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International market power analysis of China's tungsten export market – from the perspective of tungsten export policies

Xuehong Zhu[a,b], Xinyuan Li[a,b], Hongwei Zhang[a,b,*], Jianbai Huang[a,b]

[a] School of Business, Central South University, Changsha 410083, China
[b] Institute of Metal Resources Strategy, Central South University, Changsha 410083, China

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ABSTRACT

Tungsten is a widely used metal related to national strategic security. As the world's largest tungsten producer and exporter, China has restricted tungsten exports over the past decade. Has China acquired the corresponding international market power in the export market after these export restrictions? Based on an expansion of the Song-Marchant-Reed (SMR) model, this paper selects 17 of China's major tungsten importers and estimates the international market power of Chinese tungsten exports over the period from 1992 to 2016. In addition, the effectiveness of China's tungsten export control policies is examined. The empirical results show that China has stronger market power relative to the major tungsten importers. Moreover, from the encouragement phase to the restraint phase of China's export policy, the difference in the export market power between China and the importers has substantially increased from 0.027 to 0.161. This shows that due to the implementation of export restrictions, China has gained more export market power, indicating that its tungsten export control policies are very effective. Based on the empirical results, this paper analyses the reasons for China's rising market power and the effectiveness of its export policies and proposes corresponding policy recommendations.

1. Introduction

Tungsten is a whitish-grey metal with the highest melting point of all metals and one of the highest densities. When combined with carbon to make tungsten carbide, it is almost as hard as diamond. These properties make it critical in applications in several important sectors, such as defence, aerospace, mining, manufacturing, and telecommunications, all of which are crucial to economic development and national security. These important applications of tungsten make it an important strategic resource related to the lifeline of the national economy and national defence. The world tungsten supply is dominated by production in and exports from China, and the country is also the world's leading tungsten consumer (Shedd, 2014).

Since China's reform and opening up, economic exchanges between China and the world have become increasingly frequent. To encourage commodity exports, China has promulgated a series of preferential policies. With the increasingly important role of tungsten products, the Chinese government has gradually shifted its tungsten policies from encouraging exports to limiting exports. The evolution of China's tungsten export policies over the past two decades can be divided into two phases: the encouragement phase and the restraint phase. The main content of these policy adjustments has been changes to the export taxes and export quotas (Table 1). During the encouragement phase, China began to implement tax rebate policies to encourage tungsten exports in 1990, and the export tax rebates for tungsten goods were all adjusted to zero on September 15, 2006. China has raised tariffs on tungsten products and limited total tungsten exports since 2007. Since then, China's tungsten export policies had entered the restraint phase. China has regulated its tungsten industry through a series of measures, including limiting the number of exploration, mining, and export licenses; limiting foreign investment; imposing constraints on mining and processing; imposing quotas on production and exports; adjusting export quotas; and imposing export duties on tungsten materials.

After the WTO ruling that China's export restraints were inconsistent with the country's obligations (Lindeman, 2014), China discontinued its tungsten products export quota and duties system in 2015. Due to the hysteresis of the effect of the policy, however, although tungsten export tariffs were removed in 2015, the restrictive export policy continued into 2016. Nevertheless, from 2017 onwards, the Ministry of Commerce of China no longer had clear limits on tungsten export quotas and tariffs. To ensure the strategic status of tungsten resources and prevent malicious export profits, the Ministry of Commerce standardized the qualifications for tungsten export enterprises.

Changes in import and export policies will affect the price of metal

* Corresponding author at: School of Business, Central South University, Changsha 410083, China.
E-mail addresses: zhuxh@csu.edu.cn (X. Zhu), lixinyuan@csu.edu.cn (X. Li), hongwei@csu.edu.cn (H. Zhang), jbhuang@csu.edu.cn (J. Huang).

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Table 1
Evolution of China's tungsten export policies.
Source: collected and organized by the author based on the related policies released by China

Phase	Year	Main policies
The Encouragement Phase	1990	China began to implement a tax rebate policy for tungsten products
	1991	The State Council listed tungsten as a specific mineral for national protective exploitation
	1993	China began to implement license quota management for tungsten (referring to tungsten sand, ammonium paratungstate, tungsten oxide, tungstic acid)
	1995	China limited foreign investment in tungsten
	2000	China began to control the total amount of production and sales of tungsten ore, implemented quotas, and export license management
	2001	The Ministry of Land and Resources announced that it controlled tungsten ore mining and suspended the issuance of tungsten mining licenses
	2002	The Ministry of Commerce began to issue tungsten products export licenses, and 13 enterprises obtained an export license; an export quota of 1.49mt was implemented
	2003	An export quota of 1.81mt was implemented
	2004	The IRS cancelled the 13% export tax rebate policy on tungsten concentrate and tungsten waste; an export quota of 16,300 t was implemented
	2005	The State Ministry of Finance and the State Administration of Taxation reduced the export tax rebate for tungsten and tungsten products (from 13% to 8%); the Development and Reform Commission issued "On strengthening the tin antimony industry management views"; an export quota of 1.63mt was implemented
	2006	Export tax rebate for tungsten goods adjusted to zero; an export quota of 1.58mt was implemented
The Restraint Phase	2007	Tariffs on primary tungsten products increased by 5–15%; an export quota of 1.54mt was implemented
	2008	An export quota of 1.49mt was implemented
	2009	An export quota of 1.46mt was implemented; the Ministry of Commerce began to issue tungsten products supply licenses; 17 enterprises obtained a supply license
	2010	A series of export tariffs on tungsten compounds were adjusted to 10%; the export tariffs on tungsten waste scrap were adjusted to 15%; the export tariffs on ferrotungsten and silicon ferrotungsten were adjusted to 20%; an export quota of 1.43mt was implemented
	2011	An export quota of 1.57mt was implemented
	2012	The export tariffs on tungsten ores and concentrates were adjusted to 20%; an export quota of 1.54mt was implemented
	2013	The export tariffs on tungstic acid, tungsten oxide, other tungsten oxides and hydroxides, ammonium paratungstate, sodium tungstate, calcium tungstate, ammonium metatungstate, other tungstates, tungsten carbide, and tungsten powder were adjusted to 5.5%; an export quota of 1.54mt was implemented
	2014	The export tariffs on tungsten waste scrap were adjusted to 1%; an export quota of 1.25mt was implemented; the Ministry of Commerce cancelled restrictions on tungsten export quotas for 2015
	2015	The Ministry of Commerce reduced the compensation fees for rare earths, tungsten, and molybdenum to zero, stopped collection for the rare earths, tungsten, molybdenum price adjustment fund, and cancelled the export tariffs on tungsten products
	2016	The MFN's export tariffs on tungsten ore and concentrates were adjusted to 20%

international trade in goods (Zhu et al., 2017; Zhang et al., 2018), leading to affect the acquisition of market power. To protect metal resources and access their pricing power, China has promulgated a series of policies to limit its exports (Gourdon et al., 2016). Because changes in export policies can have significant effects on firms' export decisions (Feng et al., 2017), is it truly useful for China to limit exports of tungsten? As the world's largest supplier of tungsten products, can China successfully obtain international market power through restrictive policies? How can China seize market power in the tungsten export market when it cannot continue to restrict exports? This paper attempts to find empirical evidence to answer these questions.

Market power is used to measure the position of an enterprise in an industry via several methods, including marginal cost addition (Feinberg, 1980; Hall, 1988; Lerner, 1934) and market concentration (Bain, 1951; Cowling and Waterson, 1976; Hannan, 1997). Baker and Bresnahan (1988) proposed a method to estimate corporate market power based on a residual demand elasticity (RDE) model. The RDE model is widely used in research on international trade (Deodhar and Pandey, 2008; Hatirli et al., 2004; Jumah, 2004; Nakajima, 2012; Pan et al., 2009; Requena, 2005). It is noteworthy that the proposed RDE model was not able to consider market power on the demand side. International trade, as a bilateral transaction, requires an examination of the market power of both sides of the trade.

On the basis of the RDE model, Song et al. (2006) proposed the residual supply elasticity (RSE) model and combined the RSE model with the RDE model to construct the Song-Marchant-Reed (SMR) model. The SMR model reflects the market power of both the supply side and the demand side. In addition, it can reach a pricing power conclusion by comparing the size of both sides' market power. Scholars used the SMR model to test the market power in soybean trades by setting up a two-country partial equilibrium trade model (Song et al., 2009; Yamaura, 2008, 2011). Compared to the RDE model, the SMR model has greater practical significance. Scholars began to use the SMR model of Song et al. (2006) to study changes in market power in the metals market. Zhu et al. (2018a, 2018b) constructed an SMR model to calculate the market power of rare earths and indium. The above scholars' researches show that applying the SMR model to the study of metal resources is feasible.

Because a country's metal resources reserve capacity can greatly influence its industrial development, issues related to the international trade market power of metals have received increased attention in academia. Cerda (2007) found that the Asian bloc significantly affected the price of copper through an empirical study of monthly copper data. Wan (2017) measured the market power of Australia, Brazil, and India's iron ore exports to leading importing countries such as China, Japan, and Germany. He noted that China didn't have right in the iron pricing power subjected to the seller's forces. Zhang and Lawell (2017) estimated the world market power for the five non-renewable resources of copper, iron, lead, tin, and zinc. The results showed that the world markets for these resources were characterized by oligopolistic behaviour during the study period. For rare earths, scholars have found that the adjustments to resource policies can have significant effects on the market power. China's export restrictions can help it gain more market power with regard to rare earths (He, 2016; Pothen, 2014; Zhang et al., 2015; Zhu et al., 2018b). He (2016) suggested that after the WTO ruling on the exports of Chinese rare earths, the government should improve the standardization of its rare earths industry and build a more competitive domestic rare earths market. Zhu et al. (2018b) used the SMR model to measure the strength of the Chinese rare earths market and proposed policy recommendations to strengthen the industrial concentration, strictly control mining and production, and increase investment in technology. Overall, the existing research mainly focuses on ferrous metals and rare earths and does not pay sufficient attention to tungsten's trading situation. Because tungsten has become more

important to national defence, it is necessary to expand the research on this metal.

This article provides the following contributions. First, we take the international market power of tungsten as the research object. By examining China's tungsten export policies over the past two decades, we explore the influence of export policy adjustments on China's tungsten export market power. We aim to strengthen the research on China's dominant metal of tungsten. Second, we aim to fill the gap in the literature caused by previous studies mainly using seller-based one-way analyses. This paper analyses international tungsten market power from the perspective of both buyers and sellers. Finally, from the perspective of the global tungsten market, we adopt a modified SMR model and select 17 of China's major tungsten importers to study the international market power of tungsten.

The rest of the paper is organized as follows. Section 2 provides an overview of the global tungsten market. Section 3 builds an extended SMR model in order to estimate the market power of China and the major importers. Section 4 calculates the market power of buyers and sellers. In addition, it analyses the reasons for the increase in China's market power and the effectiveness of its export policies. Finally, Section 5 presents the conclusions and policy recommendations.

2. Overview of the global tungsten market

To analyse the market power of Chinese tungsten in international trade, we must first understand China's position in the international market. Thus, we need to examine the overall supply and trading of tungsten throughout the world. This section analyses the global supply and tungsten's trading situation and provides an overview of China's tungsten position in the international market.

2.1. Overview of the global tungsten supply and demand

Based on a report by the U.S. Geological Survey on tungsten over recent years, we find that there are four major tungsten producing countries in the world: the USA, Russia, Canada, and China (Fig. 1). Among them, China is the largest supplier of tungsten. The production of tungsten in China accounts for more than 65% of the world's production, and this figure has sometimes reached as high as 80%. In 2013, the tungsten output from these four countries reached 80 million tons, accounting for 95% of the global total. In addition, in 2015, China produced 71 million tons of tungsten, approximately 82% of world's production.

It can be seen from Fig. 1 that due to the unstable supply from the Chinese market over the past decade, the supply of tungsten in the global market has fluctuated. The changes in the global supply are in line with the fluctuations in the Chinese market. The United States is the second largest supplier of tungsten, accounting for approximately 8% of global tungsten production. The reduction in tungsten production in the United States after 2011 also had some impact on the global supply. In general, China occupies a very important position in the global supply of tungsten.

2.2. Overview of the international tungsten trading market

As a very important metal resource, tungsten is widely used in all countries throughout the world, which has led to the creation of a complicated international trade pattern. Using annual data on tungsten trading countries from 1996 to 2016, we analyse the import and export situation.

Table 2 provides an overview of international tungsten trading. We find that imports are the main international trade for tungsten. The total volume of imports is much higher than that of exports, indicating that there are more countries with import demand than those that export. There could be two reasons for the substantial difference in the import and export data. On the one hand, when the customs organizations in various countries collect statistics on imports and exports, there may be differences in the statistical standards in different countries. On the other hand, the existence of a significant amount of smuggled tungsten products also makes the import data much higher than the export data. In addition, the world's tungsten demand mainly depends on the supply by the leading global tungsten producing countries.

In order to measure each country's position in the international trade pattern, we use an import and export ranking of the leading tungsten suppliers (Table 3). Over the past decade, China and the United States' export volume of tungsten have almost occupied the top three spots in the world, indicating that both China and the United States both have dominated the tungsten export market. However, the high ranking of U.S. tungsten imports shows that U.S. exports of tungsten to the world depend on its imports. In contrast, China is a real net exporter of tungsten in international trade.

In summary, China is the world's largest supplier of tungsten resources. The exploitation of tungsten resources and the release of

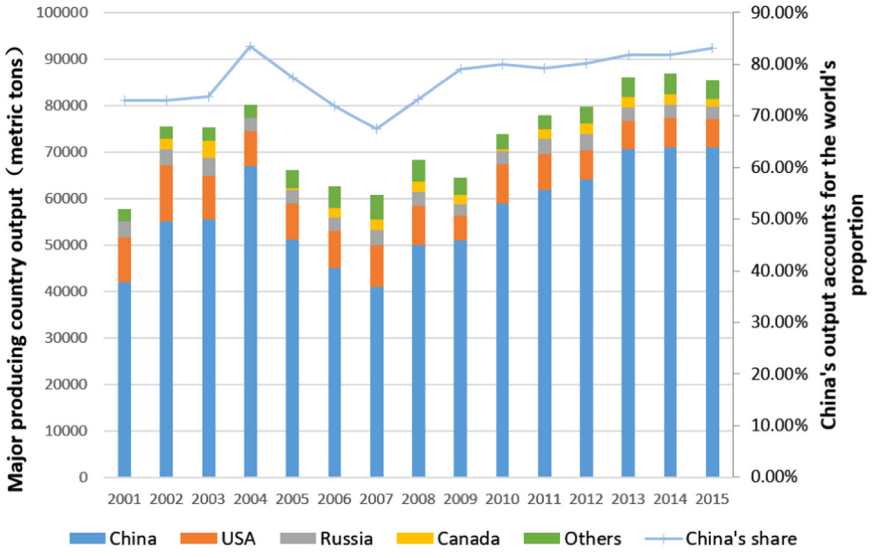

Fig. 1. Leading global tungsten producing countries.
Source: USGS, Mineral Commodity Summaries

Table 2
Descriptive statistics of international tungsten import and export.
Source: UN Comtrade Database. Customs code: HS8101

	Export		Import	
Number of countries	155		194	
Descriptive statistics	Netweight (kg)	Trade Value ($)	Netweight (kg)	Trade Value ($)
Average	352,652.87	8,807,527.51	345,679.75	5,816,591.40
Variance	9.6986E+11	6.28696E+14	4.30553E+13	3.7342E+14
Minimum	0.000	1.000	0.000	3.000
Maximum	18,630,000	236,749,535	334,750,922	304,114,797
Summation	533,916,457	13,334,596,651	929,532,867	15,890,927,716
Observations	1514	1514	2732	2732

Table 3
The import and export scale ranking of the leading global tungsten suppliers.
Source: organized by author.

Country	China		USA		Russia		Canada	
Ranking	Import	Export	Import	Export	Import	Export	Import	Export
2001	11	1	3	2	17	31	22	18
2002	8	1	5	2	17	34	19	23
2003	8	2	2	1	37	42	21	10
2004	8	2	3	4	40	27	20	12
2005	7	2	2	3	47	25	18	12
2006	6	3	4	1	37	36	18	13
2007	7	3	2	1	34	39	18	14
2008	6	2	2	3	39	34	16	22
2009	6	1	3	3	36	41	19	31
2010	8	1	2	2	29	34	22	18
2011	16	1	3	3	35	42	16	10
2012	25	5	2	1	19	41	18	16
2013	27	4	2	1	33	41	27	21
2014	21	4	2	2	25	42	18	16
2015	19	3	2	5	31	34	18	15
2016	19	3	2	5	34	18	18	23

capacity in China as well as price fluctuations will have significant impacts on the international tungsten market. At the same time, changes in China's tungsten export policies will affect the import demand of many countries. From this perspective, when China began to restrict its tungsten exports, its market power should have shown a gradual upward trend.

3. Model construction and estimation

To measure the international market power of China's tungsten export market, we select 17 major importers of Chinese tungsten, including Australia, Canada, France, Germany, India, Japan, Malaysia, Korea, Singapore, Spain, Sweden, Switzerland, Thailand, United Kingdom, and the USA. We adjust and extend the SMR model to measure the international market power of China compared to the 17 major tungsten importers. Thus, we set China as c and the major importers as j.

3.1. Theoretical model

3.1.1. Importing country j's inverse residual tungsten demand model (RDE)

According to the residual demand model proposed by Song et al. (2009), the residual demand of the major importing country's tungsten can be expressed as follows:

$$RD_j^c = D_j - (S_j + CMQ_j^{imoth}) + STK_j \tag{1}$$

where D_j is the domestic demand for importing country j's tungsten, S_j is the domestic supply of importing country j's tungsten, CMQ_j^{imoth} is the amount of tungsten imports from countries other than China, and STK_j is importing country j's tungsten stock. Thus, RD_j^c is the amount of tungsten that country j imports from China.

Meanwhile, importing country j's domestic demand function and supply function can be defined as follows:

$$D_j = D_j(P_j^{im}, Z_j^D) \tag{2}$$

$$S_j = S_j(P_j^{im}, Z_j^S) \tag{3}$$

where P_j^{im} is the import price of tungsten, D_j and S_j are the tungsten demand and supply for importing country j when the price of tungsten is P_j^{im}, respectively, and Z_j^D and Z_j^S are the factors that affect the domestic demand and supply of importing country j.

Substituting the importing country j's domestic demand function and supply function (Eqs. (2) and (3)) into the importing country residual demand function (Eq. (1)), we can get the importing countries' domestic demand for China as follows:

$$RD_j^c = RD_j^c(P_j^{im}, Z_j^D, Z_j^S, CMQ_j^{imoth}, STK_j) \tag{4}$$

The inverse residual demand of the importing country is the inverse function of function (4), which can be defined as follows:

$$P_j^{im} = P_j^{im}(RD_j^c, Z_j^D, Z_j^S, CMQ_j^{imoth}, STK_j) \tag{5}$$

3.1.2. China's inverse residual tungsten demand model (RSE)

According to the residual supply model proposed by Song et al. (2009), the residual supply of China's tungsten can be expressed as follows:

$$RS_c^j = S_c - (D_c + CMQ_c^{exoth}) + STK_c \tag{6}$$

where D_c is the domestic demand of China's tungsten, S_c is the domestic supply of China's tungsten, CMQ_c^{exoth} is the amount of tungsten export from China to the other country except the importer j, STK_c is Chinese tungsten stock. Thus, RS_c^j is the amount of tungsten export from China to country j.

Meanwhile, China's domestic demand function and supply function can be defined as follows:

$$D_c = D_c(P_c^{ex}, Z_c^D) \tag{7}$$

$$S_c = S_c(P_c^{ex}, Z_c^S) \tag{8}$$

where P_c^{ex} is the export price of tungsten, D_c and S_c are the China's demand and supply of tungsten when the price is P_c^{ex}, and Z_c^D and Z_c^S are the factors that affect the domestic demand and supply in China.

Substituting China's domestic demand function and supply function (Eqs. (7) and (8)) into China's residual demand function (Eq. (6)), we can obtain China's domestic supply for importers as follows:

$$RS_c^j = RS_c^j(P_c^{ex}, Z_c^D, Z_c^S, CMQ_c^{exoth}, STK_c) \tag{9}$$

The inverse residual tungsten supply of China is the inverse function of function (9), which can be defined as follows:

$$P_c^{ex} = P_c^{ex}(RS_c^j, Z_c^D, Z_c^S, CMQ_c^{exoth}, STK_c) \tag{10}$$

3.1.3. The partial equilibrium trade model

According to the two-country partial equilibrium trade model proposed by Song et al. (2009), the partial equilibrium model based on the perspective of buyers and sellers can be expressed as follows:

$$\begin{cases} P_j^{im} = P_j^{im}(RD_j^c, Z_j^D, Z_j^S, CMQ_j^{imoth}, STK_j) \\ P_c^{ex} = P_c^{ex}(RS_c^j, Z_c^D, Z_c^S, CMQ_c^{exoth}, STK_c) \\ P_j^{im} = P_j^{im}(P_c^{ex}) \\ RD_c^j = RS_j^c \end{cases} \tag{11}$$

In the above simultaneous equations, $P_j^{im} = P_j^{im}(P_c^{ex})$ reflects the relationship between Chinese tungsten's export price and tungsten's import price of the country j. And $RD_c^j = RS_j^c$ is the equilibrium condition where the country j's residual tungsten demand equals Chinese residual tungsten supply.

3.2. Mathematic model

Based on the theoretical extension of the SMR model and the above analysis, we identify the specific functional form of the SMR model's variables in this section.

For the inverse residual demand of the importing countries from China, there are three types of variables that must be identified. First, the tungsten import objects P_j^{im}andRD_j^c are the price and amount of tungsten exported by China to importing country j. The second type is the domestic demand shifters. The level of economic development, GDP, the price of substitutes,P_j^f (the price of ferrotungsten exports, abbreviated as f), the price of complements, P_j^{steel} (the price of imported steel), and high-technology exports, H_j, can also effect P_j^{ex}. The third type is CMQ_j^{imoth}, which is the amount of tungsten imported from countries other than China. Thus, the specific functional form of importing country j's inverse residual demand for China's tungsten can be written as follows:

$$P_j^{im} = \alpha_0 + \alpha_1 RD_j^c + \alpha_2 GDP_j + \alpha_3 P_j^{steel} + \alpha_4 P_j^f + \alpha_5 H_j + \alpha_6 CMQ_j^{imoth} + \varepsilon_j \tag{12}$$

where:

P_j^{im}: The import tungsten price of the country j from China;
RD_j^c: The import tungsten amount of the country j from China;
GDP_j: The GDP of the country j;
P_j^{steel}: The steel price of the country j;
P_j^f: The ferrotungsten price of the country j;
H_j: The high-technology exports of the country j;
CMQ_j^{imoth}: The amount of importing tungsten from other countries except China, equals to the total amount of tungsten import minus the amount of tungsten import from China;
ε_j: Error term, assumed identically and independently distributed.

Similar to the importers' inverse residual demand, the specific function form of China's inverse residual supply for the importers can be written as follows:

$$P_c^{ex} = \beta_0 + \beta_1 RS_c^{\ j} + \beta_2 GDP_c + \beta_3 P_c^{steel} + \beta_4 P_c^f + \beta_5 H_c + \beta_6 CMQ_c^{exoth} + \beta_7 EP_c + \varepsilon_c \tag{13}$$

where:

P_c^{ex}: The export tungsten price from China to the country j;
RS_c^j: The export tungsten amount from China to the country j;
GDP_c: The GDP of China;
P_c^{steel}: The steel price of China;
P_c^f: The ferrotungsten price of China;
H_c: The high-technology exports of China;
CMQ_c^{exoth}: The amount of exporting tungsten from China to other countries except the country j, equals to the total amount of Chinese tungsten exported minus the amount of tungsten exported to the country j.
EP_c: Chinese tungsten export policy, a dummy variable, equaling 0 before 2007 and 1 otherwise. ε_c: Error term, assumed identically and independently distributed.

Different from the anti-residual supply model, in order to illustrate the impact of policy adjustments, a dummy variable, EP_c, needs to be added in the anti-residual demand model. It is understood that in international trade, the duration of contract orders is often very long, generally more than six months. The introduction of a new policy will therefore have little impact on international trade in the short term (within one year). A policy change will generally exert an effect at the end of the first year or the second year after policyies implementation. Although China's tungsten export restriction policies were implemented in 2006, it had little impact on China's exports in 2007. Therefore, in this research, the variable EP_c equals 0 before 2007 and 1 otherwise.

Based on the perspective of tungsten buyers and sellers combined with the equilibrium conditions that the inverse residual tungsten demand must equal the inverse residual tungsten supply, the exact function of the partial equilibrium model can be expressed as follows:

$$\begin{cases} P_j^{im} = \alpha_0 + \alpha_1 RD_j^c + \alpha_2 GDP_j + \alpha_3 P_j^{steel} + \alpha_4 P_j^f + \alpha_5 H_j + \alpha_6 CMQ_j^{imoth} + \varepsilon_j \\ P_c^{ex} = \beta_0 + \beta_1 RS_c^{\ j} + \beta_2 GDP_c + \beta_3 P_c^{steel} + \beta_4 P_c^f + \beta_5 H_c + \beta_6 CMQ_c^{exoth} + \beta_7 EP_c + \varepsilon_c \\ P_j^{im} = \Theta_0 + \Theta_1 P_c^{ex} \\ RD_j^c = RS_c^j \end{cases} \tag{14}$$

The basic assumption of the partial equilibrium model is that the inverse residual tungsten demand of the importers and the inverse residual tungsten supply of China is equivalent. Based on this assumption, we use the logarithmic form of the equation on both sides. The estimated coefficient of the equation is the price elasticity. Therefore, the log form of the partial equilibrium model can be written as follows:

$$\begin{cases} LnP_j^{im} = \alpha_0 + \alpha_1 LnRD_j^c + \alpha_2 LnGDP_j + \alpha_3 LnP_j^{steel} + \alpha_4 LnP_j^f + \alpha_5 LnH_j + \alpha_6 LnCMQ_j^{imoth} + \varepsilon_j \\ LnP_c^{ex} = \beta_0 + \beta_1 LnRS_c^{\ j} + \beta_2 LnGDP_c + \beta_3 LnP_c^{steel} + \beta_4 LnP_c^f + \beta_5 LnH_c + \beta_6 LnCMQ_c^{exoth} + \beta_7 LnEP_c + \varepsilon_c \\ LnP_j^{im} = \Theta_0 + \Theta_1 LnP_c^{ex} \\ LnRD_j^c = LnRS_c^j \end{cases} \tag{15}$$

where j = importers: Australia, Canada, France, Germany, India, Japan, Malaysia, Korea, Singapore, Spain, Sweden, Switzerland, Thailand, United Kingdom, and the USA.

Thus, Eq. (15) is the finalized specific functional form of the partial equilibrium tungsten trade model. In addition, coefficient α_1 measures the market power of China's tungsten in the international export trade, and coefficient β_1 measures the market power of country j.

4. Empirical results and analysis

4.1. Data description

To measure tungsten's international market power, we selected the tungsten annual trade data between China and 17 major importers from 1992 to 2016. We organize the data according to the model design and the availability of the data. By comparing the relative strength of the buyers' and seller's market power, we can determine whether China has attained pricing power in the international tungsten trade. Specifically, the variables used in this paper and their sources are listed in Table 4.

Table 4
Definitions of variables and data sources.
Source: organized by author.

Varibles	Definitions	Sources
P_j^{im}	The import tungsten price of the country j from China; Price = Export Value / Amount exported Unit: $/kg	UN Comtrade Database Customs code: HS8101
RD_j^c	The country j's residual demand for China. Unit: kg	UN Comtrade Database Customs code: HS8101
GDP_j	The gross domestic product of the country j. Unit: $	The World Bank Database
P_j^{steel}	The steel price of the country j. Price = (Export Value / Amount exported + Import Value / Amount imported)/2 Unit: $/kg	UN Comtrade Database Customs code: HS7301
P_j^f	The ferrotungsten price of the country j. Price = (Export Value / Amount exported + Import Value / Amount imported)/2 Unit: $/kg	UN Comtrade Database Customs code: HS720280
H_j	The high-technology exports of the country j. Unit: $	The World Bank Database
CMQ^{imoth}	The amount of importing tungsten from other country except China. Quantity = Total Imported-Imported from China Unit: kg	UN Comtrade Database Customs code: HS8101
P_c^{ex}	The China tungsten export price to the country j. Price = Import Value / Amount imported Unit: $/kg	UN Comtrade Database Customs code: HS8101
RS_c^j	Chinese residual supply for the country j. Unit: kg	UN Comtrade Database Customs code: HS8101
GDP_c	The gross domestic product of China. Unit: $	The World Bank Database
P_c^{steel}	The steel price of China. Price = (Export Value / Amount exported + Import Value / Amount imported)/2 Unit: $/kg	UN Comtrade Database Customs code: HS7301
P_c^f	The ferrotungsten price of China. Price = (Export Value / Amount exported + Import Value / Amount imported)/2 Unit: $/kg	UN Comtrade Database Customs code: HS720280
H_c	The high-technology exports of China. Unit: $	The World Bank Database
CMQ_c^{exoth}	The amount of exporting tungsten to other country except the country j. Quantity = Total Exported-Exported to the country j Unit: kg	UN Comtrade Database Customs code: HS8101

4.2. Model selection and inspection

Before the empirical test, the model must first be examined. The Wald test, B-P test and Hausman test are conducted for both the inverse residual tungsten demand of the importers and the inverse residual tungsten supply of China. The test results are shown in the Table 5.

For the choice of a fixed effect model or pooled OLS, the fixed effect model is selected for the inverse residual tungsten demand (RDE) and the inverse residual tungsten supply (RSE) functions according to the results of the Wald test. For the choice of a random effect model or pooled OLS, the random effect model is selected for the RDE and RSE functions according to the results of Breusch and Pagan Lagrangian multiplier test (B-P test). Finally, based on the result of the Hausman test, the fixed effect model is selected for the RDE function and the RSE function.

Table 5
Model selection results.

Test	Function	RDE	RSE
Wald test	F test	24.70	9.89
	Prob > F	0.0000	0.0000
	Result	Reject H_0	Reject H_0
		Select the fixed-effect model	
B-P test	chibar2	454.26	314.38
	Prob > chibar2	0.0000	0.0000
	Result	Reject H_0	Reject H_0
		Select the random-effect model	
Hausman test	chi2	53.95	6.94
	Prob > chi2	0.0000	0.0738
	Result	Reject H_0	Reject H_0
		Select the fixed-effect model	

4.3. Estimated results and analysis

In view of the possibility for heteroskedasticity, autocorrelation, and multicollinearity, we employ the fixed effects regression with Driscoll and Kraay (1998) standard errors for coefficients. Driscoll-Kraay standard errors are robust to very general forms of cross-sectional (spatial) and temporal dependence when the time dimension becomes large. Table 6 reports the estimated results.

As mentioned in Section 3, in the empirical tests, the data for the export encouragement phase are annual data from 1992 to 2007, while the data for the export restraint phase are annual data from 2008 to 2016. It is feasible to use the 2007 data for the policy encouragement phase. Due to the lagging nature of the policy, the 2006 policy likely was not fully effective until 2008. Therefore, it is advisable to move the 2007 data forward.

4.3.1. The estimated results of the entire phase

The third column of Table 6 shows the results of the inverse residual tungsten demand (RDE) and the inverse residual tungsten supply (RSE) functions for the entire study period (from 1992 to 2016).

In the estimation results of the RDE model, the sign of the estimated coefficient for the residual demand, $LnRD_j^c$, is negative, indicating a downward sloping residual demand for Chinese tungsten. The estimated coefficient for the importers' inverse residual demand is also the price flexibility of China's inverse residual demand function, which can be used to measure the market power of Chinese tungsten. It is

Table 6
Estimation results of RDE and RSE models.

Function	Variables	The whole phase	The supportive phase	The restrictive phase
Major importers' reverse residual demand:	$\text{Ln}RD_j^c$	**-0.269*****	**-0.257*****	**-0.300*****
		(0.0380)	(0.0594)	(0.0233)
	$\text{Ln}GDP_j$	**1.113*****	**0.477****	**0.733*****
		(0.145)	(0.223)	(0.168)
$LnP_j^{im} = \alpha_0 + \alpha_1 LnRD_j^c + \alpha_2 LnGDP_j + \alpha_3 LnP_j^{steel} + \alpha_4 LnP_j^{ti} + \alpha_5 LnH_j + \alpha_6 LnCMQ_j^{imoth} + \varepsilon_j$	$\text{Ln}P_j^{steel}$	**0.119***	0.0730	-0.162
		(0.0620)	(0.0491)	(0.0884)
	$\text{Ln}P_j^{ti}$	**0.173*****	**0.403****	**-0.0430***
		(0.0739)	(0.141)	(0.0223)
	$\text{Ln}H_j$	**0.209****	0.352	**0.491****
		(0.0779)	(0.243)	(0.188)
	$\text{Ln}CMQ_j^{imoth}$	0.0297	0.00997	-0.0547
		(0.0477)	(0.0728)	(0.0357)
	Constant	-10.45***	-7.673**	-11.59*
		(1.388)	(3.536)	(6.089)
China's reverse residual supply:	$\text{Ln}RS_c^j$	**-0.185*****	**-0.230*****	**-0.139*****
		(0.0229)	(0.0198)	(0.0182)
	$\text{Ln}GDP_c$	**0.622*****	0.723	**1.182*****
		(0.168)	(0.507)	(0.226)
$LnP_c^{ex} = \beta_0 + \beta_1 LnRS_c^j + \beta_2 LnGDP_c + \beta_3 LnP_c^{steel} + \beta_4 LnP_c^{ti} + \beta_5 LnH_c + \beta_6 LnCMQ_c^{exoth} + \beta_7 LnEP_c + \varepsilon_c$	$\text{Ln}P_c^{steel}$	**0.440****	-0.242	**0.930*****
		(0.195)	(0.436)	(0.109)
	$\text{Ln}P_c^{ti}$	**0.0461***	**0.0799****	-0.000675
		(0.0246)	(0.0309)	(0.0308)
	$\text{Ln}H_c$	0.0604	0.114	-0.440
		(0.114)	(0.236)	(0.310)
	$\text{Ln}CMQ_c^{exoth}$	**-0.160****	**-0.142****	**-0.163*****
		(0.0576)	(0.0656)	(0.0440)
	$\text{Ln}EP_c$	**-0.418*****		
		(0.134)		
	Constant	1.753	-0.467	9.699
		(1.380)	(2.286)	(6.307)
Price relationship:	Constant	**0.616*****	**0.298*****	**0.453*****
$LnP_j^{im} = \theta_0 + \theta_1 LnP_c^{ex}$	LnP_c^{ex}	(0.0441)	(0.0645)	(0.0861)

estimated to be −0.269 (at a 1% significance level), indicating that the market power of Chinese tungsten is 0.269. From another perspective, the estimated coefficient also indicates the market margin of China's tungsten exporting enterprises (the difference between China's tungsten export price and the sum of China's tungsten mining prices and the transaction costs of exports). This implies that the marketing margin of China's tungsten export enterprises is 26.9% of China's tungsten mining price.

For the estimated coefficient of importing country j's GDP, the results imply that keeping the other variables constant, a 1% increase in country j's GDP leads to a 9.75% increase in country j's import price from China. This result indicates that the demand for tungsten increases as the economy of the importing country improves, leading to an increase in the tungsten import price. The estimated coefficients of importing country j's prices of steel and ferrotungsten are 0.119 and 0.173, respectively, and they move in the same direction as the tungsten import price. The results indicate that as the price of steel and ferrotungsten, the alternative tungsten products, increase, the importing countries will reduce their demand for these products. However, this may increase the import demand for tungsten, resulting in an increase in the price of tungsten. Meanwhile, for the estimated coefficient of the country j's high-tech export scale, a 1% increase can lead to a 20.9% increase in the price of tungsten imports. When the scale of high-tech exports by importing countries is greater, the importing countries' investment in high technology is higher, and the more they need high-tech metal materials such as tungsten. Greater demand for tungsten in importing countries will inevitably lead to an increase in tungsten prices.

For China's reverse residual supply (the RSE model), we can analyse the major importers' import market power in the international tungsten trade. $LnRS_c^j$, which provides a measure of China's inverse residual supply, is estimated to be −0.185 (at a 1% significance level). This result indicates that the price elasticity of China's inverse residual supply is 0.185, which can be used to measure the import market power of the importers. From another perspective, the estimated coefficient also indicates the market margin of the tungsten importers (the difference between the import price and the transaction costs of imports). The results show that the importers' marketing margin is 18.5%.

Regarding the estimated coefficient of the GDP of China and the price of steel and ferrotungsten, the results show that they all have positive influences on tungsten's export price. The estimated coefficient of the amount of exported tungsten to countries other than country j, $\text{Ln}CMQ_c^{exoth}$, is −0.160. This result indicates that a 1% increase in the scale of exports to other countries leads to a 16.0% decline in China's tungsten export price to country j. Thus, as China's exports to other countries increase, country j reduces its tungsten demand from China, resulting in a reduction in China's export prices to country j.

Moreover, for the variable measuring China's tungsten export policy, $LnEP_c$, the sign is positive as expected, indicating that the impacts of China's policy on tungsten exports to the major importers are positive. Meanwhile, the variable $LnEP_c$ is significant at the 1% level, which implies that China's tungsten export restriction policies imposed significant impacts on China's tungsten exports to the other countries in the long run. The implementation of the tungsten export restraint policies indeed helped China gain greater market power. This result is consistent with the actual observations discussed in Section 2.

Based on the results, we find that the China's export market power and the major importers' market power are both significant. The estimated price flexibility of the importers' inverse residual demand for Chinese tungsten is 0.269, implying that the market margin of China's tungsten exporter enterprises is 26.9% of the export price. Meanwhile, the estimated price flexibility of the inverse residual supply function for the importers is 0.185, implying that the market margin of the importers' marketing margin is 18.5% of the import price. Comparing the

market power of China and the importers, it can be inferred that the export market power is greater than the import market power. China has stronger market power in the international tungsten market during the entire period. This finding is consistent with Leal-Ayala et al., (2015) and Dvořáček et al., (2017), who documented that the dominant market position in tungsten has been taken by China.

The above analysis shows that China has mastered the market power in international market trade over the past two decades. However, from the export policy encouragement period (1992-2007) to export policy restraint period (2008–2016), how did China's tungsten international market power change? Are the export control policies effective? We research these two issues in the following sections by measuring the market power in the export encouragement period and the restraint period.

4.3.2. The estimated results of the supportive phase

The results for the encouragement period (from 1992 to 2007) are shown in the fourth column of Table 6. For the major importers' reverse residual demand function (the RDE model), the estimated price flexibility of the importers' inverse residual demand for Chinese tungsten is −0.257 (at a 1% significance level). This result indicates that the price elasticity of the importers' inverse residual demand is 0.257, which can be used to measure the export market power of China, implying that the market margin of China's tungsten export enterprises is 25.7% of the export price. For China's reverse residual supply (the RSE model), the estimated price flexibility of the inverse residual supply function for the importers is −0.220 (at a 1% significance level). This result indicates that the price elasticity of China's inverse residual supply is 0.230, which can be used to measure the import market power of the importers, implying that the market margin of the importers is 23.0% of the import price. Comparing the market power of China and the importing countries, it is clear that 0.257 > 0.230, which means that the export market power is greater than the import market power. This result indicates that China had more market power in the international tungsten market during the encouragement period. During this period, China changed the supply of tungsten in the world by encouraging tungsten exports. As a result, China had a greater impact on the tungsten trade and greater market power.

For the estimated coefficient of the steel price, the results are nonsignificant in both the RDE model and in the RSE model. However, the results for ferrotungsten prices are still significant. The main reason for this phenomenon is that the amount of tungsten contains in ferrotungsten is much higher than that of steel. During the period when China was encouraging tungsten exports, the amount of tungsten needed for steel was sufficient. Therefore, the tungsten demand caused by changes in steel prices did not change much. At the same time, the impact of the scale of high-tech exports by the importing countries on the price of tungsten imports also became nonsignificant. This result indicates that during the period when China was encouraging exports, the importing countries' demand for high-tech tungsten materials was well met.

4.3.3. The estimated results of the restrictive phase

The results for the restraint period (from 2008 to 2016) are shown in the last column of Table 6. For the major importers' reverse residual demand function (the RDE model), the estimated price flexibility of the importers' inverse residual demand for Chinese tungsten is −0.300 (at a 1% significance level). This result indicates that the price elasticity of the importers' inverse residual demand is 0.300, which can be used to measure the export market power of China, implying that the market margin of China's tungsten exporter enterprises is 30.0% of the export price. For China's reverse residual supply (the RSE model), the estimated price flexibility of the inverse residual supply function for the importers is −0.139 (at a 1% significance level). This result indicates that the price elasticity of China's inverse residual supply is 0.139, which can be used to measure the import market power of the importers, implying that the market margin of the importers' marketing margin is 13.9% of the import price. Comparing the market power of China and the importing countries, it is clear that 0.300 > 0.139, indicating that the export market power is more than double the import market power. China thus had much greater market power in the international tungsten market during the restraint period. Due to the implementation of its export restriction policies. China, as the largest supplier of tungsten, has restricted tungsten mining and trade through a series of policy measures and gained even more pricing power in international trade.

In examining the entire period, the results show that the coefficient of Ln*GDP* has become larger. The results indicate that under the trend of economic globalization, the influence of the development of a country's economy on the price of metal resources has strengthened. However, the coefficient of the scale of high-tech exports by importing countries also more than doubled. This shows that after China restricted exports of tungsten, it became more difficult for the importing countries to import tungsten in order to develop high-end technologies. In contrast, no matter at what stage, the impact of high-tech exports in China is not significant, indicating that China must strengthen its high-tech investment in tungsten.

4.3.4. Comparison of market power in different policies stages

Based on the previous analysis, China's market power is greater than that of the importers through the entire period, the encouragement phase, and the restraint phase. This result can also be seen in Table 7. China's market power at the different stages was 0.269, 0.257, and 0.300, respectively, and the market power of the corresponding importing countries was 0.185, 0.230, and 0.139. China's market power at each stage was higher than that of the importing countries, showing that China has the most power in the international tungsten market. Then, what is the vertical change in market power from the perspective of the buyer and the seller?

As shown in Table 7, from the encouragement phase to the restraint phase, China's export market power increased from 0.257 to 0.300, which is an increase of 0.043. Meanwhile, the major importers' market power decreased from 0.230 to 0.139, which is decrease of 0.091. This shows that the effect of China's tungsten export restriction policies was very significant, and China has achieved effective control over tungsten resources. As a result, the difference in market power between China and the major importers increased from 0.027 to 0.161. This result further shows that after the introduction of the tungsten restriction policy in China, there was less room for the major importing countries to negotiate prices on tungsten imports. China's position in the international tungsten market has thus been further consolidated. This finding is consistent with Pothen (2014), Zhang et al. (2015) and Zhu et al. (2018b), who documented that the implementation of China's export policies has had significant effects in improving the pricing

Table 7
Comparison of international market power in different policies stages.

Phase	China	The importing countries	Market power difference
The whole phase (1992–2016)	0.269	0.185	0.111
The supportive phase (1992–2007)	0.257	0.230	0.027
The restrictive phase (2008–2016)	0.300	0.139	0.161

power of China's export products.

With the publishing of its tungsten export restriction policies, China has increased its position in the international market substantially and obtained more pricing power. The reasons for the dramatic increase in China's tungsten export power may include the following.

First, smuggling activities have been effectively controlled through export restrictions. Before the 21st century, there was a substantial amount of smuggling of China's tungsten. After the implementation of the export control policy, however, the smuggling situation improved, and the export control policy played a substantial restraining role. The export restriction policies greatly reduced the existing space for the smuggling of tungsten and improved tungsten exports.

Second, the price of tungsten has been well guided by industry associations. It is understood that changes in domestic product prices will also affect the international trade situation. The volatility in the prices of China's tungsten products from 2006 to 2008 was quite fierce, but they showed a clear downward trend. There was an urgent need for an industry association to guide the domestic tungsten products prices at the time. The Ganzhou Tungsten Cooperative, as the most influential tungsten mining industry organization in China, adopted measures to guide the price of tungsten through the issuance of forecast prices, and the downward trend in prices was effectively stabilized. The steadying of the price of domestic tungsten products also had a positive impact on export prices of tungsten in China.

Finally, the structural reform of the tungsten industry gradually yielded results. Since China proposed the "Belt and Road Initiative", structural reforms in the non-ferrous metal industry have been steadily pushed forward. Based on the supply-side structural reform goals, the Chinese Tungsten Cooperative and major tungsten enterprises have further reduced the inventory of tungsten products. With the reduction in the excess supply of tungsten in the domestic market, the effects of the tungsten industry reforms have gradually emerged. This has helped increase the industrial concentration and enhanced the position of China's tungsten industry in the international market.

5. Conclusions

5.1. Summary and conclusions

By extending the SMR model, this paper measures China's tungsten export market power during the period from 1992 to 2016. To analyse the effectiveness of China's tungsten export control policies, this paper measures China's market power during the encouragement stage and the restraint stage. By comparing the changes in market power in different policy periods, we evaluate the effects of the policies and analyse the reasons for the validity of China's export policies.

First, China's tungsten export policy has shifted from encouraging exports to limiting exports over the past two decades. As the world's largest supplier of tungsten, China occupies a very important position in the global supply of the metal. Meanwhile, as a net exporter of tungsten, China has fulfilled the tungsten demand of many countries.

Second, the empirical results show that China's market power is higher than that of the importing countries. In the entire period (1992–2016), China's market power was 0.269, and the importing countries' market power was 0.185. Moreover, during the encouragement phase (1992–2007) and the restraint phase (2008–2016), China's market power was 0.257 and 0.300, respectively, while the importing countries' market power was 0.230 and 0.139, respectively. China's market power in each stage was greater than that of the importers, which reflects China's has strong price influence in tungsten trading.

Finally, China's tungsten export market power has greatly improved from the encouragement period to the restraint period, and the difference in market power between China and the major importers increased from 0.027 to 0.161. The results support the finding that China has gained more export market power due to the implementation of export restrictions, and China's export control policies have effectively improved its market position.

5.2. Policy recommendations

On August 7, 2014, the WTO decided that China's tungsten export trade policy violated the trade rules. The WTO believes that China should manage its resource products in a manner consistent with WTO rules and maintain a fair international market environment. In fact, China's tungsten export pattern and the industry's pattern have already taken shape. China no longer needs to restrict exports to protect its rare metal resources. However, as can be seen from the results of Section 4, China's export market power will become even greater during the export restrictions on tungsten. If an export restriction policy cannot be implemented for tungsten, what can China do to maintain its dominant position in the international tungsten trade market? How to implement reasonable policies under the WTO rules is an urgent problem for the Chinese government. As the world economy becomes more closely linked, China can stabilize its tungsten export market power through the following policies.

First, China should increase its efforts to rectify the tungsten industry and build an effective leadership system. Under the WTO ruling that China cannot continue to impose export quota restrictions on tungsten, China can protect its tungsten resources by screening tungsten enterprises to meet export standards. This screening of companies requires an authoritative industry association. Moreover, in the short term, the overcapacity of tungsten products in China is difficult to eliminate. Once the supply is too great, the price of tungsten products will be greatly affected, and prices will be likely to decline. Even if China no longer restricts exports of tungsten products, tungsten companies will not be able to obtain more profits from exports at low price levels. The supply balance of tungsten products can be guaranteed only under the reasonable guidance of industry associations. Through industry associations, the government can vigorously promote structural reforms on the supply side of the tungsten industry to resolve the industry's overcapacity. These measures can also reduce the vicious competition and improve the concentration of the tungsten industry.

Second, China should formulate incentive policies to promote the technological upgrading of enterprises. Although China has dominated the international market for tungsten, tungsten in China is still at the low end of the industrial chain. The lack of high-end technology makes some advanced products available only through imports. The results in Table 6 show that high-tech exports have a significant impact on the price of tungsten. Therefore, it is necessary to strengthen the investment in tungsten in high-tech technology. The government can promulgate policies to support the development and application of high-end products in the rare metals industry. The incentive policy can be established in three ways. First, enterprises can be provided financial support for high-tech technology. Then, the government and companies can jointly invest in setting up key laboratories. Finally, the government can strengthen intellectual property protections for innovative tungsten technology and occupy a core link in the industrial chain. This approach could help China overcome the existing technical difficulties and break through the monopoly of foreign rare metal technologies. In addition, it can further consolidate China's position in the tungsten market.

Finally, China needs a larger and a more influential futures trading platform. Under the trend of commodity financialization, the prices of commodities are increasingly affected by the prices of their futures products. The futures market can help to adjust the speed of production and circulation of domestic tungsten mineral resources. When a country's futures market is functional and closely linked to the rest of the world, the country can gain more spot pricing rights for products. To obtain more international market power, the government needs to first concentrate on the domestic tungsten futures market. China's tungsten resources should have their own futures products. In addition, domestic

financial institutions should actively participate in price discovery in the futures market. With a functional futures market, China will undoubtedly obtain more pricing power in the international market.

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