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Market impacts of environmental regulations on the production of rare earths: A computable general equilibrium analysis for China

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ABSTRACT

Rare earths are important strategic mineral resources, but their production causes serious environmental pollution. As the largest producer of rare earths in the world, China is particularly susceptible to ecological destruction, water pollution, and soil erosion. In order to promote the green development of its rare earth industry, the Chinese government will implement more stringent environmental regulations. In this study, we construct a computable general equilibrium (CGE) model to investigate the market impacts of environmental regulation on the production of rare earths in China. Three scenarios are used to simulate the different environmental regulatory intensities that the Chinese government may adopt in the near future. The results show that an increase in the environmental regulation of the production of rare earths would have a negative impact on the macro-economy. Regarding the rare earths market, due to an increase in the environmental cost, producer prices and domestic consumer prices would increase by 1.59%–5.78% and 0.55%–1.96%, respectively. Under the stimulation of a price increase, the total demand and sectoral demand for rare earths both decrease. Specifically, the demand for rare earths in the mining and processing of rare earths sector decreases by 18.17%–43.59%. The reduction in the demand for rare earths would lead to a decrease in rare earths production of −4.79% to −13.49%. Therefore, the supply to the domestic market would decrease by 3.02%–7.72% and to the foreign market by 5.43%–15.61%. Based on the analysis, the Chinese government could adopt a relatively loose regulatory policy with the intensity of 20% or 10% currently, and then upgrade to a complete environmental compensation level for rare earths production in the next stage.

1. Introduction

Rare earths are important strategic mineral resources that are widely used in generating new energy and materials, in energy conservation and environmental protection, and in the aerospace and electronic information industries (McLellan et al., 2013; Golev et al., 2014; Wang et al., 2015). Until recently, rare earths have mainly been distributed in the United States, Australia, Brazil, China and India. Among these nations, China is the world's largest producer and exporter of rare earths, satisfying 85% of global rare earth demand and holding 31% of rare earth reserves in 2015 (Wübbeke, 2013; Han et al., 2016; USGS, 2016; Wang et al., 2016).

The production of rare earths can alter original environmental conditions and create major environmental problems, including ecological destruction, pollution, soil erosion, and geological disasters (Salomons, 1995; Klukanová and Rapant, 1999; Aguilar et al., 2004; Liu et al., 2006; Luís et al., 2011; Liang et al., 2014). Rare earths also cause the generation of large amounts of waste and high levels of radiation (Ye and Wu, 2014). As the world's largest producer of rare earths, China is particularly susceptible to the serious environmental problems mentioned above. For example, the

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production of 1 ton of rare earth oxide from ionic-adsorbed clays requires 300 m^2 of ground cover and soil to be removed, 2000 tons of tailing to be created and 1000 tons of wastewater – containing heavy metals and concentrated leaching solution – to be released into the environment (Su, 2009; Packey and Kingsnorth, 2016). In Ganzhou, the total cost of pollution control is as high as 38 billion CNY (China Yuan) in prices for the year 2012 (Fan and Bian, 2015).

In addition to the current technical limitations of producing rare earths, weak environmental regulation is also an important cause of serious environmental pollution (Han et al., 2015). Some environmental policies are particularly affected by the rare earths industry. For example, because the in-situ leaching of ion-absorption REE uses large amounts of ammonia sulfate solutions, the ammonia emission standard of 2009 was not changed and remains the same as the general discharge standards of 1996 (Wübbeke, 2013). Moreover, rare earths producers face very low economic costs for the environmental pollution they generate. There are a series of environmental fees, including sewage charges, forest-vegetation recovery payments, water and soil conservation facilities compensation, soil-erosion compensation fees and mining recovery margins. However, the average economic cost for 1 ton of rare earth oxide is only 1600 CNY at the 2012 price (Ye and Wu, 2014). Taking the China Northern Rare Earth (Group) High-tech Co., Ltd. (CNREHT) as an example, its environmental fee in 2015 was 1.69 million CNY at the current price, which accounts for only 0.03% of the total production cost (CNREHT, 2015).

In 2016, the Chinese government released its "Rare Earth Industry Development Plan (2016–2020)" to guide high value applications of rare earth products and the green development of the rare earth industry. According to this policy, by 2020, the emission intensity of major pollutants in the rare earth industry will decrease by 20% compared with 2015. In order to achieve this goal, the Chinese government will impose more stringent environmental regulations, such as sewage discharge permits and environmental taxes (Han et al., 2015; Ge et al., 2016a, b).

The environmental problems caused by the production of rare earths have been widely recognized and discussed. Many studies have used the LCA model to assess the environmental impacts of rare earth production in China and in foreign countries; they have concluded that rare earth production results in eutrophication and acidification, soil erosion, CO_2 emission and other problems (Navarro and Zhao, 2014; Lee and Wen, 2016; Schreiber et al., 2016; Vahidi et al., 2016; Weng et al., 2016). In addition, some studies have considered the recycling and waste management aspects of rare earths because both can contribute to minimizing the environmental impacts of rare earth production (Binnemans et al., 2013; Morf et al., 2013; Rademaker et al., 2013; Habib and Wenzel, 2014; Machacek et al., 2015; Wan and Wen, 2015). Studying the environmental pollution resulting from rare earth production, Keith-Roach et al. (2015) proposed that environmental legislation is the best option for the emerging European rare earth industry. Wübbeke (2013) indicated that the "Pollutant Discharge Standards for the Rare Earth Industry" released in 2011 would increase production costs by 70% for rare earth producers in China. Most of the studies mentioned above focus on the emissions and types of pollution that result from the production of rare earths; there are few studies of the market response under different environmental regulatory conditions in China. Against this background, our paper simulates the market impacts of environmental regulations on rare earth production under different policy scenarios and proposes some policy implications.

The rest of this paper is organized as follows. Section 2 describes our CGE model for China, including the general model structure, model blocks, calibrations, and simulation design. Section 3 provides the simulation results, including macroeconomic impacts and rare earth market impacts. Section 4 concludes the study and provides policy implications.

2. Methodology and data

2.1. Overview

CGE models are suitable for analyzing the impacts of contemporary policy issues such as environmental taxes and subsidies (Ge et al., 2014). To assess the effects of environmental regulations on market supply and demand for rare earths, we first specify a CGE model of the Chinese economy. This study adopts the rare earths CGE model developed by Ge et al. (2016a, b), which is constructed based on Ge et al. (2014) and Zhong et al. (2016). In this study, rare earths are considered as the natural capital for each sector's production and are expected to be imperfectly substituted by the monetary capital, which could monetize the value of rare earths and simulate the loss and gain of rare earths use. The model includes 26 sectors (including 1 sector of rare earth mining), as listed in Table 1. The model is a system of equations describing 2 primary factors (labor and capital), 6 economic agents (product, investment, household, export, government and stock) and the equilibrium conditions and constraints of the economy for factors, commodities, savings and investment, and the rest of the world. Fig. 1 displays the general structure of the CGE model in this study.

2.2. Model blocks

2.2.1. Production block

Producers maximize profits subject to technological constraints. As shown in Fig. 1, the technology of production is represented by a nested Leontief production function between the value-added and intermediates. This means that the value-added cannot be substituted by the intermediates and that the substitution between these two inputs is zero. The Leontief production function is expressed as the following equation (Hosoe et al., 2010):

$$Y = min\left(\frac{B_1}{ab_1}, \ldots, \frac{B_n}{ab_n}\right) \quad (1)$$

where Y is the aggregate output of the firm, $B_1, \ldots, B_n$ are the aggregates of various inputs, and $ab_1, \ldots, ab_n$ are the input requirement coefficients.

Moreover, the substitution relationship between labor and capital is described by a CES (constant elasticity of substitution) production function. At the next nested level, the capital input is decided by natural capital, which in this study refers to ores of rare earths, and monetary capital with a CES function. The CES function can be expressed as follows (Hosoe et al., 2010):

$$VA = A\left(\sum_{i=1}^{n} \delta_i F_i^{-\rho}\right)^{-\frac{1}{\rho}} \quad (2)$$

where VA is the value-added, F_i is the i-th input factor, and A, δ, and ρ are the parameters.

Each nesting level is characterized by a specific substitution elasticity, which shows the extent to which the factors can be substituted for each other (Ge et al., 2014).

2.2.2. Consumption block

The consumption block shows the total demand of the domestic market, including household consumption, government consumption, investment and intermediates.

For household consumption, the model includes both urban and