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What drives embodied metal consumption in China’s imports and exports

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A B S T R A C T  
The expansion of trade has not only increased imports and exports, but also increased metal consumption embodied in them. Based on China’s input-output tables from 1997 to 2017, this study uses structural decomposition analysis (SDA) to analyze China’s consumption of embodied metal in imports and exports in each sector, and identify their driving factors at the holistic, industrial and sub-sectoral levels. The results show the following.  
1) China is a net importer of embodied ferrous metal and a net exporter of embodied non-ferrous metal, and the change of the embodied metal consumption showed an inverted U-shape.  
2) The scale effect was the main driver for these increases; the technology and intensity effect were the primary inhibitor of embodied ferrous and non-ferrous metal consumption, respectively; the structure effect increased metal consumption embodied in imports more than in export.  
3) Industry contributed most to the consumption, and the factors were heterogeneous in different industrial sub-sectors: the inhibitory effect of technology was more obvious in imports than in exports, and the structure effect promoted more embodied ferrous metal consumption import and more non-ferrous metal consumption export; the intensity effect was promoter before 2007 while its inhibitory effect became more obvious after 2012.  
4) China’s technology level and metal utilization efficiency were still lower than those in foreign countries; the effect of technology to reduce embodied metal consumption was small but had potential impact. Based on these results, relative policy recommendations are proposed.

1. Introduction  
Accompanied by the rapid economic growth and development of international trade in recent decades, China has become the largest exporter, the second largest importer, the largest consumer of resources and the second largest economy in the world (Global Environmental Outlook report, 2013; National Bureau of Statistics of China, 2018). Especially since China’s accession to the WTO in 2001, the volume of foreign trade has boomed: the import volume increased from RMB 1863.8 billion in 2000 to RMB 18,409.8 billion in 2017 and the export volume increased from RMB 2063.4 billion to RMB 22,635.2 billion, which was eleven times than that in 2000, making China the leading trade country in the world (National Bureau of Statistics of China, 2018). Nevertheless, the expanding imports and exports may exacerbate the depletion of natural resources (Liang et al., 2007; Shui and Harriss, 2006; Tian et al., 2018), as there are substantial amounts of resources embodied in trade, such as water (Han et al., 2018), coal (Wang et al., 2019), land (Yu et al., 2013) and metal resource in particular. However, when discussing the trade of metal resources, imported and exported products containing metals are rarely considered. Beyond the large direct metal resource trade, there is still a substantial amount of products or goods that indirectly contain metals (Wang et al., 2019), which we can call as embodied metal consumption in trade.

As global value chains continue to expand and deepen, the traditional statistical methods of metal trade have many significant shortcomings (Ang, 2004). The trade of metals should not be limited to the direct volume, but should also focus on metals consumed in import and export commodities, because metal is not only a trade product, but also an important intermediate input (Zhang et al., 2019). This is especially important for developing countries with high dependence on foreign trade, such as China. On the one hand, China’s large metal consumption is not entirely for domestic use (Li et al., 2018). Through exports, metals used indirectly for the production of exported products are massively consumed abroad (Wang et al., 2019; Feng et al., 2019). On the other hand, China also imports metal-containing products, such as home appliances, automobiles, machine tools, etc., which will substitute domestic metal consumption and alleviate to a certain extent the shortage of resources (Wang et al., 2019).

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Ignoring the metal consumption embodied in imports and exports will misestimate the utilization efficiency of metals, making it impossible to accurately understand the relationship between China’s economic development and its actual metal consumption. This will further lead to the deviation of policy orientation, which makes the metal resource consumption more unbalanced and unstable; especially when the severe resource shortage happened in China is restricting the sustainable development of the economy. Furthermore, the current studies on metal trade mainly focus on the national level or the external relations with trading countries, while the internal characteristic of each sector is neglected. Besides, ferrous and non-ferrous metal may have different importance in the imports and exports in different sectors, which is also an integral part that should be evaluated. How much ferrous and non-ferrous metal does each sector indirectly consume in imports and exports? Is China a net importer or exporter of embodied metal? What are the main driving factors to the change in the consumption of embodied metals in imports and exports? Are there any sector characteristics of the consumption? The study of these issues is of great significance in deepening our understanding of the relationship between trade, economic growth and metal consumption in order to formulate appropriate policies. Under this circumstance, we quantify all products and services in Chinese imports and exports containing metals and calculate the metal input ratio of each sector to obtain the consumption of ferrous and non-ferrous metal embodied in imports and exports for each sector; and further study the changes of the consumption to identify the drivers behind the changes.

The contribution of this study can be summarized as follows. First, this study is the first attempt to analyze China’s embodied metal consumption in imports and exports by applying China’s latest input-output data, which can build an integrated understanding of total metal consumption. In addition, by developing the concept of ‘embodied metal’, we further enrich the theoretical system of ‘embodied resource’ by extending it to a deeper level. Second, this study calculates embodied metal consumption in each sector but not only on the holistic level, which is significant for reference. And it can provide a more detailed and specific explanation of the drivers of changes in embodied metal consumption in imports and exports, for more targeted policy recommendations on specific sectors are able to be proposed. Third, we distinguish the ferrous and non-ferrous metal to make the study more subtle and more policy-applicable. Moreover, the consumption of embodied metals in imports and exports is both studied, providing a comprehensive understanding of this consumption in trade, which can better serve the policymaking.

The rest part of this study is organized as follows. Section 2 reviews the related literature. Section 3 presents the method in this study and the data collected. In Section 4, we present the results on the changes in China’s consumption of embodied metals in imports and exports and analyze the drivers of the changes. Section 5 concludes the study and proposes recommendations for relative policy implementation.

2. Literature review

2.1. The concept of embodied

The term ‘embodied’ was first proposed in the 1970s at a meeting of the energy analysis working group of the International Federation of Institutes for Advanced Study (IFIAS). It was pointed out that the term ‘embodied’ can be used to measure the total quantity of a resource consumed directly and indirectly in production (Slesser, 1974). ‘Embodied’ means materialization, containing, and implications. In principle, any resources can be added to the term ‘embodied’ (Brown and Herendeen, 1996), such as energy, CO2 (Dong et al., 2018; Ju et al., 2019) copper (Leontief, 1970), labor forces (Bezdek and Hannon, 1974) or ammonia (Herendeen, 1990), to name but a few. Therefore, the term ‘embodied’ can be used to measure the total amount of direct and indirect use of a particular type of resource during the production process of a product or service (Slesser, 1974). Previous researches analyze resources and energy for the intention to quantify the relationship between human activities and some types of important resources, indicating that compared with the indicators of traditional economic analysis, resources are more essential to the development of the economy and society (Brown and Herendeen, 1996). For example, Wang et al. (2019) examine global embodied mineral flows and construct a global embodied mineral flow network, showing that China has lower mineral use efficiency than other countries. Han et al. (2018) analyzes global water transfers embodied in international trade and assesses transfer patterns, efficiency, and pressures. Liu et al. (2018) study energy embodied in international trade in the construction industry using a measure of vertical specialization from the perspective of demand and supply.

The literature discussed above provides a better understanding of embodied resources which lays a solid foundation for our research. However, there are little researches focusing on embodied metals in international trade. In this study, we define the embodied metals in imports and exports as the total metal input used in the production of imported or exported commodities and services.

2.2. Exports and imports of metals

There are 3 types of studies on the metal trade in current researches: First, a bulk of current studies focus on direct trade in metals to analyze the demand and supply in the international metal market or global flows of metal resources. For example, Zhang et al. (2017) analyzes copper flows from ore to final products in international trade from 1975 to 2015 and finds that China’s copper resources showed stable supply and demand. Wang et al. (2019) studies global embodied rare earth flows using a complex network approach and finds that the world embodied rare earth flow network is clearly divided into two communities and that this network presents the characteristics of a small-world nature characteristics. Second, another type of study analyzes the effects of trade policy adjustment on trade in metals. For example, Zhu et al. (2018) proposes a mode decomposition counterfactual analysis method to estimate the effects of China’s export policy on tin prices and conclude that this export policy mainly influences the supply side of the international tin market. Ge and Lei (2018) develop a computable general equilibrium model and find that resource tax reforms will increase the prices of rare earths, thus limiting production and demand. The third type of study focuses on identifying the factors influencing the trade of metals. For example, Zheng et al. (2017) extend the standard gravity model to investigate the determinants of China’s imports and exports of non-ferrous metals using panel data from 40 countries or regions between 1995 and 2015. They find that market size, ore resource endowment, trade openness and port development affected this trade. Lin establishes a framework based on four stages of the indium life cycle to analyze the dynamics of import and export trade from 2007 to 2014.

According to the literature, China is one of the largest importers and exporters of metals in the world. However, it lacks the corresponding power discourse in international trade (Jiang et al., 2019a, 2019b). Large amounts of metal resources are imported and exported, challenging the security of domestic supply. Although many studies focus on the total amount of metals and some particular types of metal resources in trade, few studies examine embodied metal resources in imports and exports, let alone distinguishing it into ferrous and non-ferrous metal, which gives us the necessary space for further analysis.

2.3. SDA method

In recent years, structural decomposition analysis (SDA) has been widely applied to study changes in energy consumption and issues related to emissions and materials. Myers and Nakamura (1980) and Bossanyi et al. (1980) were the first to use decomposition analysis to study changes in energy consumption. Since 2000, the SDA method has
been increasingly used in to study the increase of CO2 emissions (Kagawa and Inamura, 2001; Su and Ang, 2012). In addition, energy consumption and emissions embodied in trade, which are based on consumption, have gained increasing attention. The SDA method is often used to study the driving factors related to different final demands, such as international trade (imports and exports), household consumption (Song et al., 2019) or government consumption (Fan et al., 2019). Applications of the SDA method in trade can be divided into three types: The first type is to determine the environmental consequences of an economy’s international trade on imports or exports, as it can determine what drives the changes in emissions in trade (Liu et al., 2010a; Xu et al., 2011; Jiang et al., 2019a, b). For example, Duan and Yan (2019) applies the SDA approach to provide a comprehensive picture of the structure of international trade in terms of the environmental consequences of trade, concluding that China suffers greater environmental losses through exports than most of its trading partners. Zhao et al. (2016) investigate the drivers of CO2 emissions in China-US trade and find that CO2 emissions are mainly driven by total demand abroad. The second type is to analyze the resources of international trade. For example, Distefano et al. (2018) applies the SDA method and reveals that size-related, technological and structural components contribute substantially to changes in virtual water use. The third type focuses on the effect of trade on economic growth. For example, Magacho et al. (2018) applies the SDA method to determine whether there is a substitution of imported inputs for domestic inputs in Brazil and other countries. The study concludes that in Brazil’s growth path in the 2000s, the substitution of imported inputs played a key role and offset the positive effect of export growth, especially in the high-tech sector.

This study applies the SDA method based on the IO model to calculate the embodied ferrous and non-ferrous metal input and output ratio of each sector and analyze the changes in the consumption of embodied metals in China’s imports and exports, and identify the drivers for their fluctuation. This study can lead to a better understanding of the flow of essential metal resources embodied in China’s trade, with corresponding policy implications based on the decomposition results.

3. Methodology and data

3.1. Input-output analysis

Normal input-output (IO) models analyze the flow of goods between different industries in an economy (Xu and Liang, 2019), which is a mature approach dating back to Leontief’s former work in the 1930s (Leontief, 1951). Input-output models include the single-region IO (SIO) model and multi-region IO (MIO) models. Su and Ang (2013) compared the merits and demerits of the SIO and MIO model, and further found difference between competitive SIO (treating the imports as the same of the domestic ones) versus non-competitive SIO (treating the imports as different from the domestic ones). In the I-O literature, studies on sector aggregation mainly employ the SIO model, while those on spatial aggregation often use the MIO model (Su and Ang, 2010). The multi-region IO model requires global input–output tables, which are more difficult to obtain and update (Wiebe et al., 2012). Because lower data requirement, the SIO model has been used by most single-country studies (Su and Ang, 2013).

The purpose of this study is to identify driving factors of embodied metal consumption on China’s sector aggregation, the SIO model is our primary choice. Moreover, the sector classification of the World Input–Output Table does not include the mining of metal ores, we cannot use the MIO model to obtain metal consumption in various sectors (Song et al., 2019). Since China uses the competitive imports assumption to compile national I-O tables (Su and Ang, 2013), this study uses the SIO model with the competitive imports assumption.

As is shown in Table 1, in an economy, sectors are linked by supply and demand; thus, the IO model can be defined as

Table 1

| Structures of the SIO tables with competitive imports assumption. |
|---------------------------------------------------------------|
| Intermediate | Final demands | Imports | Total outputs |
| Transactions | | | |
| Inputs | $Z_1 = Z_0 \cdot 1 + Z_1 \cdot 1$, $y_1 + c + k + e = i = Z_1 \cdot 1 + x$ | $1 - Ax$ | $y_1$ |
| Value added | $\nu$ |
| Total inputs | $x$ |

where $x$ denotes the total output vector and $Z$ denotes the intermediate demand matrix. $Z_0$ denotes domestic intermediate demand matrix and $Z_1$ denotes imported intermediate demand. $A = (a_{ij})$ is the matrix of direct input coefficients $(n \times n)$ representing the relationship between all sectors in an economy, where $a_{ij} = x_j / x_i$ $(i, j = 1, 2, ..., n)$ is one unit of output in sector $j$ requiring how much of the input of sector $i$ directly. The vector of intermediate input is described as $Ax$. $y$ is the total domestic final consumption vector, including $y_0$ (domestic final consumption vector), $y_1$ (imports for final consumption), $c$ (consumption) and $k$ (capital formation). $i = Z_1 \cdot 1 + y_1$ is total imports vector and $e$ is total exports vector. As this study mainly measures the changes in China’s embodied metal consumption in imports and exports, the relevant analysis is mainly carried out on $i$ and $e$.

Eq. (1) is defined as

$$x = (I - A)^{-1} (c + k + e - i) = B (c + k + e - i)$$

$$B = (I - A)^{-1}$$

where $I$ is the identity matrix, $B$ is the Leontief inverse matrix, which demonstrates the total amount of output from sector $i$ needed to produce one unit of final demand from sector $j$ directly and indirectly.

3.2. Structural decomposition analysis

In this study, the SDA method is applied to study the changes in China’s imports and exports of embodied metal consumption and to compare and analyze the degree of contribution of the factors from 1997 to 2017. $f$ is defined as the total metal consumption intensity, its elements represent the total metal consumed per unit of output of each sector (Song et al., 2019). This study applies substitution method which assumes that the total metal consumption intensity coefficient of imports is equal to the total domestic metal consumption coefficient, and $df$ times the import or exports volume represents the metal consumption embodied in imports and exports. Thus, the equation of embodied metals in imports and exports can be obtained as Eq. (4) and Eq. (5):

$$n'f = n' \times e$$

$$n'f = n' \times i$$

where $i$ and $e$ are the total amount of imports and exports, including intermediate inputs and direct consumption. $n'$ and $n''$ are the embodied metal consumption in imports and exports, superscripts $i$ and $e$ represent imports and exports, respectively. However, it should be noted that China’s major importing countries are developed countries with relatively low metal intensity, such as EU countries, the United States, Japan and Australia. Therefore, the embodied metal consumption in imports calculated by the substitution method is relatively high. Then the changes of embodied metal consumption in imports and exports can be computed as
\[ \Delta n' = F_1 i_1 - F_0 i_0 \]  
\[ \Delta n'' = F_1 e_1 - F_0 e_0 \]  
where \( F \) represents the diagonalization of vector \( f \Delta \) represents the changes of variables. Subscripts 1 and 0 represent the report period and basic period.

Non-uniqueness problems often arise with structural decomposition analysis (Dietzenbacher and Los, 1998), from different order of factors will result in different forms of decomposition. A change determined by \( n \) factors will lead to \( n! \) types of decomposition form. If these \( n! \) types of changes will result in different forms of decomposition. A change determined by \( \Delta n \) from different order of factors will result in different forms of decomposition. A change determined by \( \Delta n \)

According to Eq. (4), changes in the total intensity of metal consumption \( (I) \) multiplying the Leontief inverse matrix,
\[ f = (I - A)^{-1} \times I = BI \]  
According to Eq. (4), changes in the total intensity of metal consumption \( \Delta f \) results from the changes in the intensity of direct sectoral metal consumption \( (\Delta I) \) multiplied by the change of the Leontief inverse matrix \( (\Delta B) \); that is,
\[ \Delta f = \frac{1}{2} A B (l_1 + l_0) \quad \frac{1}{2} B (l_1 + B_0) \Delta I \]  
where \( l_i \) and \( l_0 \) are the intensity of direct sectoral metal consumption in the comparative year and the basic year, respectively. \( B_1 \) and \( B_0 \) are the Leontief inverse matrices of the comparative year and the basic year, respectively. Furthermore, the change of the Leontief inverse matrix is due to the changes in the matrix of direct input coefficients.
\[ \Delta B = B_1 - B_0 \]  
Finally, by replacing the above formulas with \( \Delta n \), the changes in China’s consumption of embodied metals in imports and exports can be defined as follows:
\[ \Delta n = 1/4 B_1 l_1 + B_0 l_0 \Delta s + s_0 \Delta n \]  
where the superscript \( i \) and \( e \) can be added to \( \Delta n \)s and \( n \), which means the imports and exports decomposition formulas, respectively.

Equation (17) shows that the changes in China’s consumption of embodied metal in imports and exports are decomposed into four drivers, each row of the equation represents each driver: the first driver is the technology effect \( (T) \), representing the influence of technological advances on embodied metal consumption resulting from the change in the proportion of inputs and outputs, and can be further described as the structural change of the Leontief inverse matrix; The second driver is the intensity effect \( (F) \), representing the change in embodied metal consumption during the economical production, which indirectly affects the amount of embodied metal consumed, and can be either an increase or a decrease; The third driver are the export structure effect \( (S) \) and the import structure effect \( (S') \), which are the resulting from upgrading or downgrading the structure of imported and exported goods and services, and can have a dual effect; The last driver are the import scale effect \( (I) \) and export scale \( (E) \), representing the effect of scaling out and scaling in on China’s consumption of embodied metals in imports and exports.

3.3. Data source

3.3.1. Input-output tables

This study obtains the original data from input and output tables of basic flows in 1987, 1990, 1992, 1995, 1997, 2000, 2002, 2005, 2007, 2010, 2012, 2015 and 2017 in China, which come from China’s National Bureau of Statistics. However, the IO tables for 1987, 1990, 1992, 1995, 2000, 2005, 2010 and 2015 do not separate the imports and exports data, which only have the net exports data. Therefore, we only use the IO tables of 1997, 2002, 2007, 2012 and 2017 in this study. As shown in Table 2, the sectors in IO tables in different years are inconsistent, and the data of each sector can only be merged, there is no way to split. Although sector aggregation may cause uncertainties to results of IO models (Lenzen, 1998; Su et al., 2010; Wiedmann et al., 2011), to facilitate comparison, all sectors are merged into 99 sectors based on their close links. The aggregations include agricultural sector (1 to 5) as the primary industry, industrial sectors (6 to 75) as the secondary industry, and services (77 to 99) as the tertiary industry, which is shown in Table A1 in supporting file.

Based on the price index deflation method (Du et al., 2011; Gui et al., 2014), this study converts the original IO tables into 99 sectors based on fixed prices in the year of 1997 to eliminate the uncertainty caused by the price fluctuation. Various price indices are applied with consideration for sectoral heterogeneity, which are all come from China’s National Bureau of Statistics, including producer price index of agricultural products (from 1 to 5), the producer price index of industrial products (from 6 to 75), and installation engineering price index, retail price index, traffic and communication consumer price index, dining out food price index, financial price deflator, real estate price index (S90) and price index of services (from 77 to 99).

3.3.2. Direct metal consumption

Because metal ores can only get into the industrial value chain from extraction, metal consumption is equal to metal ore mined domestically, and we only consider the extraction of used metal and exclude the unused metal for it does not enter into the economic system (S. Zhang et al., 2019; Y. Zhang et al., 2019). The data is obtained from www.materiateflow.net (World Steel Association, 2015).

The output of mining of metal ores sector is used in the sectors with their close links. The aggregations include agricultural sector (1 to 5), as the primary industry, industrial sectors (6 to 75), as the secondary industry, and services (77 to 99) as the tertiary industry, which is shown in Table A1 in supporting file.

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so we rely on the assumption of identical prices (Wang et al., 2017) to obtain the consumption of each sector. It indicates that the specific value of the commodities and services in the sector of mining of metal ores contain the same amount of metal, no matter their output are sold to whom (Song et al., 2019). Thus, based on the IO table, the coefficient of metal ore consumption (D) is calculated as follows:

$$D = (I - A)^{-1} - I$$

Then, the ferrous ($m^f_i$) and non-ferrous ($m^n_i$) metal consumption of sectoral level can be obtained as

$$m^f_i = m^f \times D_{ni}$$

$$m^n_i = m^n \times D_{ni}$$

where $m^f_i$ and $m^n_i$ is the consumption of ferrous and non-ferrous metal in sector $i$, and $m^f$ is the total ferrous metal consumption, $m^n$ is the total non-ferrous metal consumption. $D_{ji}$ and $D_{ni}$ is the sectoral consumption coefficient of the mining of ferrous metal ores sector (S8), and the mining of non-ferrous metal ores sector (S9).

### 4. Results and discussion

#### 4.1. Holistic analysis

The changes and the contributions of the four drivers of ferrous and non-ferrous metal consumption embodied in imports and exports in China in different periods are shown in Table 3 (ferrous metal) and Table 4 (non-ferrous metal), respectively. As shown in Table 3, from 1997 to 2017, the ferrous metal consumption embodied in imports and exports in China increased by 762.29 million tons and 668.20 million tons, respectively. The total changes of ferrous metal consumption embodied in imports and exports by 96.59 million tons and 200.31 million tons. Such large scale has greatly promoted the total change of metal consumption embodied in the imported and exported commodities and service. It is worth noting that from 2007 to 2012, the ferrous and non-ferrous metal consumption embodied in imports increased even faster, while in exports decreased. On the one hand, affected by the 2008 financial crisis, China’s exports suffered greatly due to the rising of RMB exchange rate and the loss of international competitiveness (Zheng et al., 2017; Yu et al., 2020), which led to the decrease in metal consumption embodied in exports. On the other hand, the 4 trillion RMB economic stimulus plan enacted in 2009 encouraged the domestic demand (Zhou et al., 2011), and the sharp decline in the international price of raw materials such as steel, promoted the metal consumption embodied in imports (Song et al., 2019). However, the influence of the scale effect has been declined from 2012 to 2017, for China has entered ‘the new normal of economy’, characterized by a slow-down in trade growth (Chen and Groenewold, 2019). From the above results, it can be infer that the scale effect will continue to decline moderately (Song et al., 2019).

The structure effect increased the ferrous metal consumption embodied in imports by 86.67 million tons while decreased that in exports by 96.59 million tons. From 2002 to 2007, it was a promoting effect in imports and exports. On the one hand, as ‘the world factory’, China had exported many low-end and metal-intensity products (Zhu et al., 2011), which contributed to the rising metal consumption embodied in exports. On the other hand, after 2002, domestic resource cannot meet the requirement of strong production and the rapid industrialization, especially the non-agricultural products, which contain more metal resource (Roberts and Rush, 2012; Zhang et al., 2017; Wiedmann et al., 2015). However, from 2007 to 2017, the structure effect became the inhibiting effect, especially from 2007 to 2012 and rapidly declined from 2002 to 2017, while the decrease in exports slowed down from 2012 to 2017. The intensity effect was the only factor to reduce the embodied non-ferrous metal consumption in both imports and exports, and the other three factors promoted the growth.

The scale effect was the most important factor in increasing the ferrous and non-ferrous metal consumption embodied in both imports and exports, with imports larger than exports. Since the entry into WTO, the trade scale has increased rapidly and China’s economic growth also depends much on foreign trade (Zheng et al., 2017). For example, the ferrous metal consumption embodied in imports increased from 49.32 million tons (from 1997 to 2002) to 176.39 million tons (from 2002 to 2007), and in exports from 35.03 million tons to 200.31 million tons. Such large scale has greatly promoted the total change of metal consumption embodied in the imported and exported commodities and service. However, from 2007 to 2012, the ferrous and non-ferrous metal consumption embodied in imports increased even faster, while in exports decreased. On the one hand, affected by the 2008 financial crisis, China’s exports suffered greatly due to the rising of RMB exchange rate and the loss of international competitiveness (Zheng et al., 2017; Yu et al., 2020), which led to the decrease in metal consumption embodied in imports. On the other hand, the 4 trillion RMB economic stimulus plan enacted in 2009 encouraged the domestic demand (Zhou et al., 2011), and the sharp decline in the international price of raw materials such as steel, promoted the metal consumption embodied in imports (Song et al., 2019). However, the influence of the scale effect has been declined from 2012 to 2017, for China has entered ‘the new normal of economy’, characterized by a slow-down in trade growth (Chen and Groenewold, 2019). From the above results, it can be infer that the scale effect will continue to decline moderately (Song et al., 2019).

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### Table 3

Decomposition results of ferrous metal consumption embodied in imports and exports.

| Year | Growth (million tons) | Contribution (%) |
|------|-----------------------|------------------|
|      |                      | 1997–2002 | 2002–2007 | 2007–2012 | 2012–2017 | 2007–2002 | 2002–2007 | 2007–2012 | 2012–2017 | 2007–2017 |
|      | Import T              | –1.58     | 47.32    | –1.15     | –121.77   | –14.19    | –8.70     | 11.28     | –0.33     | 59.36     | –1.86     |
|      | P                    | –28.52    | 172.71   | 187.61    | –239.19   | 31.71     | –156.97   | 41.16     | 53.24     | 116.59    | 4.16      |
|      | S^1                  | –1.05     | 23.24    | –61.99    | –10.13    | 86.67     | –5.79     | 5.54      | –17.59    | 4.94      | 11.27     |
|      | I                    | 49.32     | 176.39   | 227.90    | 165.94    | 658.10    | 271.47    | 42.03     | 64.67     | 80.89     | 86.33     |
|      | Total                | 18.17     | 419.66   | 352.38    | –205.15   | 762.29    | 100       | 100       | 100       | 100       | 100       |
|      | Export T             | 0.09      | 41.22    | 0.99      | –79.05    | 29.10     | 0.78      | 8.39      | 0.34      | 24.23     | 4.35      |
|      | P                    | –7.88     | 267.98   | 235.88    | –382.94   | 154.84    | –67.20    | 42.34     | 80.13     | 117.38    | 23.17     |
|      | S^1                  | –15.51    | 41.66    | –105.95   | –19.80    | –93.59    | –122.18   | 8.48      | –35.99    | 6.07      | –14.01    |
|      | I                    | 35.03     | 200.31   | 163.45    | 155.56    | 577.85    | 298.59    | 40.78     | 55.53     | 47.69     | 86.48     |
|      | Total                | 11.73     | 491.18   | 294.37    | –326.22   | 668.20    | 100       | 100       | 100       | 100       | 100       |

Note: MT is master table and ET is extension table.
2012, reducing the ferrous metal consumption embodied in imports and exports for 61.99 million tons and 105.95 million tons, respectively. This may be due to the optimization of the import and export commodity structure, which had shifted from resource-based products to medium or high tech-based products (Li et al., 2018). The change trend of the structure effect on embodied non-ferrous metal consumption was similar to that of ferrous metal, while the effect was smaller, increased by 41.45 million tons in imports and 4.17 million tons in exports. Overall, the structure effect may continue to reduce the ferrous metal consumption embodied in imports and exports, while may increase the non-ferrous metal consumption in exports.

From 1997 to 2017, the intensity effect increased the ferrous metal consumption embodied in imports and exports by 31.71 million tons and 154.84 million tons, respectively. The results indicate that foreign metal utilization efficiency is higher than China, for export production consumes more metal than imports. From 2002 to 2012, the embodied ferrous metal consumption increased rapidly, which partly promoted by the intensity effect. The industrialization and urbanization in China has greatly developed (Xia et al., 2016; Feng et al., 2019), and many resource-intensity sectors were encouraged to ensure economic growth. The ferrous metal consumption and economic growth had been strongly coupled (Song et al., 2019). However, the intensity effect significantly reduced the embodied ferrous metal consumption when economic development faced more serious constraints in terms of resource bottlenecks so that the efficiency was greatly improved, leading to this sharp drop in imports and exports, accounting for 116.59% and 117.38% of the total change from 2012 to 2017. Different from ferrous metal, the intensity effect was the primary inhibitor for non-ferrous metal consumption embodied in both imports and exports, reducing it by 309.07 million tons and 146.98 million tons, respectively. It indicates that non-ferrous metal utilization has improved more than ferrous metal. The decrease trend has begun in 2007, with imports faster than exports, and it can be inferred that the intensity effect will keep playing the important role in reducing the ferrous and non-ferrous metal consumption embodied in imports and exports.

Technology was a potential effect to reduce the embodied metal consumption. Although it increased the ferrous and non-ferrous metal consumption embodied in imports and exports from 2002 to 2007, the promoting effect was weak and became inhibiting effect after 2012. It decreased ferrous metal consumption embodied in imports by 121.77 million tons and in exports by 79.05 million tons, and decreased non-ferrous metal consumption embodied in imports for 28.05 million tons and 24.88 million tons. More and more effort will be paid to technological improvement and the effect of technology to reduce embodied metal consumption will be enhanced. Especially we are facing the new round of technological revolution marked by information, which greatly affected the production progress and further influenced consumption of metal embodied in imports and exports, with aspects to resources saving, substitution and application development (Song et al., 2019). For example, technology has improved in metal resources recycling to recover more varieties of metal, such as aluminum (Gaustad et al., 2012) and copper (Teh et al., 2010), and to improve the recycling efficiency.

### 4.2. Sectoral analysis

This study further divides the change of ferrous and non-ferrous metal consumption embodied in imports and exports from 1997 to 2017 at the sectoral level. Table 5 (ferrous metal) and Table 6 (non-ferrous metal) show the effects of the four drivers in Ag-, In- and Se-, representing agriculture, industry and services, respectively.

The scale effect was the main factor promoting the growth of ferrous and non-ferrous metal consumption embodied in imports and exports in each sector, while its influence shows a decrease trend. The intensity effect shows differences between ferrous and non-ferrous metal: it was a promoter in the growth of embodied ferrous metal while was an inhibitor of embodied non-ferrous metal in each industry. However, the promoting effect became the inhibiting effect after 2012, and the contribution of technology to reduce the embodied metal consumption has gradually increased. In each sector, the structure effect was the promotor of ferrous metal consumption embodied in imports while reduced that in exports. The promoting effect of structure on non-ferrous metal was most obvious in industry and import service, while was not obvious in agriculture and export service. Technology reduced embodied metal consumption in agriculture. It indicates that agricultural production technology in China and abroad has both been improved. With the acceleration of agricultural automation, metal plays an important role in the planting and transportation of agricultural raw materials (Jiang et al., 2018). It also increased the embodied non-ferrous metal consumption in industry, while the promoting effect was not obvious in ferrous metal consumption embodied in export of industry. It was worth noting that technology increased both embodied ferrous and non-ferrous metal consumption in service, and its contribution was largest in service, especially from 2007, with exports increased faster than imports. It shows that the development of service in China is not as sufficient as abroad. In addition, China’s service exports continue to grow in a traditionally backward way, which are supported by the traditional telecommunications services, transport services and other services, and are mainly resource-based, labour-intensive and relatively low-tech.

From the above results, it shows that industry has decisive effect on promoting the ferrous and non-ferrous metal consumption embodied in both imports and exports. In comparison, agriculture had the smallest effect. Economic growth requires constant stimulation from the manufacturing sectors (Feng et al., 2019). At the same time, there shows a rising demand for embodied metal consumption in services. Service sectors such as transportation and communications require metal input indirectly, especially the strategic non-ferrous metal. As China has taken more important part in the global service trade market, embodied metals consumption in service will increase.

#### 4.3. Sub-sectoral analysis in industry

As industry accounts for the largest proportion of the change in China’s ferrous and non-ferrous metal consumption embodied in imports and exports, it is necessary to further decompose it into sub-
The intensity effect increased the ferrous metal consumption in most sectors, and only had the inhibiting effect on five sectors in imports, with mining of ferrous metal ores being the most affected ($S_8$, 116.14 million tons), and two in exports, with manufacture of generators and electric motors being the most affected ($S_{63}$, -17.96 million tons). Different from embodied ferrous metal consumption, the intensity effect was the main inhibiting effect in embodied non-ferrous metal consumption, with manufacture and casting of non-ferrous metals and related alloys being the most affected in imports ($S_{51}$, 64.77 million tons) and processing of non-ferrous metals being the most affected in exports ($S_{52}$, 19.86 million tons). It only increased the consumption in four sectors in imports and thirteen sectors in exports, and the promoting effect was small. The structure of imports and exports had different effects in sectors; overall it increased more ferrous and non-ferrous metal consumption embodied in imports than in exports, which shows a trade structure of importing more metal-intensity products. In contrast, technology reduced more metal consumption embodied in imports than exports, which shows that the foreign technology has improved better in saving metal resources. Furthermore, the influence of technology was the smallest compared to other factors, it is urgent to attach more importance to technological advancement in order to reach its full potential of promoting industrial upgrading (Zhang et al., 2019).

Fig. 1 shows that the scale effect constantly promoted the growth of embodied ferrous metal consumption, after 2007, it became the main driving force to the consumption embodied in import sectors. The results are more significant in non-ferrous metal: as shown in Fig. 2, the scale effect was the primary driving force of embodied non-ferrous metal consumption in all industries, especially from 2002 to 2012, in mining industry, light industry and equipment manufacturing industry. The

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### Table 5

Decomposition results of ferrous metal consumption embodied in imports and exports.

| Sector | Import | Export |
|--------|--------|--------|
|        | 1997-2002 | 2002-2007 | 2007-2012 | 2012-2017 | 1997-2017 | 1997-2002 | 2002-2007 | 2007-2012 | 2012-2017 | 1997-2017 |
| Ag     | -0.46  | 0.43   | 0.08  | -2.45  | -3.57  | -0.42  | 0.56   | 0.14   | -2.05  | -2.28   |
| F      | -0.31  | 2.43   | 1.70  | -3.89  | 1.19   | -0.07  | 4.04   | 3.10   | -6.40  | 4.31    |
| S      | -0.12  | -0.06  | -0.64 | 0.55   | 0.17   | -0.18  | -0.12  | -2.09  | 0.07   | -3.06   |
| I/E    | 0.81   | 2.20   | 2.74  | 1.87   | 9.69   | 0.77   | 3.57   | 2.70   | 2.41   | 10.54   |
| Total  | -0.08  | 5.01   | 3.88  | -3.91  | 7.48   | 0.10   | 8.04   | 3.85   | -6.11  | 9.54    |

### Table 6

Decomposition results of non-ferrous metal consumption embodied in imports and exports.

| Sector | Import | Export |
|--------|--------|--------|
|        | 1997-2002 | 2002-2007 | 2007-2012 | 2012-2017 | 1997-2017 | 1997-2002 | 2002-2007 | 2007-2012 | 2012-2017 | 1997-2017 |
| Ag     | -0.57  | 0.23   | 0.04  | -0.65  | -2.23  | -0.52  | 0.31   | 0.07   | -0.84  | -2.01   |
| F      | -0.73  | 0.46   | -0.24 | -0.37  | -3.21  | -0.64  | 0.91   | 0.31   | -0.04  | -0.67   |
| S      | -0.10  | -0.08  | -0.19 | 0.20   | -0.03  | -0.13  | -0.18  | -0.82  | 0.13   | -1.26   |
| I/E    | 0.95   | 1.27   | 1.15  | 0.69   | 7.50   | 0.87   | 1.98   | 1.12   | 1.06   | 8.01    |
| Total  | -0.46  | 1.88   | 0.76  | -0.13  | 2.02   | -0.42  | 3.02   | 0.68   | 0.32   | 4.07    |

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sectoral level to explore the underlying changes. This study classifies the 70 industrial sub-sectors into five categories: mining industry (from S6 to S10), light industry (from S11 to S30), resource processing and energy industries (i.e. R and E industry, from S31 to S52 and from S73 to S75), equipment manufacturing industry (from S53 to S70) and other industry (from S71 to S72). The codes and details of the industrial sub-sectors are provided in Table A1 in supporting file.

Table A2 and Table A3 in supporting file show the results of structural decomposition of embodied ferrous and non-ferrous metal consumption in imports and exports at industrial sub-sector level between 1997 and 2017. From 1997 to 2017, the ferrous metal consumption embodied in imports and exports both increased in all industrial sectors, with mining of ferrous metal ores in imports and manufacture of electronic components and parts in exports contributing most to the increase. The non-ferrous metal consumption also increased in most industrial sectors; however, it decreased in four sectors in imports and two sectors in exports, which were all manufacture sectors. Same as holistic analysis, the scale effect increased the embodied ferrous and non-ferrous metal consumption in all sectors, and the influence in imports was more significant than in exports. China is still in the process of transition to the late stage of industrialization, and its economic development still relies on a strong demand for metal-containing products (Feng et al., 2019), which inevitably makes the scale effect in industrial sectors the most important factor, receding the influence of other factors (Harvey and Sedegah, 2011).

The intensity effect increased the ferrous metal consumption in most sectors, and only had the inhibiting effect on five sectors in imports, with mining of ferrous metal ores being the most affected ($S_8$, 116.14 million tons), and two in exports, with manufacture of generators and electric motors being the most affected ($S_{63}$, -17.96 million tons). Different from embodied ferrous metal consumption, the intensity effect was the main inhibiting effect in embodied non-ferrous metal consumption, with manufacture and casting of non-ferrous metals and related alloys being the most affected in imports ($S_{51}$, 64.77 million tons) and processing of non-ferrous metals rolling in exports ($S_{52}$, 19.86 million tons). It only increased the consumption in four sectors in imports and thirteen sectors in exports, and the promoting effect was small. The structure of imports and exports had different effects in sectors; overall it increased more ferrous and non-ferrous metal consumption embodied in imports than in exports, which shows a trade structure of importing more metal-intensity products. In contrast, technology reduced more metal consumption embodied in imports than exports, which shows that the foreign technology has improved better in saving metal resources. Furthermore, the influence of technology was the smallest compared to other factors, it is urgent to attach more importance to technological advancement in order to reach its full potential of promoting industrial upgrading (Zhang et al., 2019).

Fig. 1 shows that the scale effect constantly promoted the growth of embodied ferrous metal consumption, after 2007, it became the main driving force to the consumption embodied in import sectors. The results are more significant in non-ferrous metal: as shown in Fig. 2, the scale effect was the primary driving force of embodied non-ferrous metal consumption in all industries, especially from 2002 to 2012, in mining industry, light industry and equipment manufacturing industry. The
large metal resource inputs in these sectors are corresponding to China’s economic growth over the 10 years, which was partly stimulated by the foreign trade (Zheng et al., 2019). However, the impact has gradually decreased in most industries except for mining industry imports, with a rapid increase from 2007 to 2017 caused the large metal resource demand in imports.

The structure effect was not significant before 2007 in most industries. Except in mining industry, it promoted the ferrous and non-ferrous metal consumption embodied in imports. While from 2007 to 2012, it became the most important inhibitory factor of embodied ferrous metal consumption in light industry, resource processing and energy industry, equipment manufacturing industry and other industry;
Fig. 2. The decomposition results of non-ferrous metal consumption embodied in imports (left) and exports (right) in industrial sub-sectors in different periods (Unit: million tons).
however, it promoted non-ferrous metal consumption embodied in imports in resource processing and energy industry, mining industry and other industry. It indicates that the trade structure appeared the tendency to import more metal embodied in the products of resource-based industries (Zheng et al., 2017), while to export metal embodied in the products of manufacturing industries (Du et al., 2020). After 2012, the impact of trade structure decreased in most industries. However, compared to blindly control the volume of imports and exports, it is more important to optimize the trade structure in the key industries, such as mining industry (Song et al., 2019).

The intensity effect significantly increased the ferrous metal consumption embodied in imports and exports from 2002 to 2012 in all industries, which shows the coupling of economic growth and metal resource consumption. The intensity use hypothesis indicates that industrialization leads to the expansion of manufacturing, which further causes metal intensity in low-income countries rising in line with GDP growth (Laegkau and Espinoza, 2018). From 2002 to 2012, the growth rate of direct ferrous metal consumption in China even exceeded that of GDP. Similarly, the intensity effect also significantly increased the embodied ferrous metal consumption. However, after 2012, China’s industrialization has entered into a new stage and the relative policies to conserve resources has been initiated, the impact decreased and the intensity effect became the inhibitory factor and significantly reduced the ferrous metal consumption in all sectors except for mining industry in imports, especially in equipment manufacturing industry. It indicates a large improvement of metal utilization efficiency of industrial sectors. Similarly, the intensity effect on embodied non-ferrous metal consumption also experienced the change from promoting effect to inhibitory effect in most industries; only the impact was not as significant as ferrous metal. Overall, the change of intensity effect demonstrated the upgrading of China’s industries: the increase from 2002 to 2007 showed the transformation from labor-intensity to machine-intensity, with the embodied metal consumption also increased; and after 2012 the later decrease may show the tendency to technology-intensive. It can be inferred that the intensity effect will further decrease the metal consumption embodied in imports and exports.

The inhibitory effect of technology on embodied ferrous and non-ferrous metal consumption was not significant before 2012. While from 2012 to 2017, it played an important role in reducing the consumption in resource and energy industry, mining industry and light industry, with the imports decreased more than exports. It indicates that the results of the fourth technological revolution have been reflected in various production links and the technological exchanges are more frequent in countries. Especially in mining industry, before 2007 the insufficiency of technological advancement increased both ferrous metal and non-ferrous metal consumption embodied in imports and exports, indicating that China’s mining industry was affected by waste and technological backwardness and had relatively low efficiency (Zhu et al., 2018; Huang et al., 2019). In addition, the mining technology of developed countries is superior to that of China, and most Chinese exports are primary metal products (Feng et al., 2019). However, due to the implementation of policies emphasizing the importance of technology in saving resources, both ferrous and non-ferrous metal consumption was reduced by the factor. Special attention should be paid to equipment manufacturing industry which includes strategic sectors with high added value and the support of the state (Tao et al., 2018; Xiao et al., 2018). Technology should have the power to reduce the waste of embodied metal consumption embodied in equipment manufacturing industry, although the impact were small. At the same time, some rare earth metals are important resources widely used in many strategical sectors, such as the electronic information industry, the new energy automobile industry and the aerospace industry (Wang et al., 2017). Insufficient input to the improvement of technology in these key industries is another way to deplete these strategic metal resources (Wang and Ge, 2019). The technological level of these sectors still needs to be upgraded (Zhong et al., 2019).

5. Conclusions and policy implications

This study is the first attempt to analyze Chinese ferrous and non-ferrous metal consumption embodied in imports and exports and calculate the consumption in each sector by using China’s latest IO tables. The main purpose is to identify what drive the embodied consumption, for which the SDA method is applied at holistic, sectoral and sub-sectoral levels, thereby extending the ‘embodied theory’ to international trade and metal resource aspect. Some meaningful conclusion and implications are drawn as follow.

From 1997 to 2017, Chinese ferrous metal consumption embodied in imports and exports increased by 762.29 million tons and 668.20 million tons, respectively; the non-ferrous metal consumption in imports and exports increased by 231.49 million tons and 319.10 million tons, respectively. Overall, China was a net importer of embodied ferrous metal and a net exporter of embodied non-ferrous metal, and the changes both showed an inverted U-shape. On the one hand, technology was the only factor to reduce the embodied ferrous metal consumption while the intensity effect, the structure effect and the scale effect were the promoting effect in imports; while in exports, all factors drove the growth. On the other hand, the intensity effect was the only factor to reduce the embodied non-ferrous metal consumption, and the other three factors promoted the growth in both imports and exports. Among them, the scale effect was the most important promoting factor in both embodied ferrous and non-ferrous metal consumption while it had a decreased trend. The intensity effect and technology had the great potential to reduce the embodied metal consumption, especially the non-ferrous metal. The structure effect increased ferrous and non-ferrous metal consumption embodied in imports more than in export. These factors have heterogeneous in different sectors. Industry and its sub-sectors contributed most to the embodied metal consumption. The inhibitory effect of technology was more obvious in imports than in exports, and the structure effect promoted more embodied ferrous metal consumption import and more non-ferrous metal consumption export. The intensity effect was promoter before 2007 while its inhibitory effect became more obvious after 2012 in embodied ferrous metal consumption. Although the volume of embodied non-ferrous metal consumption was not as large as that of ferrous metal, the technological level and metal utilization efficiency are inferior.

Based on the study, the following policy implementations are provided. Due to the large imports and exports of products and services, net import of embodied metal can partially mitigate the situation of limited domestic resources (Li et al., 2018). Therefore, excessive trade surplus is not beneficial to save embodied metal resources. Properly changing the balance of trade and narrowing the trade surplus will play a positive role in alleviating China’s embodied metal outflow. Besides, with a certain scale of trade, the import and export structure of commodities plays a decisive role in control embodied metal consumption. Policymaker must further adjust and optimize the structure of foreign trade, make full use of the limited domestic metal to produce and export low-intensity products, while import of high-intensity products is conducive to ease the pressure on resources (Zhang et al., 2018). Especially in the key industries such as equipment manufacturing, the import and export structure should be of particular concerns. First, establish reasonable import and export structure standards. For example, reduce the export of scarce or primary domestic products and increase the export proportion of capital-intensive products; introduce technology-intensive products especially the one that can significantly impact economic development; promote the imports of resource-intensive products, especially those of strategic non-ferrous metal. For example, through direct investment, well-developed but declining industries of high metal consumption can be transferred to less developed countries through direct investment, and then export the products to the home country. Second, adjust industrial policies from the perspective of taxation to play the role of preferential policies for tax: further reduce and cancel export tax rebates and impose higher export taxes on resource-based products. Through
the adjustment of trade structure, China can further realize the import of net trade embodied metal consumption on the premise of trade surplus.

Technology and efficiency improvement are the key factor to reduce the embodied metal consumption. Especially among external structure shocks, technology affects economic fluctuations in industry significantly (Zhang et al., 2019). It was improper to simply restrain the growth of imports and exports to reduce the embodied metal consumption. Relatively small changes in key industries will lead to big improvements (Zhang et al., 2019). Attention should be paid to the utilization efficiency of metals in key industries. Embodied metal consumption can be reduced by improving technology and the intensity (Song et al., 2019). First, increase technical support. Encourage enterprises to increase R&D investment in metal utilization technology research, development and promote the upgradation of technology and equipment. Second, metal utilization efficiency can be improved by optimizing the input and output structure of intermediate products. The inter-sectoral links and mechanism should be emphasized to build a more comprehensive industrial policy. For example, the overcapacity of the downstream sectors such as smelting should be restrained, while extending the deep processing chain of metal should be encouraged to upgrade the industry and increase more added values. Third, develop modern services, focusing on the extension of high and new technology services and specialized services that support scientific and technological innovation; develop leading industries that focus mainly on the technology-intensive electronics and communications, transportation and electrical machinery and equipment industries. Last, cooperation and communication should be made with countries and companies that possess advanced technology in the extraction, smelting and recovery of metal resources (Zhong et al., 2019).

Nevertheless, our study has some limitations, which suggest future research directions. First, in this study, metals are only subdivided into ferrous metals and non-ferrous metals. Although modern society is relatively small changes in key industries will lead to big improvements (Zhang et al., 2019). Attention should be paid to the utilization efficiency of metals in key industries. Embodied metal consumption can be reduced by improving technology and the intensity (Song et al., 2019). First, increase technical support. Encourage enterprises to increase R&D investment in metal utilization technology research, development and promote the upgradation of technology and equipment. Second, metal utilization efficiency can be improved by optimizing the input and output structure of intermediate products. The inter-sectoral links and mechanism should be emphasized to build a more comprehensive industrial policy. For example, the overcapacity of the downstream sectors such as smelting should be restrained, while extending the deep processing chain of metal should be encouraged to upgrade the industry and increase more added values. Third, develop modern services, focusing on the extension of high and new technology services and specialized services that support scientific and technological innovation; develop leading industries that focus mainly on the technology-intensive electronics and communications, transportation and electrical machinery and equipment industries. Last, cooperation and communication should be made with countries and companies that possess advanced technology in the extraction, smelting and recovery of metal resources (Zhong et al., 2019).

Nevertheless, our study has some limitations, which suggest future research directions. First, in this study, metals are only subdivided into ferrous metals and non-ferrous metals. Although modern society is completely dependent on the use of "major metals" (Elskikai et al., 2018), the high-tech manufacturing and machinery industries have produced a huge demand for rare metals. Further research should break through the data limit to study embodied rare metals in various sectors. Second, further research can be carried out by applying multi-regional input-output models to study embodied metals between countries, especially under the influence of some emergencies such as COVID-19.

CRediT authorship contribution statement

Jian-Bai Huang: Visualization, Investigation, Supervision, Writing - review & editing. Xi Chen: Data curation, Writing - original draft, Software, Validation. Yi Song: Conceptualization, Methodology, Software, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resourpol.2020.101862.
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Further reading

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