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An effects analysis of China's metal mineral resource tax reform: A heterogeneous dynamic multi-regional CGE appraisal

Meirui Zhong[a,b], Qing Liu[a], Anqi Zeng[a,*], Jianbai Huang[a]

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

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ABSTRACT

The heterogeneity in resource endowment and the "resource curse" require different tax rates for different regions in resource tax ad valorem reform. Considering that copper is critical, widely distributed and closely related to the economy, a dynamic multi-regional computable general equilibrium (CGE) model is constructed to investigate the impacts of different copper resources tax rates on regional economies, thus obtaining the optimised resource tax rate due to the "resource curse" in different regions. Under different policy scenarios of the copper resource tax, namely, 2%, 5% and 8%, this paper estimates the impacts of resource tax ad valorem reform on copper consumption, macroeconomic variables and sector outputs among 4 representative regions, which is significantly different from the results from national perspective in previous studies. The simulated results are as follows: resource tax ad valorem reform has an enormous influence on copper consumption and has slightly positive impacts on resident income, government revenue, total consumption and real gross domestic product (GDP), while it affects copper-related sectors outputs in a negative way. Additionally, the impacts under the same scenario are significantly different among 4 regions. Moreover, under different tax rate scenarios, copper consumption increases first and then decreases, resulting in an inverted U-shaped pattern. This paper built a dynamic computable general equilibrium (DCGE) model of copper resource tax ad valorem reform from a regional perspective, thus improving the CGE model on a national scale compared to previous studies and providing an analytical paradigm for the reform of other strategic metal mineral resource taxes in China.

1. Introduction

As key components in China's industrial development, metal minerals are crucial to national defence and strategic emerging industries that support the development of major national strategies such as national large-scale aircraft construction, aerospace engineering, nuclear power engineering and high-speed traffic engineering. Therefore, many minerals (including copper) are defined as national strategic mineral resources (Hao and Li, 2015). Over a long period of time, however, the defect in the metal mineral resource policy of China has given rise to a series of problems. For example, from 2003 to 2013, the base reserves of nine kinds of minerals such as coal, chromite and phosphorus dropped by more than 20%, and reserves of antimony, germanium, indium and tin decreased by more than one-third (in Yu et al., 2015). The main reason for these situations could be the adoption of a specific duty resource tax in China. This means that the cost of intergenerational externalities and environmental externalities cannot be transferred to the price of mineral resources, leading to the excessive and wasteful consumption of mineral resources. For a similar reason, the adoption of a specific duty resource tax partly leads to the blindness choice in the export policy of rare metal resources, which has resulted in a series of trade disputes over rare metal resources between China and other countries (Zhu et al., 2018). Therefore, there is an urgent need for China to formulate more scientific and effective resource policies to internalize the cost of intergenerational externalities and environmental externalities and thereby achieve mineral supply security, ecological security and intergenerational security.

As a useful resource and environmental management tool, the core of resource tax policy design is the collection method and standard of taxation. An effective and reasonable resource tax should be designed based on the scarcity and intrinsic value of nature resources, thus containing resource depletion costs and external losses (Lin and Liu, 2012). Additionally, the external costs could be transmitted to resource prices by adopting ad valorem taxation, which to some extent restrains the wasteful consumption of resources. For this reason, China piloted resource tax reform on crude oil and natural gas in Xinjiang province in 2010 and has expanded the resource tax reform comprehensively since 2016. The collection of resource tax has been transformed from a

* Corresponding author.
E-mail addresses: zmr726@163.com (M. Zhong), 420777397@qq.com (Q. Liu), angietsang77@hotmail.com (A. Zeng), jbhuang@mail.csu.edu.cn (J. Huang).

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specific duty into an ad valorem taxation. The tax rate range for a certain resource is formulated by the central government, while the specific tax rate is set by the local government of each province in view of differences in resource endowment (Xie and Gu, 2017).

Many scholars have defined and calculated the standard of resource taxation, especially for energy and metal mineral resources. Hoteling (1931) noted the depreciation of the limited stock of non-renewable resources, which could be regarded as the user cost for the development and utilization of non-renewable resources. Hartwick (1977) proposed that this depreciation is the depletion value of resources. Serafy (1981) developed a theoretical framework for calculating the depletion cost of non-renewable mineral resources. Experience shows that a reasonable resource tax system can not only make resource users bear the relevant costs, improve resource use efficiency, reflect the value of resource consumption, and correct the negative externalities of resources but also reasonably control the speed of resource exploitation and ensure the fairness of the intergenerational allocation of resources (Dasgupta and Heal, 1980; Gamponia and Mendelsohn, 1985; Lin and Liu, 2012). According to previous studies, many scholars have drawn on and revised the theoretical framework for fruitful exploration, and the user costs of resources are calculated as the theoretical standard of resource tax. Adelman (1991) and Lin and He (2008), Lin and Liu (2012) used the user cost method to calculate the user cost of energy minerals (coal, oil, natural gas) in companies. Young and Motta (1995), Blignaut and Hassan (2002), and Zhong et al. (2016) calculated the user costs of metal minerals in Brazil, South Africa and China, respectively, in application of the user cost method.

There are plenty of methods for estimating the impact of resource tax policy outlined in previous studies. Early scholars generally adopted the qualitative analysis method according to resource characteristics and resources and environmental policies from a macro perspective (Gupta and Mahler, 1995; Groth and Schou, 2007; Eisenack and Stecker, 2012). Subsequently, the method of quantitative analysis in application of the globalisation model or national model has gradually replaced the qualitative analysis method. Examples include econometric models (Hung and Quyen, 2009; Lv and Guo, 2009), input-output models (Llop and Pié, 2008; Gemechu and Butnar, 2014), tax transfer models (Du and Wang, 2015; Zhu et al., 2016) and computable general equilibrium (CGE) models (Ferran, 2010; Anton and Harald, 2012; Lin and Liu, 2012; Doumax and Philip, 2014; Guo and Zhang, 2014; Anton, 2015a, 2015b; Shi and Tang, 2015; Xu and Xu, 2015; Zhong and Zeng, 2016; Tang and Shi, 2017; Zhang and Yang, 2017). Compared with other methods, the CGE model owes its unique merit in tax policy simulations to providing a comprehensive analysis under the general equilibrium framework.

The CGE model is widely employed in resource policy analysis (Löfgren and Harris, 2015; Dixon and Rimmer, 2016). Considering that the taxation cost will be transferred to different economic agents, the sensitivity and impacts on the macro economy, society and the environment must be estimated to obtain the optimal resource tax rate. Therefore, many scholars construct CGE models at the national level (Lin and Mou, 2008; Lin and Liu, 2012; Tang et al., 2015; Liu et al., 2015; Zhong et al., 2016). An obvious shortcoming of CGE models on a national scale, however, is the implementation of uniform policy standards, which will widen the regional gap and impede balanced and sustainable development among regions (He and Li, 2009). Because the taxation situation varies from region to region, a CGE model on the national scale is not suitable for regional analysis. The multi-regional CGE model is based on the single-area CGE model, however, which has increased the description of interregional economic linkages, especially the interregional flows of commodities and factors. It is an optimal tool for analysing regional policies and regional development issues (Yuan et al., 2016). Li et al. (2009), Xu (2012), Zhang et al. (2013) and Wang et al. (2015a, 2015b) constructed dynamic CGE models from regional perspective to simulate and analyse the effects of the carbon tax, the coal resource tax, and the water resource tax on regional economic development, energy conservation, emissions reduction and the "resource curse" problem, respectively.

Previous studies have mostly focused on the impacts of energy resources taxes, such as taxes on petroleum and coal, for the significant influence on economy and environment and effective data collection. The resource tax of metal minerals has rarely been utilised in existing studies, however, especially when applying a CGE model. The main reason lies in the difficulty of obtaining metal-related data that satisfy the application of CGE models. Moreover, many studies analyse the impacts of resource tax ad valorem reform at the national level, ignoring the heterogeneity in resource endowment and the "resource curse". Since it has been proven that relatively scarce and limited resources are the bottlenecks that restrict regional development (Zhang et al., 2007; Zhang and Liang, 2010), the implementation of a resource tax rate should satisfy the actual situations of different regions.

Under these circumstances, copper is selected as the exemplar metal resource in this paper because it is widely distributed and critically important: it was rated one of the top 24 important strategic mineral resources in China by the National Mineral Resources Planning (2016–2020). Further, Zhong et al. (2016) proved that there is a close correlation between copper consumption and macroeconomic variables, making the choice of copper suitable for performing CGE simulation analysis. In addition, this paper analyses the heterogeneity of copper resource endowment and the resource curse in different provinces to account for the deficiency in the current taxation policy and built a dynamic multi-regional CGE model of copper resource tax reform that takes the flows of factors and commodities between regions into consideration. Moreover, considering the complex problems of copper mining in different regions, such as low-grade, associated and difficult-to-dress copper ores, the resource tax module in this paper contains the sales revenue of copper mines linked with the extract and concentration recovery rate, which is more in line with the actual resource endowment of different regions.

Generally speaking, this paper constructs a dynamic multi-regional CGE model to estimate the overall impact of China's copper resource tax ad valorem reform on regional economies and the resource dilemma, in order to obtain the optimised resource tax rate in consideration of resource endowments and the "resource curse" among different regions. The remainder of the paper is organised as follows. Section 2 analyses the heterogeneity of provincial copper resource endowment and degree of "resource curse". Section 3 describes the construction of the dynamic multi-regional CGE model. Section 4 provides the tax rate scenario design and simulation results analysis, while Section 5 contains the conclusion and policy implications.

2. The analysis of the regional copper endowments and resource curse heterogeneity

2.1. Heterogeneity analysis of copper in different regions

Resource endowment refers to the resource advantages of a region, which includes not only natural resources but also other economic and non-economic factors affecting economic development (Li and Li, 2015). To distinguish between the differences in the mineral resource endowment in different regions, according to mineral resource endowment advantage theory (Pan and Harris, 1991; Shen and Cao, 2009), a mineral resource endowment evaluation index system is constructed. This system includes the agglomeration degree of mineral resources, mineral resource quality, the reserve-production ratio of mineral resources, and mineral resource reserves, accounting for four types of national indicators. When the index value is larger, the resource endowment is stronger. By using the analytic hierarchy process (AHP) approach, the weights of the four indicators in the index system were determined to be 0.097, 0.309, 0.060 and 0.534, respectively, to obtain the comprehensive evaluation scores of the mineral resource endowments in different regions. According to the "China Statistical

Table 1
Quantitative indexes of copper in China's regions.

Regions	Mineral resources agglomeration (%)	Resource quality (%)	Reserve-production ratio (%)	Storage ratio (%)
Beijing	0.00	0.00	0.00	0.00
Tianjin	0.00	0.00	0.00	0.00
Hebei	0.00	0.36	0.16	0.48
Shanxi	0.40	0.53	0.28	5.85
Inner Mongolia	0.20	1.07	0.15	13.55
Liaoning	0.00	1.45	0.28	1.19
Jilin	0.00	1.01	0.14	0.74
Heilongjiang	1.00	0.41	0.33	4.10
Shanghai	0.00	0.00	0.00	0.00
Jiangsu	0.00	0.14	0.06	0.14
Zhejiang	0.00	1.02	0.07	0.22
Anhui	0.08	1.40	0.15	6.42
Fujian	1.00	0.40	0.10	2.04
Jiangxi	0.78	0.54	0.13	24.21
Shandong	0.00	1.34	0.20	0.56
Henan	0.00	1.10	0.24	0.35
Hubei	0.14	0.99	0.11	3.97
Hunan	0.00	1.00	0.06	0.28
Guangdong	0.33	1.29	0.22	1.13
Guangxi	0.00	0.95	0.03	0.12
Hainan	0.00	0.00	0.00	0.13
Chongqing	0.00	0.00	0.00	0.00
Sichuan	0.33	0.99	0.08	2.59
Guizhou	0.00	0.00	0.00	0.01
Yunnan	0.17	1.05	0.14	11.00
Tibet	0.80	1.69	1.71	10.03
Shanxi	0.00	1.24	0.33	0.73
Gansu	0.17	0.93	0.35	5.83
Qinghai	0.40	0.87	0.07	1.31
Ningxia	0.00	0.00	0.00	0.00
Xinjiang	0.25	2.36	0.24	3.00

Yearbook 2004-2004", the "China Non-ferrous Metals Industry Yearbook 2004–2015", the provincial statistical yearbooks dating from 2004 and other data, we can obtain the copper endowment quantitative indicators for the different regions, as shown in Table 1.

The following equation describes the comprehensive evaluation score of the copper endowment:

$$A = \sum_{i=1}^{4} C_i \lambda_i \tag{1}$$

where A represents the comprehensive evaluation score of copper in various regions; C_i is the weight for each indicator; and λ_i quantifies the value of copper in the regions. According to the calculation, the comprehensive evaluation scores of copper resources in China's regions are shown in Table 2.

According to the above calculation results, the heterogeneity of copper in the regions is divided into four kinds of regions; the specific divisions are shown in Table 3.

2.2. Heterogeneous analysis of the metal resource curse in different regions

The phenomenon of the resource curse reflects the possible adverse relationship between regional economic development and resource endowment. In the existing quantitative research on the resource curse, the main methods are source abundance index (Wu, 2007; Hu and Jiao, 2008), mineral resource poverty index (Su, 2007) and resource curse coefficient (Yao et al., 2011; Xu et al., 2015). The first two methods may exaggerate the contribution rate of mineral resources to economic growth and cannot accurately reflect the contrast between regional economic development and resource endowments. Therefore, this paper chooses the resource curse coefficient method to analyse the different degrees of "resource curse" in different regions, because it is important to consider the relationship between the economy and the resource endowment. Particularly, considering that some regions have no copper resources, the resource endowment of copper is replaced by that of non-ferrous metals. The calculation formula of the resource curse coefficient of non-ferrous metals is as follows:

$$RCI = (R_i/\sum R_i)/(GDP_i/\sum GDP_i) \tag{2}$$

where RCI is the resource curse coefficient, R is non-ferrous metal production, GDP is the gross domestic product, and i is the number of region. When the resource curse coefficient is greater than 1, the area is cursed. When the resource curse coefficient is larger, the "resource curse" is more serious, which means the deviation between the resources endowment of non-ferrous metals and economic growth will be larger. Based on data from the National Bureau of Statistics and the "China Non-ferrous Metal Statistics Yearbook 2004–2015", the resource curse coefficient of non-ferrous metals in regions from 2005 to 2014 is available, as shown in Table 4.

The weighted average of the resource curse coefficient of national non-ferrous metals in the past 10 years and the resource curse coefficient of the non-ferrous metals in provinces are shown in Table 5.

According to the magnitude of the regional resource curse coefficient, areas are divided into null, low, medium and high resource curse areas, Namely, the four different areas are differentiated by the above factor as (0, 1), (1, 2), (2, 3), and 3 (shown in Table 6). Among them, in the "null resource curse area", the economic growth of Jiangsu is much higher than that of the non-ferrous metal resource endowment condition, which belongs to the resource curse region. The economic growth of Jiangxi is slightly less than its own non-ferrous metal resource endowment conditions in the "low resource curse area". The advantages of non-ferrous metals are basically transformed into economic growth. Jiangxi is a medium resource curse area. The economic growth of Inner

Table 3
The resource endowment division of copper in China's regions.

Division	Valve value	Regional distribution
No priority area	$A < 1$	Beijing, Tianjin, Hebei, Jilin, Shanghai, Jiangsu, Zhejiang, Shandong, Henan, Hunan, Guangxi, Hainan, Chongqing, Guizhou, Shanxi, Ningxia
Low priority area	$1 \le A < 5$	Shanxi, Liaoning, Heilongjiang, Anhui, Fujian, Hubei, Guangdong, Sichuan, Gansu, Qinghai, Xinjiang
Medium priority	$5 \le A \le 9$	Inner Mongolia, Yunnan, Tibet
Superior area	$A > 9$	Jiangxi

Table 2
The comprehensive evaluation of copper in China's regions.

Regions	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia	Liaoning	Jilin	Heilongjiang	Shanghai
A	0.000	0.000	0.379	3.346	7.595	1.101	0.715	2.433	0.000
Regions	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Shandong	Henan	Hubei	Hunan
A	0.123	0.438	3.879	1.317	13.180	0.725	0.54	2.448	0.462
Regions	Guangdong	Guangxi	Hainan	Chongqing	Sichuan	Guizhou	Yunnan	Tibet	Shanxi
A	1.047	0.358	0.070	0.000	1.723	0.006	6.223	6.060	0.793
Regions	Gansu	Qinghai	Ningxia	Xinjiang					
A	3.440	1.010	0.000	2.369					

Table 4
The resource curse coefficient of 10 non-ferrous metals from 2005 to 2014.

Regions	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
Beijing					0.004	0.003					0.004
Tianjin	0.14	0.1	0.09	0.06	0.06	0.06	0.04	0.03	0.01	0.006	0.06
Hebei	0.15	0.09	0.009	0.007	0.13	0.07	0.09	0.09	0.1	0.11	0.08
Shanxi	2.34	2.5	2.89	3	2.82	1.91	1.9	1.98	1.85	1.73	2.29
Inner Mongolia	1.69	1.83	2	2.2	2.34	2.51	2.62	2.54	2.55	2.76	2.3
Liaoning	0.91	0.71	0.65	0.6	0.58	0.5	0.55	0.48	0.4	0.42	0.58
Jilin	0.3	0.01	0.003	0.02	0.09	0.07	0.009	0.01	0.02	0.02	0.06
Heilongjiang	0.03	0.03	0.02	0.01	0.01	0.01	0.005	0.004	0.003		0.01
Shanghai	0.23	0.19	0.18	0.12	0.11	0.1	0.14	0.14	0.07	0.07	0.14
Jiangsu	0.2	0.21	0.17	0.18	0.16	0.21	0.19	0.2	0.17	0.16	0.19
Zhejiang	0.28	0.31	0.27	0.31	0.24	0.24	0.28	0.27	0.23	0.17	0.26
Anhui	1.12	1.31	1.5	1.26	1.27	1.62	1.55	1.35	0.99	1.08	1.31
Fujian	0.11	0.11	0.13	0.12	0.11	0.13	0.13	0.19	0.28	0.27	0.16
Jiangxi	1.63	1.42	1.37	1.38	1.7	1.67	1.58	1.5	1.73	1.7	1.57
Shandong	0.62	0.74	0.73	0.87	0.82	0.91	0.86	0.89	0.86	0.85	0.84
Henan	3.05	3.33	3.17	3.29	3.47	3.41	3.15	3.2	3.1	2.59	3.18
Hubei	0.92	0.9	0.87	0.89	0.81	0.68	0.68	0.6	0.54	0.61	0.75
Hunan	2.53	2.31	2.2	1.94	2.21	2.05	2.09	2.02	1.9	1.81	2.11
Guangdong	0.21	0.18	0.13	0.14	0.16	0.16	0.14	0.09	0.1	0.13	0.14
Guangxi	2.32	2.07	1.84	1.64	1.86	1.91	1.98	1.73	1.46	1.41	1.82
Chongqing	0.31	0.39	0.4	0.35	0.44	0.47	0.38	0.4	0.31	0.39	0.38
Sichuan	1.21	1.02	0.85	0.81	0.65	0.63	0.73	0.76	0.65	0.64	0.8
Guizhou	4.13	3.69	3.75	3.36	2.28	3.04	2.71	2.25	2.27	2.13	2.96
Yunnan	4.63	5.09	5.68	5.54	4.89	4.9	4.5	4.3	4.25	4.22	4.8
Tibet				0.05	0.04	0.07	0.04			0.002	0.04
Shanxi	1.21	1.02	1.29	1.18	1.33	1.46	1.46	1.48	1.36	1.45	1.32
Gansu	7.48	7.38	6.96	6.44	7.02	7.02	6.25	6.59	7.99	7.9	7.1
Qinghai	15.7	15.6	15.7	14	14.4	12.4	16.9	16.5	17.3	17.6	15.61
Ningxia	8.47	8.95	10.8	8.76	7.44	7.53	8.08	9.34	10.9	9.86	9.01
Xinjiang	0.31	0.27	0.27	0.26	0.24	0.2	0.23	0.84	2.12	4.62	0.94

Mongolia and four other regions is slightly less than its own non-ferrous metal resource endowment conditions. The advantages of non-ferrous metals have not fully translated into economic growth. Inner Mongolia is a medium resource curse area. The economic growth of Gansu and four other regions lags far behind its non-ferrous metal resource endowment conditions. The resource endowment advantage is seriously hindering regional economic growth, and Gansu is a high “resource curse” area. In addition, from the spatial distribution of the resource curse, more economically underdeveloped areas appear in central and western China.

2.3. Selection of sample provinces and data source

Based on the heterogeneity analysis of copper resource endowment and the “resource curse” of non-ferrous metals among regions, while also considering the differences in scale, natural conditions, economic development and social structure from a regional perspective, we choose Gansu, Zhejiang, Inner Mongolia and Jiangxi as 4 representative provinces in which to employ dynamic multi-regional CGE model simulation analysis of copper resource tax reform.

The data from the 2012 SAM (social accounting matrix) mainly come from the input-output tables for Gansu, Jiangxi, Zhejiang, and Inner Mongolia, “The China Non-Ferrous Metals Industry Yearbook 2013”, “China Statistical Yearbook 2013”, “China Financial Yearbook 2013”, and “China Tax Yearbook 2013”. Based on the SAM of the four regions in 2012, the scale and proportion parameters are calibrated by the model and the elasticity of substitution between factors is referenced to Zhong et al. (2016).

3. Multi-regional dynamic CGE model construction

CGE models are adopted as effective tools to analyse the impacts of resources and environmental policies (Wang et al., 2015a, 2015b; Liu et al., 2016a, 2016b; Zhong et al., 2016). In recent years, CGE models for resource policies research from a regional perspective are gaining increasing popularity for considering the regional differences of resources (Zhang et al., 2013; Xu et al., 2015). Thus, based on the previous studies, this paper constructs a dynamic multi-regional CGE model to further investigate the economic and resource impacts of different levels of copper resource tax reform among different regions. The model decomposes or integrates all sectors in China into 9 non-metallic mineral sectors and 3 metal ore sectors (including copper mining, non-ferrous metal mining and mining industries of other metals), as shown in Table 7. To better estimate impacts of resource tax reform on the demand and supply of copper, as a critical resource, copper is regarded as one of production factors with labour and capital in this paper (Zhong et al., 2016). There are 5 economic agents in the model, i.e., households, enterprises, local government, central government and the rest of the world. To obtain the interaction between different sectors and economic agents, the model mainly involves 5

Table 5
The resource curse coefficient of non-ferrous metals in China's regions.

Regions	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia	Liaoning	Jilin	Heilongjiang	Shanghai	Jiangsu
RCI	0.004	0.06	0.08	2.29	2.3	0.58	0.06	0.01	0.14	0.19
Regions	Zhejiang	Anhui	Fujian	Jiangxi	Shandong	Henan	Hubei	Hunan	Guangdong	Guangxi
RCI	0.26	1.31	0.16	1.57	0.84	3.18	0.75	2.11	0.14	1.82
Regions	Chongqing	Sichuan	Guizhou	Yunnan	Tibet	Shanxi	Gansu	Qinghai	Ningxia	Xinjiang
RCI	0.38	0.8	2.96	4.8	0.04	1.32	7.1	15.56	9.01	0.94

Table 6
Regional division of the resource curse coefficient of non-ferrous metals in China.

Division	The "resource curse" range	Region distribution	Degree of resource curse
Null resource curse area	$0 \leq RCI < 1$	Beijing, Tianjin, Hebei, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Hubei, Guangdong, Chongqing, Sichuan, Tibet, Xinjiang	No existence
Low resource curse area	$1 \leq RCI < 2$	Anhui, Jiangxi, Guangxi, Shanxi	Low level
Medium resource curse area	$2 \leq RCI < 3$	Shanxi, Inner Mongolia, Hunan, Guizhou	Medium level
High resource curse area	≥ 3	Henan, Yunnan, Gansu, Qinghai, Ningxia	High level

modules, including the production module, trade module, income and expenditure module, resource tax module and dynamic module. The structure of the dynamic multi-regional CGE model is shown in Fig. 1.

3.1. Production module

The production structure is characterised by producer profits maximisation and expressed by three-level nested production function, as shown in Fig. 2.

A Leontief production function is adopted to combine intermediates and value added to total gross output, which means that the substitute elasticity between these two inputs is zero. The Leontief production function is expressed as follows:

$$QA_{i,t} = \min\left(\frac{QIA_{1,i,t}}{\alpha_{1,i}}, \frac{QIA_{2,i,t}}{\alpha_{2,i}}, \ldots, \frac{QIA_{n,i,t}}{\alpha_{n,i}}, \frac{QVA_{i,t}}{\alpha_{VA,i}}\right) \quad (3)$$

where $QA_{i,t}$ is the output of sector i at time t, $QVA_{i,t}$ denotes capital-labour value-added inputs of sector i at time t, $QIA_{1,i,t}, \cdots QIA_{n,i,t}$ are n types of intermediate inputs in each sector, and $\alpha_{1,i}, \cdots\alpha_{n,i}, \alpha_{VA,i}$ stand for input-output coefficients.

Metal is regarded as one of production factors with labour and capital in this paper (Zhong et al., 2016), value added is split into a labour and capital-copper bundle, and then the capital-metal bundle is further divided into capital and metal with a nested constant elasticity of substitution (CES) production function. Eq. (4) describes the nested CES production function as follows:

$$QVA_i = \alpha_i^v\left(\delta_i^v \cdot QL_i^{\rho_i^v} + \left(1-\delta_i^v\right)QKM_i^{\rho_i^v}\right)^{\frac{1}{\rho_i^v}} \quad (4)$$

$$QKM_i = \alpha_i^{km}\left(\delta_i^{km} \cdot QK_i^{\rho_i^{km}} + \left(1-\delta_i^{km}\right)QMETAL_i^{\rho_i^{km}}\right)^{\frac{1}{\rho_i^{km}}} \quad (5)$$

where QVA_i denotes value-added inputs, QL_i is the input factor labour of sector^i, QKM_i is the capital-copper bundle of sector^i, $QMETAL_i$ stands for the input of copper resource of sector^i, and α_i^v, α_i^{km} are efficiency parameters, which $\alpha_i^v, \alpha_i^{km} > 0$. δ_i^v, δ_i^{km} are distribution parameters, which $0 < \delta_i^v, \delta_i^{km} < 1$. ρ_i^v, ρ_i^{km} are coefficients that are closely related to the elasticity of substitution, and the elasticity of substitution denotes the extent of substituting one factor for another under certain price and technological constraints.

3.2. Trade module

Due to the regional perspective taken in this paper, the trade module takes the provincial level into consideration compared to the national level in previous studies (Xu et al., 2015; Zhong et al., 2016). As shown in Fig. 1, the category total imports is composed of imports from abroad and from other provinces, similar to the category total exports. Total production is sold in local markets and for total exports. The total demand in local markets comes from total imports and local production, which is sales in local markets. The Armington hypothesis is adopted to describe total demand in local markets and total imports, assuming that imports from abroad and other provinces are not completely replaced, similar to total imports and local production, which are sold in local markets. The model uses the CES function to describe this hypothesis, which is:

$$QAM_i = \alpha_i^{aq} \cdot \left(\delta_i^{aq} \cdot QM_i^{-p_i^{aq}} + (1-\delta_i^{aq}) \cdot QDM_i^{-p_i^{aq}}\right)^{-\frac{1}{p_i^{aq}}} \quad (6)$$

$$QAM_i = QM_i + QDM_i \quad (7)$$

where QAM_i stands for total imports of commodity i, QM_i denotes imports from abroad and QDM_i is imports from other provinces. The CES function of total demand in local markets is similar to that of total imports.

For the export demand, it is also assumed that there is an incomplete replacement in total exports and total production, and which is described by the constant elasticity of transformation (CET) function. The equations are as follows:

Table 7
Departments and scopes in the dynamic multi-regional CGE model.

CODE	Department/Product	Scope
AGRI	Animal husbandry and fishery	Planting, forestry, animal husbandry, fisheries and other agriculture
MIN	Mining and dressing industry (excluding metal ore)	Coal, oil, natural gas, non-metallic minerals and other minerals
LIGH	Light industry	Food and tobacco, textiles, clothing, shoes and hats, leather and its products, wood processing and furniture, paper making, printing and stationery
HEAV	Heavy industry	Petroleum, coking, chemicals, non-metallic mineral products, metal smelting and pressure processing, metal products, equipment, machinery and equipment, instruments and metres, other manufacturing, waste materials
ELEC	Production and supply of electric power, heat, gas and tap water	Production and supply of electric power, heat, gas and tap water
CONS	Construction business	Construction business
WHOL	Wholesale and retail trade	Wholesale and retail trade
TRAN	Transportation and warehousing industry	Transportation, storage and postal service
SERV	Other services	Accommodation, catering, information services, finance, insurance, real estate, leasing, social services, scientific research, education, culture, sport, entertainment, social security
COPP	Copper mining	copper
OTHN	Basic non-ferrous metal (except copper) mining and dressing industry	Aluminium, lead, zinc, tin, nickel, antimony, mercury, magnesium, titanium
OTHM	Other metal minerals mining and dressing industry	Other metallic minerals not listed

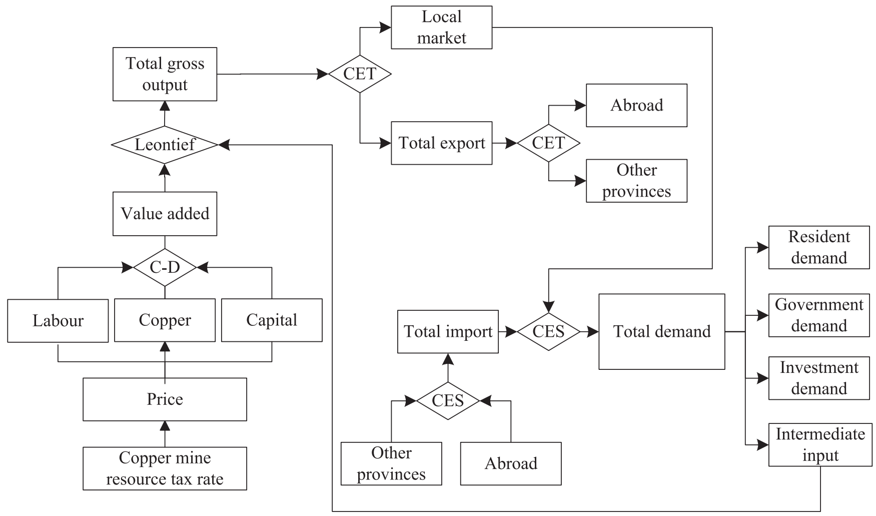

Fig. 1. The dynamic multi-region CGE model structure.

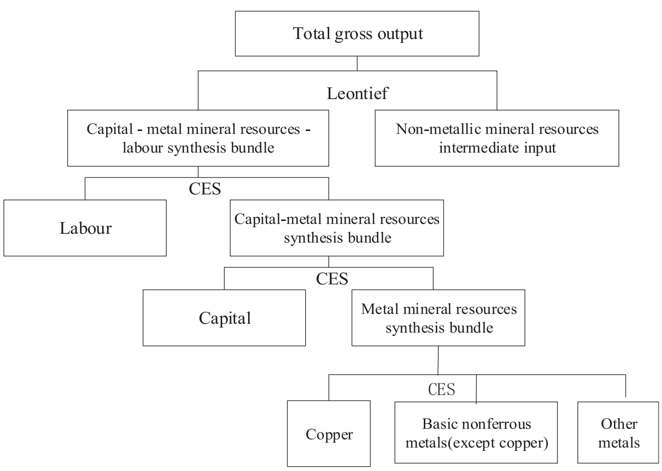

Fig. 2. A nested sketch map of production functions.

$$QX_i = \alpha_i^x\left(\delta_i^x \cdot QAE_i^{-p_i^x} + (1-\delta_i^x)\cdot QD_i^{-p_i^x}\right)^{\frac{1}{p_i^x}} \quad (8)$$

$$QX_i = QAE_i + QD_i \quad (9)$$

where QX_i stands for total production of sector i, QAE_i denotes total exports, and QD_i is total production sold in local markets. The CET function of total exports is similar to that of total production.

3.3. Income and expenditure module

The income of residents mainly comes from labour income, capital income and transfer payments from enterprises and government, mainly used for consumption and savings. The consumption demand function is expressed by Extend Linear Expenditure System (ELES) satisfying the Stone-Geary utility function assumption (Wang et al., 2017a, 2017b, 2017c), which is:

$$C_i = P_i \cdot \theta_i + \beta_i\left(YH - \sum_j P_j \cdot \theta_j\right) \quad (10)$$

where C_i is total expenditure on consumption for commodity i, P_i denotes the price of commodity i, YH is disposable income of household, θ_j represents subsistence household consumption for commodity j, and β_i denotes marginal propensity of consumption.

Enterprises mainly obtain income from capital and transfer payments from government. After paying corporate income tax, the net profit is used for investments and transfers to residents. The income of local government comes from direct and indirect taxes and fiscal appropriations by the central government, and it spends on government consumption and transfer payments to households, enterprises and the central government.

3.4. Copper resource tax module

The resource tax is a kind of indirect tax that reflects the scarcity of specific exhaustible resources (Tang et al., 2015). The copper resource tax module mainly aims to capture the changes in the new resource tax reform and better analyse its impacts. The copper resource tax is levied by the means of ad valorem, which could precisely mirror the costs of resource utilization and resource price fluctuation. In particular, the resource tax is associated with the recovery rate of resources, which could establish the link between the resource tax and the specific characteristic of metal minerals. The amount of resource tax is influenced by sales revenue of resource products, resource tax rate and recovery percentage, which is described as follows:

$$Tax = \sum_i QA_i \cdot PA_i \cdot \xi_i \cdot \tau_i \quad (11)$$

where QA_i represents the number of copper ore outputs, PA_i represents the copper price, ξ_c is the coefficient of copper mining recovery, and τ_c stands for the specific copper resource tax rate of each province.

3.5. Dynamic module

The dynamic model is based on capital accumulation, growth of the labour supply and copper consumption, as shown in Eq. (13). The growth rate of the labour supply is set exogenously as 0.006; meanwhile, the depreciation rate of capital and growth rate of copper consumption are set to 0.05 (Tang et al., 2015):

$$K_t = (1-\sigma_t)K_{t-1} + I_t \quad (12)$$

$$L_t = (1+g')L_{t-1},\ C_t = (1+\mu')C_{t-1} \quad (13)$$

where K_t, K_{t-1} denotes the capital stock at time t and $t-1$, respectively, σ_t represents the depreciation rate, I_t and is the new investment at time t. Eq. (12) illustrates that capital is accumulated by depreciated current capital stock adding up the new investment. L_t is the input of the labour supply at time t, C_t is the current consumption of copper resources, g' is the growth rate of labour, and μ' is the growth rate of copper consumption. The labour supply and copper consumption are set to increase exogenously year by year at a fixed growth rate.

Table 8
The specific copper resource tax rates of the regions.

Province	Hebei	Shanxi	Inner Mongolia	Heilongjiang	Zhejiang	Anhui
Tax rate	7%	3%	4%	5%	3%	4%
Province	Jiangxi	Hunan	Guangdong	Sichuan	Shanxi	Gansu
Tax rate	6.5%	2%	2%	4%	4%	3%

4. Tax rate scenario and analysis of the simulation results

4.1. Tax rate scenario

The comprehensive resource tax reform of China has been gradually implemented since 1 July 2016; thus, the resource tax is transformed from a specific duty into ad valorem collection. For copper, the resource tax is in the 2–8% range at the national level, and the tax rate of each province is shown in Table 8. It has been proven that there is a real correlation between resource scarcity and economic development (Zhang et al., 2007; Zhang and Liang, 2010). Additionally, the resource tax rate should be designed to consider resource scarcity and economic impacts simultaneously. Therefore, in order to obtain the optimised resource tax rate in view of the "resource curse" among different regions by analysing the impacts of different tax rates within the specified range, this paper chooses 3 levels of resource tax, namely, a low tax rate (2%), medium tax rate (5%) and high tax rate (8%), as scenario 1 (S1), scenario 2 (S2) and scenario 3 (S3), respectively (Shi et al., 2015).

The dynamic multi-regional CGE model is based on the regional 2012 SAM and run up to the year 2025, and general algebraic modelling system (GAMS) software is adopted to simulate and analyse the impacts of different levels of ad valorem reform resource tax policy on copper resource consumption, macroeconomic variables, and the sector output in four resource heterogeneous regions: Zhejiang, Gansu, the Inner Mongolia and Jiangxi.

4.2. Simulation results

(1) Copper consumption impacts.

The impacts of overall trends on copper consumption under the copper resource tax ad valorem reform in Inner Mongolia (see Fig. 3), Jiangxi, and Zhejiang are positive. Among the 4 regions, the impact of the reform on copper consumption in Jiangxi is greatest in the long term, increasing by 35.48% (S1), 24.16% (S2), and 20.20% (S3), respectively, by 2025 (see Fig. 4). Specifically, the growth of copper resource consumption of Jiangxi is an inverted U-shaped pattern, which reaches a turning point at 37.84% (S1), 27.24% (S1) and 24.63% (S1) in the years 2023, 2023 and 2022, respectively, and the increase of S1 is larger than that of S2 and S3. Jiangxi is rich in copper resources and has a large smelting and processing company, the Jiangxi Copper Corporation, to consume copper resources and support regional economic development. Thus, to low resource curse regions such as Jiangxi, the copper resource tax ad valorem reform will stimulate the economy and expand production, thus increasing copper resource consumption. In the long term, on the other hand, as a resource and environmental management tool, the resource tax ad valorem reform could initialize external costs to copper prices, restrain the excessive copper consumption and improve the efficiency of resource utilization to some extent.

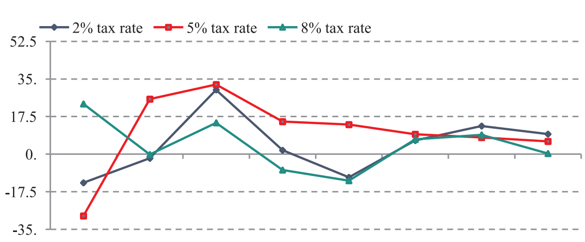

Fig. 3. The impact of changes in Inner Mongolia copper consumption growth trends under different copper resource tax rates.

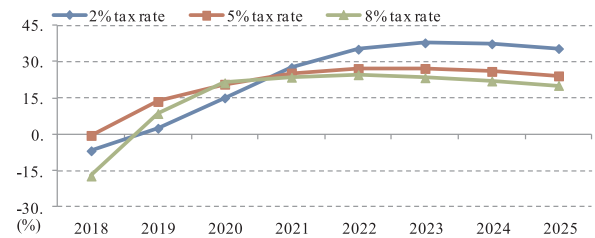

Fig. 4. The impact of changes in Jiangxi copper consumption growth trends under different copper resource tax rates.

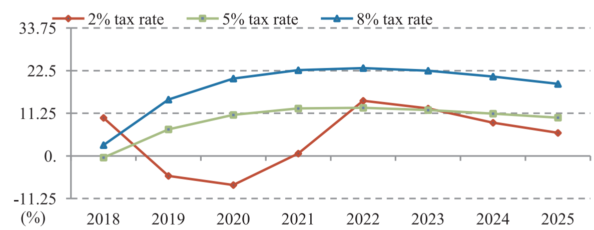

Fig. 5. The impact of changes in Zhejiang copper consumption growth trends under different copper resource tax rates.

The increase of copper consumption in Zhejiang under S2 and S3 also presents an inverted U-shaped pattern, reaching its growth peak at 12.7% and 23.19%, respectively, in the year 2022 (see Fig. 5). Under S1, on the other hand, a U-shaped pattern occurs, and the variation in copper consumption will be smaller than the two other scenarios. Combining the results of real GDP, the economy of Zhejiang will be stimulated by the copper resource tax ad valorem reform, thus expanding the demand for copper resources. As a null resource curse region, a large proportion of copper resources in Zhejiang derive from other regions or abroad due to the deficiency in copper resources. When the tax rate increases, it is more likely for Zhejiang to choose the import option to satisfy the increasing demand for copper resource. The impact on copper consumption in Gansu is negative, however, as shown in Fig. 6. For example, copper consumption will decrease by approximately 13.78% and 16.8% when the tax rate is set to 2% and 8%, respectively, in 2025. Integrating the results of real GDP, the resource tax ad valorem reform will not expand copper resource consumption through promoting economic development in Gansu. The decline of copper consumption could be explained by resource savings, resource substitution and improvement in resource utilization efficiency due to the current industrial structure and underdeveloped economy in high resource curse regions like Gansu.

Generally, the copper consumption will be higher under a higher tax rate in null resource curse regions and lower under a higher tax rate in low and medium resource curse regions. Additionally, the copper

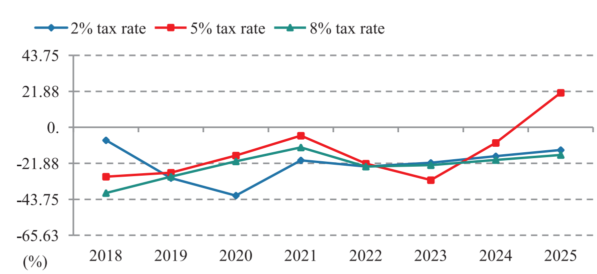

Fig. 6. The impact of changes in Gansu copper consumption growth trends under different copper resource tax rates.

Table 9
The impact of changes in copper resource tax policies on macroeconomic variables (2020); unit (%).

	S1				S2				S3			
	Zhe jiang	Gan su	Inner Mongolia	Jiang xi	Zhe jiang	Gan su	Inner Mongolia	Jiang xi	Zhe jiang	Gan su	Inner Mongolia	Jiang xi
Total resident income	0.58	0.65	0.81	0.43	0.57	0.65	0.80	0.44	0.48	0.65	0.84	0.44
Government revenue	0.75	0.46	0.47	0.22	0.67	0.97	0.46	0.23	0.65	0.45	0.28	0.32
Total consumption	0.58	0.65	0.79	0.45	0.59	0.65	0.80	0.45	0.58	0.65	0.79	0.44
Real GDP	1.89	0.30	1.30	1.87	1.47	0.82	1.22	1.58	1.59	0.29	2.20	3.79

resource tax ad valorem reform will improve the efficiency of resource utilization as a policy management tool in the long term. In high resource curse regions, however, the copper consumption will decrease as the tax rate increases.

(2) Macroeconomic impacts

As shown in Table 9, the impacts of copper resource tax ad valorem reform on total consumption and resident income are positive but stable. For example, when the tax rate is set to 2%, 5% and 8%, in Zhejiang, the total consumption will increase by approximately 0.58%, 0.59% and 0.58%, respectively, and the resident income will increase by 0.58%, 0.57% and 0.48%, respectively, in the year 2020. The stable increase of total consumption could be explained by the major influences on enterprise production rather than households exerted by resource tax ad valorem reform. Government revenue, however, will increase differently among the 4 regions. As an essential part of local financial revenue, the revenue from the resource tax will increase after the implementation of the copper resource tax ad valorem reform. Interestingly, the impacts on the government revenue of low resource endowment regions such as Zhejiang and Gansu are larger than that of resource-rich regions such as Inner Mongolia and Jiangxi, by 0.67%, 0.97%, 0.46% and 0.23%, respectively, under scenario 2 in the year 2020, illustrating that the resource tax is a resource and environmental policy tool apart from being a component of financial revenue.

Copper resource tax reform will have a positive impact on the real GDP of four regions to different extents (see Table 9). For example, when the tax rate is set to 2%, 5% and 8%, the real GDP will increase by approximately 1.30%, 1.22% and 2.20%, respectively, in Inner Mongolia in the year 2020. Specifically, different tax rates will have significantly diverse impacts on the four regions. The real GDP of Inner Mongolia and Jiangxi, regions that have an advantage on copper resource endowment, will increase faster than other regions under S3, by 2.20% and 3.79%, respectively, in 2020. This is because it is more likely to get a higher price of copper resource products in advantageous resource endowment regions under a higher tax rate, while the demand will not decrease due to the competitiveness of quality resource products. For Gansu, a region of low resource endowment and low economic development, the increase in real GDP is lower than in other regions by 0.30% (S1), 0.82% (S2) and 0.29% (S3) in 2020, respectively, which shows a higher “resource curse” level. In addition, the real GDP of Zhejiang will increase 1.89%, 1.47% and 1.59% under S1, S2 and S3, respectively, in the year 2020. Zhejiang is a developed region lacking in copper resources, and the real GDP of resource tax reform is mostly affected indirectly by total consumption, total investment and net export, rather than direct influences. In general, for low and medium resource curse regions, especially those rich in resource endowments, a higher tax rate is preferable; for null resource curse regions, a lower tax rate is better; and for high resource curse regions, a medium one is optimal.

(3) Sector output impacts.

The impacts on the output of sectors, such as light industry, heavy industry, electric and thermal power generation and the construction industry, are relatively significant, which indicates a close correlation between these sectors and copper consumption. Heavy industry will suffer most compared to other sectors; in particular, the output will decrease by 6.47% and 4.74% under S3 in Inner Mongolia and Jiangxi, respectively (see Figs. 9, 10). Heavy industry has high demand for copper resources, and the copper prices will rise due to the resource tax reform, which will result in an increase in costs and thus reduce the production of heavy industry.

Under different tax rates, the impact on the output of the copper mining and dressing industry is also negative. For example, the output of the copper mining and dressing industry will be cut by approximately 0.81%, 0.65% and 1.94% in Jiangxi in 2020 (shown in Fig. 10). Because many copper mines in China produce low-grade ore and ad valorem reform will increase the cost of the related enterprises, the output of copper mining and dressing industry will be reduced. Given the above situation, China's resource tax ad valorem reform should be linked to the mining recovery rate, the mineral processing recovery and comprehensive utilization rate to be more scientific and reasonable.

Comparing the four different regions, we can observe that under the same tax rate, the influence on the same department will not be the same. In low and medium resource curse regions as Jiangxi and Inner Mongolia, except for heavy industry and the copper mining and dressing industry, the outputs of the remaining sectors increase with the increased tax rate. For null resource curse regions as Zhejiang (see Fig. 8), a lower tax rate is preferable for most sectors. Gansu (see Fig. 7), as a representative of a high resource curse region, generally shows the best results under a high tax rate scenario.

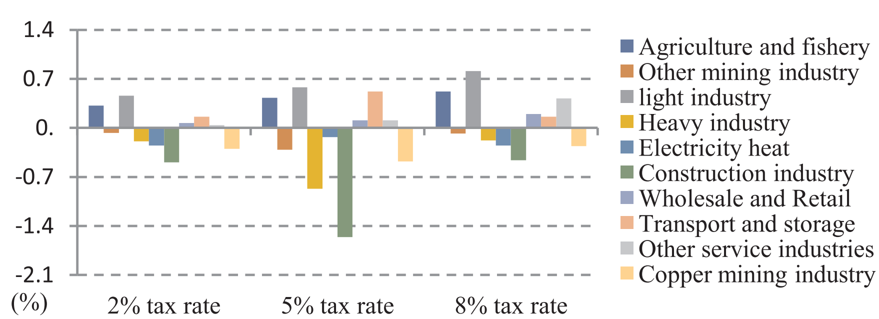

Fig. 7. The impact of output changes in different sectors in Gansu Province under different copper resource tax rates.

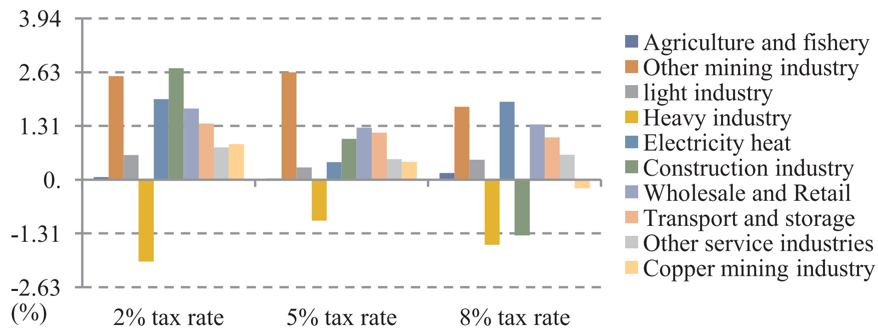

Fig. 8. The impact of output changes in different sectors in Zhejiang Province under different copper resource tax rates.

5. Conclusions and policy implications

Against the background of China's resource tax ad valorem reform, this paper analyses the heterogeneity of the copper resource endowment and metal resource curse in different regions, and selects four representative regions (Gansu, Inner Mongolia, Jiangxi and Zhejiang) to build a dynamic multi-regional CGE model and simulate the impacts of different tax rates on the intensive utilization of copper resources, macroeconomic variables and sector outputs in the four regions. The following conclusions are drawn:

(1) The copper resource tax reform has a large but diverse influence on the consumption of copper resources in different provinces. Under different tax rate scenarios, the impacts are remarkably different. The results are essentially in accordance with the conclusion that China's copper consumption presents an S pattern, as found in previous studies (Chen et al., 2016; Wang et al., 2017a, 2017b, 2017c). This indicates that the dynamic computable general equilibrium (DCGE) model is effective and applicable in forecasting the consumption of mineral resources in different regions.

(2) The copper resource tax reform has a positive impact on resident income, government income, total consumption and real GDP in different regions, albeit slightly lower than that found by Xu et al. (2015), because the higher output value and coal consumption will lead to greater impacts than copper. The obtained results are in opposition to those of Lin and He (2008); Lin and Mou (2008), Lin et al. (2012), Anton (2015a, 2015b) and Zhong et al. (2016), however, all of whom investigate from the national perspective. Our results indicate that the ad valorem resource tax reform could have completely different impacts on regional economies. Given that the resource tax belongs to local taxes, it is necessary to investigate the impacts of the ad valorem resource tax reform from a regional perspective when applying a DCGE model.

(3) The reform of the copper resource tax generally has a negative impact on copper mining sector and copper-related sectors, mainly because ad valorem reform improves the sensitivity of copper prices. The degree of influence under the same tax rate scenario varies from region to region, which reflects the phenomenon of the "resource curse" to some extent. Therefore, the "resource curse" could be induced by an unreasonable policy formulation of resource tax, rather than the resource itself (Papyrakis and Gerlagh, 2007).

According to the above conclusion, policy implications could be obtained as follows: (1) The tax rate should be designed scientifically. If the tax rate is set too low, it will not contribute to improving the allocation and utilization of metal mineral resources; in contrast, if it is set too high, the burden on enterprises will increase, which may impede supply-side structural reform in the mining industry. An appropriate resource tax rate should simultaneously consider the effectiveness of the tax rate and the sensitivity of the economy to external costs of metal minerals, thus making the resource tax reform affordable and sustainable. Specifically, the null resource curse region should set a lower resource tax rate, while the low and medium resource curse regions with abundant resources should set a higher resource tax rate. For high resource curse regions, a medium or high resource tax rate is optional. (2) The meaning and the scope of resource tax ad valorem reform of metal minerals must be further investigated, and the differentiated tax rate should be linked with metal ore characteristics. In particular, for low-grade, associated and difficult-to-select metal minerals, their tax rates must be linked with the extract recovery rate, concentration recovery rate, multipurpose utilization rate, and so on. (3) The further support system must be established. Considering that resource taxes belongs to local governments, the process of metal mineral resource tax reform must be accompanied by the redistribution of interests, which leads to an interest game between local and central government, between provinces (resource-exporting provinces and net purchasing provinces) and between enterprises and governments (especially the key enterprises of metal minerals and local governments). To make the resource tax achieve the goal of resource conservation and environmental protection, the construction of a paid use system of metal minerals and benefit distribution system of resource development must be strengthened and improved.

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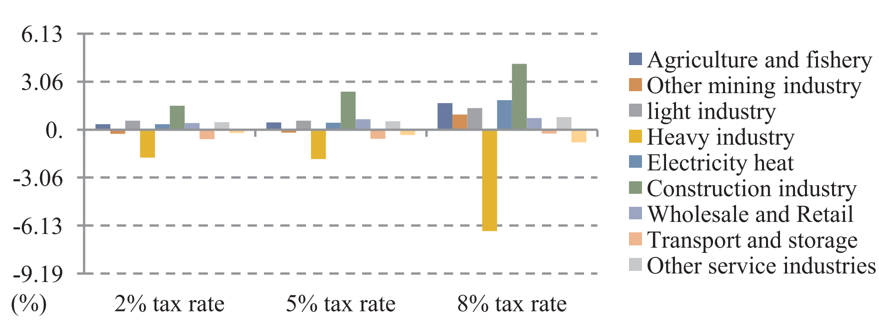

Fig. 9. The impact of output changes in different sectors in Inner Mongolia Autonomous Region under different copper resource tax rates.

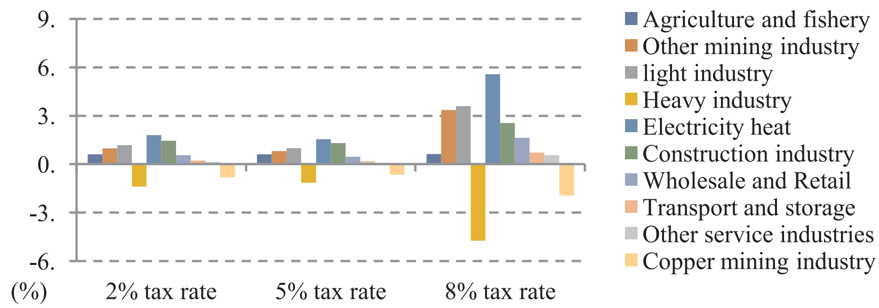

Fig. 10. The impact of output changes in different sectors in Jiangxi Province under different copper resource tax rates.

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Appendix

The remaining equations are as follows:

(1) Production Block

$$\frac{WL\cdot(1+tval_i)}{PKM_i} = \frac{\delta_i^v}{1-\delta_i^v}\cdot\left(\frac{QKM_i}{QL_i}\right)^{1-\rho_i^v} PVA_i\cdot QVA_i = (1+tval_i)\cdot WL\cdot QL_i + PKM_i\cdot QKM_i \frac{PMN}{WK\cdot(1+tvak_i)} = \frac{\delta_i^{km}}{1-\delta_i^{km}}\cdot\left(\frac{QK_i}{QMN_i}\right)^{1-\rho_i^{km}} PKM_i\cdot QKM_i = PMN$$

$$\cdot QMN_i + WK\cdot(1+tvak_i)\cdot QK_i QMN_i = (\lambda_i^e)^{\varepsilon_i^e-1}\cdot\delta_i^e\cdot\left(\frac{PMN_i}{PQ_i}\right)^{\varepsilon_i^e}\cdot QMNI_i PMN_i = \left[\sum_e \sigma_i^e\cdot\left(\frac{PQ_i}{\lambda_i^e}\right)^{1-\varepsilon_i^e}\right]^{\frac{1}{1-\varepsilon_i^e}}$$

(2) Trade Block

$$QM_i = QDM_i\cdot\left(\frac{PDM_i}{PM_i}\cdot\frac{\delta_i^{aq}}{1-\delta_i^{aq}}\right)^{\frac{1}{1+\rho_i^{aq}}} QAE_i = \alpha_i^{ae}\cdot\left(\delta_i^{ae}\cdot QE_i^{-\rho_i^{ae}} + \left(1-\delta_i^{ae}\right)\cdot QDE_i^{-\rho_i^{ae}}\right)^{-1/\rho_i^{ae}} QAE_i = QE_i + QDE_i QE_i = QDE_i\cdot\left(\frac{PE_i}{PDE_i}\cdot\frac{1-\delta_i^{ae}}{\delta_i^{ae}}\right)^{1/\rho_i^{ae}-1}$$

(3) Income and Expenditure

$$YI_h = \left(\sum_f YIF_{h,f}\right) + translo_{h,logov} + transfr_{h,row}\cdot EXR + transop_{h,oprov} PQ_i\cdot QH_i = shrh_i\cdot mpc\cdot(1 - cetins_h - lotins_h)$$

$$\cdot YI_h YI_{en} = \left(\sum_f YIF_{en,f}\right) + translo_{en,logov} + transfr_{en,row}\cdot EXR + transop_{en,oprov} EINV = \sum_i PQ_i\cdot QINV_i GTAX = \sum_{en}(cetins_{en} + lotins_{en})\cdot YI_{en} ENTSAV$$

$$= \sum_{en} mps_{en}\cdot(1 - cetins_{en} - lotins_{en})\cdot YI_{en} PTAX_i = ta_i\cdot PA_i\cdot QA_i CEPTAX = \beta_{produce}\cdot\sum_i PTAX_i LOPTAX = (1-\beta_{produce})\cdot\sum_i PTAX_i IMTAX = EXR$$

$$\cdot\sum_i tm_i\cdot pwm_i\cdot QM_i CEGrev = CEPTAX + IMTAX + \sum_{insdng}(cetins_{insdng}\cdot YI_{insdng}) + LOtoCELOGrev$$

$$= LOPTAX + IMTAX + \sum_{insdng}(lotins_{insdng}\cdot YI_{insdng}) + CEtoLO$$

(4) Model Closure and Market Clearing

$$QQ_i = \sum_j QINT_{i,j} + \sum_h QH_{c,h} + CEGD + LOGD + \overline{QINV_i}\sum_i QL_i = QLS\sum_i QK_i = QKSQLS = \overline{QLS}QKS$$

$$= \overline{QKS}\sum_i(QM_i\cdot pwm_i + QDM_i\cdot ppm_i) + \overline{TR^{erow}} + \overline{TR^{grow}} = \sum_i(QE_i\cdot pwe_i + QDE_i\cdot ppe_i) + \overline{TR^{rowh}} + \overline{saveF} + \overline{saveOP}EINV = (1-mpc)$$

$$\cdot(1 - cetins_h - lotins_h)\cdot YI + ENTSAV + GSAV + EXR\cdot\overline{saveF} + VBIS$$

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