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# Shadow prices and production inefficiency of mineral resources

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ABSTRACT

With the Millennium Development Goal focusing on the eradication of poverty in developing countries expiring in 2015, the international focus is shifting toward sustainable development. The sustainability of the natural resources that are used as energy sources and in the production of goods is a global issue that is not specific to developing nations. We contribute to the need for quantitative targets for natural resources by calculating the shadow prices and production inefficiency levels of 32 mineral resources by using a stochastic frontier analysis and panel data from 1980 to 2010 in 162 countries. In addition, we provide estimated shadow prices and production inefficiency levels up to 2020 with various levels of production restrictions. The results show the following: (1) The shadow prices and production inefficiency levels of major metals are generally higher in Asian countries than in non-Asian countries; (2) there is an upward trend in the inefficiency levels in Asian countries, whereas the inefficiency levels remain rather stable in non-Asian countries; (3) production restrictions do not guarantee an increase in shadow prices, but the magnitude of the impact of such restrictions seems to be larger in Asian countries compared to non-Asian countries; (4) production restrictions do not seem to affect production inefficiency; thus, they may not be effective in reducing gaps in production inefficiency between Asian and non-Asian countries.


## 1. Introduction

An increase in the consumption of minerals is inevitable, given the pace of economic development and modernization and the increase in production and energy consumption. Nevertheless, the current consumption patterns raise concerns from the perspective of the sustainability of mineral resources. In recent years, international efforts have been made to provide solutions for poverty on a global scale. The UN established the Millennium Development Goals (MDGs) in 2000, the main goal of which was to eradicate extreme poverty; thus, the targets were the poor in developing countries. With a deadline in 2015, the next goals mentioned are Sustainable Development Goals (SDGs), which were discussed at the United Nations Conference on Sustainable Development (Rio+20) in 2012. One issue with the MDGs was that quantitative targets

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were not established, which may have hindered the effectiveness of the global program, and researchers have claimed that the SDGs can be distinguished from the MDGs by focusing the discussion on the latest research on the issue of sustainability (Jung et al., 2000; Griggs et al., 2013).

In recent years, there has been a shift in terms of how to approach economic development and growth, and designing quantitative targets for sustainable development has become the focus in the latest debate. Dasgupta et al. (2015) noted that neither the SDGs nor their background documents explain how governments should judge whether the development programs they undertake to meet the goals are sustainable. Moreover, the authors indicated that economic growth should reflect growth in the Inclusive Wealth Index (IWI). At Rio+20, an Inclusive Wealth Report (Agarwala, 2012) was proposed as an aggregate measure that includes factors that may affect countries' development and sustainability. Gross Domestic Product (GDP) essentially measures short-term economic activities; in contrast, the IWI attempts to evaluate the stocks of other assets, such as physical capital (including infrastructure), human capital and natural capital.

The IWI uses the shadow prices of various types of assets. The shadow prices of mineral resources are essential for the establishment of global production targets for mineral resources that are limited in availability. Lin and Zhang (2011) estimated the shadow prices of various minerals using the Hotelling model (Hotelling, 1931). The model analyzes the optimal usage of mineral resources through the estimated maximization of producers' discounted present value of minerals; however, the estimation assumes perfect information about mineral reserves, which is difficult to grasp and quantify because new mining spots are continuously being discovered. Many studies have provided shadow price calculations for different capitals and assets using various estimation methods. Ishinabe et al. (2013), Mekaroonreung and Johnson (2012), Kumar et al. (2015) and Molinos-Senante et al. (2015) calculated the shadow prices of $CO_2$ emissions and greenhouse gas emissions. Furthermore, Lee and Zhang (2012), Du and Mao (2015), and Du et al. (2016) focused on China, which is the world's largest $CO_2$ producer and energy consumer, and estimated the shadow prices of $CO_2$ emissions to assess potential cost savings. In particular, Du et al. (2016) proposed a new meta-frontier method to investigate technical efficiency.

$CO_2$ emissions and the production of undesirable outputs often have negative impacts on the natural environment and the sustainable development of a society and economy. The shadow prices of undesirable outputs are usually derived from the market prices of desirable outputs using distance functions and duality theory, which can be further calculated using parametric or nonparametric efficiency models (Zhou et al., 2014). Existing studies on estimations of efficiency and shadow prices have used the non-parametric Data Envelopment Analysis (DEA) approach and the parametric Stochastic Frontier Analysis (SFA) approach.[1]

The parametric SFA approach constructs the production frontier and offers the benefit of taking statistical noise into account. This approach applies to the directional distance function but not to the Shephard distance function (Du and Mao, 2015). Many existing studies have explored the theoretical and application aspects of distance functions, and both the Shephard distance function and the directional distance function have been successively employed in shadow pricing estimations. Relevant studies include Färe et al. (2005), Murty et al. (2007), and Wei et al. (2013). The directional distance function was developed to enable asymmetric changes in input and output vectors, which is favorable for modeling production technologies (Chung et al., 1997; Färe and Grosskopf, 2000). In application, some of the studies estimating shadow prices have mainly focused on single polluting industries, such as electricity, paper and pulp, and agriculture, but shadow pricing for multiple sectors and multiple regions has also been studied. Moreover, regarding the shadow price calculations of input resources, He et al. (2007) estimated the shadow price of water, and Misra and Kant (2007) employed a parametric linear programming approach to estimate a deterministic input distance function characterizing the production structure of Joint Forest Management (JFM) organizations in the Gujarat state of India. The distance function includes economic, biological and social outputs as well as neo-classical (land, labor, and capital) and non-neo-classical (social, political, institutional, and organizational) factors. The results are used to calculate the production efficiency and shadow prices of the neo-classical and non-neo-classical factors for different village-level JFM organizations.

Natural resources such as oil, natural gas and coal have received broad attention as crucial energy resources for growth. Despite the importance of mineral resources in industrialization and manufacturing and the fact that metals have the highest growth rate in terms of natural resource extraction of the resource categories,[2] there are few studies that focus on mineral resources (Behrens et al., 2007). Goal 12 of the SDGs is to 'ensure sustainable consumption and production patterns,' and one of the main targets is to achieve 'the sustainable management and efficient use of natural resources' by 2030.[3] Nonetheless, quantitative studies on the shadow prices or efficiency of mineral resources are rather scarce. Therefore, we contribute to the discussion on optimal quantitative sustainable development targets by estimating the shadow prices of mineral resources, which can be used to estimate mineral capital for the IWI. Additionally, we demonstrate that the parametric SFA approach with a directional distance function can be used to calculate the production inefficiency of mineral resources. We estimate the effect of production restrictions on shadow prices and production inefficiency using panel data for 32 mineral resources

1 See, Sheng et al. (2015), Alfredsson et al. (2016) and Tamaki et al. (2016) for DEA approach and Nghiem et al. (2011), Zhou et al. (2014) and Du and Mao (2015) for SFA approach.

2 Behrens et al. (2007) found that global used resource extraction grew from 40 billion tons in 1980 to 55 millions in 2002, the extraction of metals increased by 56%, and the extraction of fossil fuels increased by 30%.

3 The Goal 12 targets of the SDGs are available at http://www.un.org/sustainabledevelopment/sustainable-consumption-production/.

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