}. \tag{16}$$

From equations (9) and (13), we have the equilibrium prices of the intermediate good:

$$w_1 = \frac{1}{2}\{a + (1+k)p_w\}, \tag{17}$$

$$w_2 = \frac{1}{12}\{5a + (5+2k)p_w\}\,. \tag{18}$$

Using the above equilibrium variables, we can summarize the results of comparative statics in Table 1.

Table 1. The results of comparative statics

	dp_w	dk	da
dw_1	$\frac{1+k}{2} > 0$	$\frac{1}{2}p_w > 0$	$\frac{1}{2} > 0$
dw_2	$\frac{5+2k}{12} > 0$	$\frac{1}{6}p_w > 0$	$\frac{5}{12} > 0$
dp_1	$\frac{2k+3}{6} > 0$	$\frac{1}{6}p_w > 0$	$\frac{7}{12} > 0$
dz_{11}	$\frac{1-2k}{6b}$	$-\frac{1}{3b}p_w < 0$	$\frac{1}{6b} > 0$
dz_{21}	$\frac{2k-3}{12b}$	$\frac{1}{6b}p_w > 0$	$\frac{1}{12b} > 0$
dz_{22}	$-\frac{1}{6b} < 0$	no effect	$\frac{1}{2b} > 0$
dx_{11}	$-\frac{2k+1}{12b} < 0$	$-\frac{1}{6b}p_w < 0$	$\frac{1}{4b} > 0$
dy_{21}	$-\frac{1}{6b} < 0$	no effect	$\frac{5}{12b} > 0$

First, the effects of an exogenous positive change in p_w are dependent on the level of k in dz_{11} and dz_{21}. For $0 < k < \frac{1}{2}$, $dz_{11} > 0$ and $dz_{21} < 0$. Therefore, if the upstream company of Country 1 has production technology that is more than two times superior to than that of Country 2, then for $dp_w > 0$, the production of intermediate goods in Country 1 is increased and that in Country 2 is decreased. Similarly, for $\frac{1}{2} \le k \le \frac{3}{2}$, $dz_{11} \le 0$ and $dz_{21} \le 0$. Additionally, for $\frac{3}{2} < k$, $dz_{11} < 0$ and $dz_{21} > 0$, which shows that if the upstream company of Country 1 has production technology that is more than 1.5 times inferior to that of Country 2, then for $dp_w > 0$, the production of intermediate goods in Country 1 is decreased and that in Country 2 is increased. Thus, we can see that the increase in the price of the primary good does not always decrease the production of the intermediate good in both countries under the duopoly in the market for the intermediate good and that a given level of technological difference increases the production of the upstream firm with high technology.

Second, an exogenous negative change in dk, which indicates an increase in the technological level of the upstream firm in Country 1, increases the production of the final good in Country 1 through the increase in the demand of the downstream firm in Country 1; however, it does not change the production of the upstream firm in Country 2 for the domestic downstream firm, z_{22}, because the intermediate good markets are segmented under the assumptions made in this paper.

Third, the exogenous positive change in a, which indicates an increase in the demand for the final product in Country 1, positively affects all endogenous variables in Table 1.

Since the purpose of this paper is to analyze the factors affecting the steel industry and the final goods industry related to steel products in China, we will focus on only results related to the first country in the variables analyzed by the theoretical model. Specifically, we will examine the effects of the change in the world iron ore price (pw), the demand change for final goods in China (a), and the technological progress of steel production of China (k) on the import price (w21) and the quantity (z21) of steel products from other countries, the production of steel products (z11), and the production (x11) of the final goods related to steel products in China.

4. Empirical analysis

4. 1 The focus and data resources

The data used for the estimation were obtained from the following sources. First, the data for imports of iron ore and all steel products from other countries to China were obtained from the UN Comtrade database and based on the classification of SITC Rev.2. Second, the data for the production of iron ore and all steel products and final products related to steel in China were obtained from the China Industry Statistical Yearbook, and the world price data of iron ore were from World Bank Commodity Price Data (The Pink Sheet). Third, data about the production of iron ore and crude steel in each country exporting steel products to China were obtained from the World Steel Yearbook for each year from 1990 to 2018. Therefore, the data of the demand for final goods in the Chinese market were used as the data of final consumption from the China Statistical Yearbooks. We matched the steel product data published in the China Industrial Statistics Yearbook and the data of UN Comtrade to obtain panel data on the steel products.

The codes, names and definitions of each steel product are shown in the table 2.

Additionally, the import prices of the iron ore and steel products exported from Japan, South Korea and the United States to China were divided by the respective import amounts to calculate the price of exports from each country to China.

Table 2. Name, code and definition of steel products based on the CTD and CISY

Name of steel products	Code and description in the SITC Rev.2	Name and definition in CISY
Iron ore	281, Iron ore and concentrates	Iron Ore
Pig iron	671, Pig and sponge iron, spiegeleisen, etc., and ferro-alloys	Pig iron
Ingots	672, Ingots and other primary forms of iron or steel	Ingots
Wire rods	6731, Wire rod of iron or steel	Wire rods
Light sections	67331, U, I, H sections, hot-rolled (not high carbon, alloy), of less than 80 mm	Light sections (<80 mm)
Heavy sections	67332, U, I, H sections, hot-rolled (not high carbon, alloy), of 80 mm or more	Heavy sections (>80 mm)
Plates and sheets	6744, Sheet, plates, rolled of thickness 4.75 mm or more, of iron or steel 6745, Sheet, plates, rolled of thickness 3 mm to 4.75 mm, of iron or steel 6746, Sheet, plates, rolled of thickness less 3 mm, of iron or steel	Heavy plate, medium plate and sheet
Railway tracks	676, Rails and railway track construction materials, of iron or steel	Railway tracks
Tubes	678, Tubes, pipes and fittings of iron or steel	Tubes and fittings

Furthermore, according to the theoretical model, if China's technology for producing steel from iron ore is more advanced than that of exporting countries, steel product imports will decrease, and production will increase. Specifically, if the amount of iron ore used to produce 1 unit of crude steel in a country that exports steel products to China is one, and the respective figure in China is k, k is the relative productivity of China compared with the exporting country. In this case, if k is greater than 1, China will increase its production of steel products instead of increasing imports, while if k is less than 1, China will increase imports instead of increasing its domestic production of steel products. Therefore, to analyze the impact of the relative productivity of Chinese steel products, we set k to be a ratio of the amounts of iron ore needed to produce one unit of crude steel between China and a country that exports steel products to China.

However, there are two types of crude steel production processes. One is a process of melting iron ore, coke and limestone in a blast furnace, and the other is a process of melting iron scrap in an electric furnace. We will use data that express the relative productivity of producing crude steel in blast furnaces because more than 90% of the crude steel in China is produced in blast furnaces. Specifically, we use the ratio as a proxy for China's technological progress (k), which indicates the total amount of iron ore (produced domestically or imported) needed to produce one unit of crude steel through oxygen-blown converters in China divided by the respective amount in the country exporting steel products to China in year t.

The data of crude steel production and iron ore production in each country were obtained from the World Steel Yearbook for each year from 1990 to 2017, and the yearly import amounts of iron ore were obtained from UN Comtrade.

In addition, China's accession to the WTO effective from 2002 is expected to have a significant impact on the steel industry and the industries engaged in the production of steel-related final goods. Therefore, we set a dummy variable for the years after 2002 to measure the effect of the WTO accession. The United States and other OECD countries implemented anti-dumping measures against China's steel production in 2015, with a resulting impact on China's steel production since 2016. Therefore, we also introduce a dummy variable for the years after 2016 to represent the effect of the anti-dumping measures.

As an explained variable, first, the import price of steel products from other countries to China is calculated by dividing the total value of China's imports from a given country by the import quantity. Second, the production of other countries for the Chinese market (z21) is determined according to the amount China imports from each country.

In addition, because steel products are widely used in many industries and there are a large number of related final goods, in this paper, we will use the data of the steel-related final goods with a relatively high proportion of steel products in the total products.

Because the purpose of this paper is not only to verify the theoretical model but also to analyze the impact on Chinese steel products of Japan and South Korea, which are in the same East Asian region and have close trade relations with China, in the next section, we will focus on Japan and South Korea and estimate their respective impacts using the panel data above.

4.2 Analysis of the impact of the import prices (w1) from Japan and South Korea

The theoretical analysis suggests that the export price must be at least equal to the price in the steel product market of the target country when one country exports a steel product to another country's market. The price is positively influenced by the price of iron ore, the technical level of steel production and the demand for final goods in the target country.

Therefore, the estimation formula could be set based on equation (16), which shows the result of the theoretical analysis.

$$Ln(exw)_t \quad = c_1 + \alpha_1 p_{wt} + \beta_1 a_t + \gamma_1 k_t + \sigma_1(WTOd) + \tau_1(ADd) + \mu_t \qquad (19)$$

In the above formula, Ln (exw) is the logarithm of the export price of steel products from Japan and South Korea to China, and P is the world price of iron ore. k is the productivity of crude steel in China relative to Japan and South Korea. Additionally, WTOd represents a dummy variable for China's accession to the WTO, and ADd represents a dummy variable for the anti-dumping measures against China.

Before conducting the estimation, we first tested for the existence of unit roots in the data on import prices from Japan and South Korea. Since no unit root was found, we adopted a linear model for estimation. To avoid an endogeneity problem associated with the iron ore price, we introduced a one-year lag of world iron ore production as an instrumental variable. After estimation, we performed Hausman's test on the result, and the estimation result for the random effects model was adopted. The estimation results are shown in Table 3.

Table 3. Estimation results of the impact on the import price of steel products from Japan and South Korea

Variable	Japan	South Korea
World iron ore price (pw)	0.0067***	0.0081***
	3.098	4.077
Final consumption (a)	0.0003***	0.0002**
	3.406	2.379
Crude steel productivity (kc)	0.0017	0.1112**
	0.025	2.047
WTO dummy	-0.3103*	0.0544
	-1.780	0.317
AD dummy	0.4161	0.1987
	1.639	0.825
Const.	6.0360***	5.5514***
	23.947	24.170
Number of obs	165	162
Wald Chi2	152.58	174.805
sigma_u	0.3667	0.3199
Sigma_e	0.3667	0.3199
Rho	0.4191	0.3694
Hausman test p-value	0.9999	0.9980
	RE	RE

Legend: * p<.1; ** p<.05; *** p<.01

The following estimation results were obtained. First, the coefficients for the world iron ore prices, the demand for final goods in China, and the relative productivity of crude steel in China are all positive, and all values are significant except for the productivity of crude steel in China relative to Japan.

Therefore, the estimation results for the import prices from Japan and South Korea almost match the results in the theoretical model.

In addition, the coefficient of the WTO dummy is significant and negative in the estimation for Japan. It can be seen that the import price of steel products from Japan was reduced after China entered the WTO.

4.3 Analysis of the impact on the import quantity (z21) from Japan and South Korea

According to the theoretical analysis, the quantity of steel products (export quantity) provided by steel producers of one country in the markets of the target country is positively impacted by the steel production technology and the demand for final goods in the target country. On the other hand, the impact of iron ore prices depends on the technical level of steel production in the target country (Eq. (13)).

Therefore, based on equation (13), which shows the results of the theoretical analysis, the estimation formula could be set as follows:

$$Ln(exz)_t = c_2 + \alpha_2 p_{wt} + \beta_2 a_t + \gamma_2 k_t + \sigma_2(WTOd) + \tau_2(ADd) + \mu_t \quad (20)$$

In the above formula, ln (exz) represents the logarithm of the amount imported from other countries, and the definitions of the other variables are the same as in the estimation formula (19).

We tested for the existence of unit roots in the panel data for the import quantities from Japan and South Korea before estimation. Since the result indicated the existence of a unit root, we used the dynamic panel model with a one-year lag for the explained variable and all explanatory variables to estimate the panel data. To avoid an endogeneity problem with the explanatory variables, we introduced the one-year lag of world iron ore production as an instrumental variable in the estimation model. We ran the Sargan test on the estimated result to confirm that there was no overidentification problem. The results are shown in Table 4.

In this estimation, the following results were obtained. First, the coefficient value of the import amount of the previous year is significant and positive, so the import quantity of the current year largely depends on the import quantity of the previous year. Second, regarding the coefficient of the world price of iron ore, no significant result is obtained for the previous year or the current year. In addition, the coefficient for the demand for final goods in China is significant in both the previous year and the current year, but the former is positive, and the latter is negative. Furthermore, the coefficient for the relative productivity of crude steel is not significant in either the previous year or the current year for Japan, while the coefficient in the estimation for South Korea is significantly negative in the previous year but significant and positive in the current year. Finally, the WTO dummy is significant and positive in the estimation for Japan, but the AD dummy is significant and negative in the estimation for South Korea.

From this result, we first learn that theoretical analysis using the comparative static model does not always accurately reflect reality, which entails dynamic changes. The following can be said from the estimation results of the dynamic model.

First, fluctuations in the world price of iron ore did not affect the import of steel products from Japan and South Korea. Second, imports of steel products increased due to the increase in the demand for final goods in the previous year and, conversely, decreased due to the increase in the demand in the current year. Third, the imports from Japan and South Korea are decreasing due to the improvement in the relative productivity of crude steel in China. Moreover, China's accession to the WTO increased the imports of steel products from Japan but did not affect China’s imports from South Korea. On the other hand, the launch of anti-dumping measures reduced the imports from South Korea.

Considering the above estimation results, steel products imported from Japan would be considered complementary goods that are not produced in China, but those imported from South Korea would be substitutes for goods that are produced in China.

Table 4. Estimation results of the impact on the import quantity of steel products from Japan and South Korea

Variable	Japan	South Korea
Import qty (-1)	0.4389***	0.3571***
	8.567	2.703
World iron ore price (pw) (-1)	0.0011	0.00004
	0.243	0.006
World iron ore price (pw)	-0.0010	-0.0048
	-0.281	-0.696
Final consumption (a) (-1)	0.0040*	0.0035*
	1.890	1.735
Final consumption (a)	-0.0041*	-0.0035*
	-1.953	-1.958
Crude steel productivity (kc) (-1)	-0.5973	-1.1682***
	-1.174	-2.789
Crude steel productivity (kc)	0.8125	0.9752***
	1.577	2.702
WTO dummy	0.7521**	0.4200
	2.402	0.668
AD dummy	-0.2160	-0.6973*
	-0.563	-1.887
Const.	1.9279***	3.1661***
	2.667	3.213
N	153	151
Wald Chi2	833.47	52408.78
Arellano-Bond test AR(1) P-value	0.0556	0.0990
Arellano-Bond test AR(2) P-value	0.1892	0.0452
Arellano-Bond test AR(3) P-value		0.3425
Sargan test p-value	0.1089	0.2568

Legend: * p<.1; ** p<.05; *** p<.01

4.4 The analysis of the effects on the production of Chinese steel products

According to the theoretical analysis, the production of steel products in China has a negative effect on the productivity relative to the exporting country but a positive effect on the domestic demand.

On the other hand, the influence of the world price of iron ore depends on the relative production of steel products, and if $0 < k \leq \frac{1}{2}$, the influence is negative or zero, but when $k > \frac{1}{2}$, it is positive (Eq. (13)).

Based on equation (13), the estimation formula could be set as follows:

$$Ln(prz)_t \quad = c_3 + \alpha_3 p_{wt} + \beta_3 a_t + \gamma_3 k_t + \sigma_3(WTOd) + \tau_3(ADd) + \mu_t \quad (21)$$

In the above formula, ln (prz) represents the logarithm of the production volume of Chinese steel products, and the definition of the explanatory variable is the same as in formula (19).

Before estimation, we first conducted the unit root test on the data for the production of Chinese steel products, and the existence of a unit root was not confirmed. Therefore, we used a linear model for the estimation.

In addition, to avoid an endogeneity problem associated with the world iron ore price, we introduced a one-year lag of global iron ore production as an instrumental variable.

Furthermore, import prices from other countries are thought to have an impact on domestic production. Therefore, this was also added to the estimation formula as a control variable. Based on the results of the Hausman test, the fixed effects model was adopted for the estimation for Japan, while the random effects model was adopted for the estimation for South Korea.

The following results were obtained in the estimations. First, the coefficients of the world price of iron ore are not significant, but both are positive. The demand for final goods and the relative productivity of crude steel in China are significant and positive. This result is almost consistent with the expectations of the theoretical analysis. Furthermore, in the estimation results for Japan, the coefficient of the import price of steel products from Japan is significantly negative.

These results suggest the following. The increase in the production of steel products is greatly affected by the increase in the demand for final goods and the improvement in the relative productivity of crude steel in China. High import prices of steel products from Japan also led to increased production in China. Furthermore, it seems that China's accession to the WTO from 2002 and the launch of anti-dumping measures from 2016 have had little impact on China's steel production.

Table 5. Estimation results for steel product production in China

Variable	Japan	South Korea
World iron ore price (pw)	0.0011	0.0006
	0.598	0.263
Final consumption (a)	0.0005***	0.0005***
	7.101	7.784
Crude steel productivity (kc)	-0.1828***	-0.165***
	-3.476	-3.681
Import price (ln)	0.1601**	0.1241
	2.199	1.384
WTO dummy	0.1271	0.057
	0.905	0.402
AD dummy	-0.3227	-0.3258
	-1.500	-1.497
Const.	8.4241***	8.6827***
	12.096	13.817
Number of obs	162	159
Sigma_u	1.2484	0.8080
Sigma_e	1.2484	0.8080
Rho	0.9326	0.8539
Wald Chi2	604.00	578.06
Hausman test p-value	1.000	0.9998
	RE	RE

Legend: * p<.1; ** p<.05; *** p<.01

4.5 Analysis of the influence of the production and import of steel products on final goods production in China

The theoretical analysis suggests that the production of steel-related final goods in China is negatively influenced by the world price of iron ore and the relative productivity of steel products in China compared to the countries it imports from but positively influenced by the demand for final goods in China. Based on the above results and equation (14), the estimation formula can be set as follows.

$$Ln(fgx)_{mt} = c_4 + \alpha_4 p_{wt} + \beta_4 a_t + \gamma_4 k_t + \delta_4 \ln(exz)_t + \theta_4 \ln(prz)_t + \sigma_4(WTOd) + \tau_4(ADd) + \mu_t \quad (22)$$

Note that FGX in the above formula represents the logarithm of the production of steel-related final goods (m) in China. The definition of the other variables is the same as in estimation formula ( ).

Before conducting the estimation, we first tested for a unit root in the data for the production of steel products in China. Because no unit roots were present, a linear model was selected. To avoid an endogeneity problem with the world iron ore price, a one-year lag in world iron ore production was introduced as an instrumental variable.

We also added the estimated values of China's production of each steel product and imports from other countries, the dummy variable for membership in the WTO (WTOd), and the dummy variable for anti-dumping (ADd) as control variables. The estimated results for the two countries are reported in Table ( ) and Table ( ). Note that the table shows the values of the estimates adopted according to the results of the Hausman test for individual cases.

First, regarding the impact of changes in world iron ore prices, the estimates for Japan and South Korea are similar, and all are significant. It should be noted that the coefficient for the production of railway tracks is negative, while the coefficients for the other final goods are positive. The analysis of the theoretical model, however, suggests that the world price of iron ore has a negative impact on the production of final goods related to steel products. Thus, the estimated results for the other final goods, excluding railway tracks, are contrary to the theoretical expectations.

Second, for China's demand for final goods, the results of the estimates for Japan and South Korea are similar, and all of the coefficients are significantly positive. This is consistent with the results of the theoretical analysis.

Third, for the productivity of crude steel in China relative to Japan and South Korea, the estimates for all final goods are negative. However, in both estimates, the estimates for refrigerators, cars, and oil and LNG pipelines and construction are significant. In addition, the estimates for railway tracks are significant in the estimates for Japan, and the estimates for cutting machines are also significant in the estimates for Korea. This estimate is broadly consistent with the theoretical analysis, but it also suggests that the relative productivity level of Chinese crude steel differs between Japan and South Korea.

Fourth, viewing the estimated results for the fit value of the production of Chinese iron ore products, which was estimated using world iron ore prices, China's demand for final goods and the relative productivity of crude steel, the coefficients for the production of cutting machines, railway tracks and oil and LNG pipelines are significant in the estimations for both Japan and Korea. In particular, it is interesting to note that the coefficient on railway tracks is positive, while the other coefficients are negative in both estimates. Moreover, considering the estimates for the fit value of imports from Japan and South Korea that have been estimated by using world iron ore prices, the demand for final goods, and the relative productivity of crude steel in China, the results for all final goods are positive. In the estimation for Japan, the results for electric facilities, refrigerators, cars, and construction achieve significance, while the results for Korea are significant for all of the dependent variables except railway tracks. In particular, observing the values, it becomes apparent that imports of steel products from Japan and Korea contribute significantly to the production of electric power equipment, and imports from Japan contribute significantly to the production of cars compared to other final goods in China.

Additionally, in the estimates for both countries, the WTO dummies are positive for all final goods except for railway tracks and construction, and significant estimates are obtained for cutting machines, power equipment, refrigerators, automobiles, and pipelines. In other words, accession to the WTO has increased the production of many final goods, while it has had no impact or even a negative impact on railway and building production in China. In contrast, regarding anti-dumping, the imposition of anti-dumping measures appears to have had a suppressive effect on the production of most steel product-related final goods in China since significant and negative results are obtained for all products except power equipment.

5. Conclusion

From the above findings, the following conclusions could be derived. First, of the three influencing factors (world iron ore prices, the relative productivity of crude steel in China, and the demand for final goods in China), the increase in the demand for final goods in China is the largest factor that has led to higher prices and lower import volumes of steel products from Japan and South Korea, and an increase in the domestic production of steel products and final goods related to steel products in China.

Second, the improvement in the relative productivity of crude steel compared to South Korea has also contributed significantly to the increase in the production of steel products and final goods related to steel products in China as well as a decrease in the price and volume of steel products imported from South Korea. Subsequently, the world price of iron ore increased the price of steel products imported from other countries and thereby increased the domestic production of steel products and further boosted the production of final goods related to steel products in China. This result is not consistent with the results of the theoretical analysis, perhaps because China's demand for final goods has grown too large. In this sense, the traditional comparative statics model may have limitations in interpreting China's economic growth.

Third, overall, the growing demand for final goods in China has contributed significantly to the rising price and increasing volume of steel products imported from Japan and South Korea, as well as to the increasing production of steel product-related final goods in China, but the contribution differs by product category. Steel products imported from Japan have contributed the most to China's production of passenger cars, followed by power equipment, buildings and refrigerators, but not to the production of cutting machines, tractors, railway tracks and pipelines. Steel products imported from South Korea have contributed the most to the production of power equipment, followed by tractors, cars, cutting machines, refrigerators, construction, and pipelines, and they contribute the least to the production of railway tracks. If these results are considered linked to the second conclusion noted above, it can be said that the steel products imported from Japan are mainly for the production of cars and electric equipment that cannot be produced in China, while the steel products imported from South Korea are primarily to meet the demand for final goods that can also be produced in China.

Fourth, in response to structural shifts in the demand for final goods, the domestic production and import volumes of various types of steel products have changed. Specifically, the production of steel products required for the production of cutting machines, pipelines and refrigerators has decreased, while related imports have increased. On the other hand, the steel for railway construction is mainly supplied by domestic production.

Fifth, with the accession to the WTO, the import of steel products from Japan and South Korea as well as the production of steel products within China has increased. The production of many final goods related to steel products has also increased, but there has been a rather negative impact on industries such as railway construction and construction, which have grown significantly in China. This is a new finding contributed by this study and should be further analyzed in the future.

Finally, although the imposition of anti-dumping measures has had very little direct impact on the imports and production of steel products, it has had a negative effect on the production of many final goods related to steel products in China.

It should be noted that the accuracy of the estimated results for the panel data is not high enough because the items of trade and the items of domestic production for steel products in China do not exactly match. It is necessary to better match these items for more accurate estimation in the future.

References:

Bernhofen, D. M. (1995), "Price dumping in intermediate good markets", *Journal of International Economics*, **39**, 159–73.

Hernandez, A. G., L. Paoli, J. M. Cullen(2018) "How resource-efficient is the global steel industry?" *Resources, Conservation & Recycling,* 133, 132–145.

Kuo, P. C., Y. S. Lin, and C. H. Peng (2016) "Antidumping policies in intermediate good markets" (mimeograph), 1-20.

Li, Q., W. Zhong, G. Wang, J. Cheng, T. Dai, B. Wen, L. Liang, Q. Yang (2018) "Material and value flows of iron in Chinese international trade from 2010 to 2016," *Resources Policy*, 59, 139–147.

Movshuk, O., (2004) "Restructuring, productivity and technical efficiency in China's iron and steel industry, 1988–2000," *Journal of Asian Economics*, 15, 135-151.

Sui, G., H. Li, H. Ana, Q. Sun, X. Hao, Y. Liu (2019) "Steel product prices transmission activities in the midstream industrial chain and global markets," *Resources Policy,* 60, 56–71.

Table 6. Estimated results for the impact of the import of steel products from Japan on the production of Chinese steel-related final goods

	metal_cut	Tractor	power_equip	Fridge	car	Railways	pipeline	floor_space
World iron ore price (pw)	0.0083***	0.0123***	0.0138***	0.0086***	0.0085***	-0.0006***	0.0047***	0.0035***
	4.854	3.747	4.3	6.42	3.025	-3.645	7.844	2.623
Final consumption (a)	0.0008***	0.0012***	0.0007*	0.0008***	0.0010***	0.0002***	0.0006***	0.0007***
	3.913	3.164	1.846	7.397	3.145	10.719	12.666	4.381
Crude steel productivity (kc)	-0.0753	-0.0748	-0.2162	-0.3989***	-0.6063***	-0.0235***	-0.2239***	-0.5311***
	-0.843	-0.434	-1.286	-6.356	-4.097	-2.652	-8.022	-7.618
Production of steel (ln) (Fitted value)	-1.1403***	-0.8727	-0.9297	-0.4978**	-0.0328	0.0815*	-0.2732***	0.0522
	-2.708	-1.076	-1.174	-2.106	-0.047	1.954	-2.599	0.159
Import qty of steel (ln) (Fitted value)	0.007	0.0534	0.1408**	0.0344**	0.2149***	0.0037	0.0101	0.0847***
	0.215	0.846	2.29	2.284	3.969	1.131	1.51	3.319
WTO dummy	0.8231***	0.0529	0.8396***	0.1702**	0.2391	-0.021**	0.0527	-0.1655**
	8.79	0.293	4.768	2.066	1.542	-2.262	1.44	-2.266
AD dummy	-0.396***	-0.4367*	0.1891	-0.2979***	-0.3338	-0.054***	-0.1566***	-0.3209***
	-3.189	-1.825	0.81	-2.738	-1.624	-4.394	-3.237	-3.313
Constand	12.9669***	8.8122	15.2143**	11.7341***	4.0322	1.0855***	3.3838***	11.109***
	3.252	1.147	2.029	5.282	0.611	2.749	3.426	3.572
Obs	159	159	159	159	159	159	159	159
Groups	6	6	6	6	6	6	6	6
Wald(Chi2(4))	55821.07	8758.89	84180.54	3885.42	43814.01	1790000	9586.96	934807.38
F test P-value	0.3838	0.9217	0.3704		0.0335	0.5406		0.1290
Hausman test P-value	0.0000	0.0000	0.0005	0.6410	0.0000	0.0000	0.4000	0.0000
	FE	FE	FE	RE	FE	FE	RE	FE

Table 7. Estimated results for the impact of the import of steel products from South Korea on the production of Chinese steel-related final goods

	metal_cut	Tractor	power_equip	Fridge	car	railways	pipeline	floor_space
World iron ore price (pw)	0.0098***	0.0112***	0.0134***	0.0071***	0.0071***	-0.0008***	0.0041***	0.0016
	5.554	4.019	4.856	5.523	3.167	-4.319	7.333	1.316
Final consumption (a)	0.0011***	0.0013***	0.0008*	0.0008***	0.0011***	0.0002***	0.0007***	0.0006***
	3.863	2.927	1.76	4.906	3.659	5.734	9.514	3.554
Crude steel productivity (kc)	-0.1956**	0.0222	-0.0695	-0.2488***	-0.3443***	-0.0024	-0.1751***	-0.3127***
	-2.008	0.144	-0.457	-4.057	-3.237	-0.24	-6.613	-5.457
Production of steel (ln) (Fitted value)	-1.7441***	-1.0225	-1.0126	-0.3971	-0.201	0.1503**	-0.3315**	0.2699
	-3.013	-1.117	-1.12	-1.172	-0.342	2.484	-2.266	0.852
Import qty of steel (ln) (Fitted value)	0.0507*	0.0833*	0.1822***	0.0356***	0.0679***	0.0028	0.0103*	0.0249**
	1.822	1.893	4.19	2.643	2.908	0.976	1.774	1.976
WTO dummy	0.6768***	0.2029	0.8606***	0.2131***	0.5684***	-0.0182	0.0591*	-0.0451
	6.398	1.213	5.209	2.599	3.998	-1.642	1.67	-0.589
AD dummy	-0.5306***	-0.5904**	0.1111	-0.3551***	-0.5489***	-0.0377**	-0.219***	-0.3732***
	-3.091	-2.176	0.415	-2.998	-2.672	-2.101	-4.282	-3.371
Constand	18.6119***	9.8355	15.6061*	10.591***	5.6781***	0.4254	3.8633***	9.0155***
	3.423	1.144	1.838	3.331	1.03	0.748	2.813	3.033
Obs	157	157	157	157	157	157	157	157
Groups	6	6	6	6	6	6	6	9
Wald(Chi2(4))	44625.71	10447.26	97501.19	263432.22	3315.24	1280000	10719.35	4137.89
F test P-value	0.1583	0.6518	0.0182			0.3853		
Hausman test P-value	0.0000	0.0000	0.0000	0.2551	0.1193	0.0000	0.9950	0.1040
	FE	FE	FE	RE	RE	FE	RE	RE

Table 8. Descriptive Statistics

Variable	Obs	Unit	Mean	Std. Dev.	Min	Max
World iron ore price (pw)	165	US$/dmt	64.687	45.612	26.470	167.754
Crude steel productivity (kc) (CN/JP)	165	Index	2.309	0.848	1.375	4.134
Crude steel productivity (kc) (CN/ROK)	164	Index	2.509	1.105	1.298	4.735
Import amount of steel (JP to CN)	165	1000US$	383,038	718,163.5	77.152	3,660,988
Import quantity of steel (JP to CN)	165	Kiloton	407.671	747.046	0.064	3,019.170
Import_price (JP to CN)	165	1000US$/Kiloton	1,093.032	1,110.544	147.958	5,301.443
Import amount of steel (from ROK to China)	164	1000US$	194,486	422,715	1.453	2,075,125
Import quantity of steel (from ROK to China)	164	Kiloton	238.797	509.359	0.000	2,105.517
Import_price (ROK to China)	164	1000US$/Kiloton	1,045.726	1,054.614	125.648	8,648.761
production	162	Kiloton	32,919.2	36,606	1,340	153,834
World production of iron ore	165	Kiloton	1,365,668	458,393	884,044	2,162,524
Final consumption (a) index	165	1980=100	1,231.087	973.093	210.670	3,665.990
metal_cutting	165	10th Unit	44.815	26.897	11.910	88.680
Tractor	165	10^{th} unit	22.396	22.069	3.770	68.820
Electric equipment	165	10thkw	7,070.803	5,574.997	1,164.2	15,053.02
Refrigerator	165	10th Unit	3,717.317	3,197.540	463.060	9,255.740
Vehicle	165	10th Unit	430.998	466.506	3.500	1,248.310
Railway	165	10thkm	7.919	1.981	5.780	12.700
Pipeline	165	10thkm	4.918	3.389	1.590	11.930
Buildings	165	10th ㎡	175,402.7	140,525.6	19,552.5	423,357.3
WTO_dummy	165		0.564	0.497	0	1
AD_dummy	165		0.055	0.228	0	1