A Partial Equilibrium Model of Metals with an Application for Rare Earth Elements

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1 Introduction

The Rare Earth Elements are a group of 17 metals sharing similar chemical properties. They are a hardly substitutable input in some important high tech applications, including high performance permanent magnets, phosphors, but also in military applications. Currently China has a share of supply that makes it almost a monopoly producer. Despite Rare Earths being a major input for many important high tech applications, these stylized facts were unknown to almost everyone until recently. This can be attributed to the relatively small amounts produced and traded. In 2009, for example, mines worldwide produced about 124.000 metric tons of Rare Earths, but more than 15.7 million tons of copper (USGS 2010; International Copper Study Group, 2010). The booster detonation for broad public interest was the huge price spikes which were seen for Rare Earths in recent years which are mainly attributed to increasing demand and tightened Chinese export restrictions, making Rare Earths' importance suddenly visible.

A public discussion emerged about the consequences of these developments generating very different positions. While some argue that emerging mines outside China and recycling will overcome the problems soon, others call for state intervention through government stockpiles, support for recycling, or public investment in mines.

With this paper I want to contribute to the discussion by analyzing the market for Rare Earths in a partial equilibrium model, taking into account multifarious drivers relevant to resource markets. Quantified scenarios about the future development of the Rare Earths' market are developed to analyze the main drivers for the Rare Earths' market. The analyzed factors include Chinese trade restrictions, recycling, estimated costs of mining and investment, growth rates of demand, but also the prices of other metals co-occuring with rare earths.

The paper proceeds as following. An overview about Rare Earths and their market is given in section 2. The model structure is described in section 3, the underlying data is discussed in chapter 4. The scenarios and their results are analyzed in section 5. Section 6 concludes.

2 Rare Earths in a Nutshell

Seventeen metals comprise the Rare Earths: Scandium, Yttrium, and the 15 metals standing right of Lanthanum in the periodic system of elements, the so called Lanthanides. These metals all share similar chemical properties and usually occur together.[1] Other than their name suggests Rare Earths are not rare in a geological sense. According to USGS 2012 [Mineral Commodity Summaries], there are known reserves of rare earths of about 110 million metric tons. A large number when contrasted with current annual production of about 130.000 tons.

Current extraction of rare earths is highly concentrated in China which supplies more than 95 percent of all Rare Earths with minor quantities coming from Brazil, India, Malaysia and the Commonwealth of Independent States. A notable new supplier of Rare Earths is the recently reopened Mountain Pass mine in California. The Reserves are, however, significantly less concentrated. Only about a third of the known reserves of all Rare Earths lay under Chinese ground (USGS, 2010). [The Principal Rare Earth Elements Deposits of the United States—A Summary of Domestic Deposits and a Global Perspective].

Chinese dominance in Rare Earths' supply rooted in the 1980's, when low costs of production enabled Chinese companies to take over an ever larger growing part of the world market. The supplier till then providing the lion's share of Rare Earths worldwide, the above mentioned and now reopened Mountain Pass mine in California, lost its dominant position and was eventually closed in 2002. Parallel to China's growing importance on the supply side, Chinese

[1] For more natural scientific information about Rare Earths see Gupta and Krishnamurthy (2004).

government strongly supported research aiming at discovering new applications for Rare Earths, making China also the major consumer of Rare Earths (Hurst, 2010).

Rare Earths are used today in several different applications, where they are often essential inputs being substitutable only with significant losses in performance of the final products. In USGS (2011), eight main applications are distinguished (see Annex A). These include catalysts for cars and oil refining, high performance permanent magnets, batteries, and phosphors.

3 Model

To depict the market for Rare Earths, a dynamic partial equilibrium model is developed. It is designed as a regionalized world model with China and the rest of the world currently being distinct. The model covers the complete life cycle of the Rare Earths, beginning with the extraction of ores and the winning of metals, but also including trade, the use of Rare Earths in several applications and eventually disposal or recycling of the metals.

Generally, each Rare Earth element is considered separately, with some exceptions. Promethium is not included since it has no stable isotopes and is only found in traces naturally. The elements Holmium, Erbium, Thulium, Ytterbium, and Lutetium are aggregated due to a lack of data for each metal individually.

In the model, it is assumed that extracting the ores and winning the Rare Earths out of them is done by vertically integrated firms denoted mines. For the sake of comparability, it is assumed that all mines produce separated Rare Earth Oxides (REO). The mines are modeled being profit maximizing firms. No oligopolistic behavior is assumed; therefore mines do not take into account their competitors actions. They receive revenue from selling the REO and by-products. The share of the Rare Earths in the extracted ore is fixed. While the by-products' prices are exogenously given, the Rare Earths' prices are endogenous. Operational costs exhibit constant marginal costs and are specific to each mine.

Extraction of the metals underlies two constraints, a capacity and resource constraint. The capacity of mines is determined by endogenous investment, accounting for the importance of investment costs and capacity constraints (Cairns, 2001). The investment costs are assumed quadratic. In accordance to Hotelling (1931), mines take into account the exhaustibility of their resource. The resources data is adjusted to the losses occurring during mining and winning.

To depict the international trade in Rare Earths, trading sectors are introduced for each region. The trading sectors purchase the Rare Earth Oxides globally from mines and from the domestic recycling sector and sell them to the final demand in their own region. Given that prices per kg of the metals are rather high compared to base metals, it can plausibly be assumed that transportation costs are not a main determinant of Rare Earth markets and therefore they are neglected. Contrariwise, tariffs on international trade are substantial and considered in the model. The same applies for (Chinese) export quotas on Rare Earths. Therefore, a quantitative restriction on the trade of Rare Earths is modeled.

Rare Earths are not consumed by households, but are used to produce consumer goods or intermediates. The actual production of these goods is not depicted in detail in the model. Instead, the industry demand in several applications is modeled using specific demand functions for each application. Eight different areas of application are distinguished (Listed in Annex A). The demand functions for each application are based on prognoses. To allow for demand to be price elastic, the prognoses are multiplied by the difference between the endogenous price and an expected price of the metals weighted by a parameter expressing the price elasticity of demand.

After the products containing Rare Earths reach the end of their useful lifetime, they are either discarded or recycled. This means when assuming for a constant lifetime t of the products, the metals available for recycling are determined by the demand t years ago. The maximum available metal for recycling is depicted accordingly (see van de Voet et al. 2002).

In each region, a representative firm is assumed collecting scrapped material, recycling it and selling it to the domestic trader. This approach implies no international trade in scrap. Collecting scrap and recycling is a costly task. It can plausibly be assumed that costs are increasing with the rate of recycling, the share of scrapped metal that is eventually recycled. Both because the costs for collecting the scrapped metal increases and because lower quality material has to be used. Costs of recycling are modeled accordingly.

4 Data

A large share of the data necessary to calibrate the model is specific to mines. No consistent dataset for Rare Earth mines exists, however. To overcome this problem, firm specific engineering data is employed. When developing their projects, mining companies usually prepare and publish studies assessing the technical and economic viability of their projects. These range from very preliminary scoping studies to more certain feasibility studies. While evidence suggests that these reports tend to underestimate investment costs and ramp up time (Noort and Adams, 2006; Mackenzie and Cusworth, 2007), they seem to be the most reliable source of information for all projects which are either not producing yet or only started production recently. For all mines which published a report assessing costs of investment and operation as well as estimates of resources and reserves following international standards before the 01.04.2012, the available data will employed to calibrate the mines. Employed data includes resources, investment and operational costs, planned capacity, recovery rates and expected start of production. Using this approach, data for almost all more advanced projects outside China can be gathered.

The situation is, however, different for Chinese mines, for which no reliable data is available. Their investment behavior is set exogenously along Chinese government's announcements. Two reasons legitimate this assumption. Firstly, the Chinese Rare Earths mines underlie a high degree of political influence potentially leading to a behavior different to a mine solely operated according to economic principles. Secondly, the most important Rare Earths mine in China, Bayan Obo in Inner Mongolia, is an iron ore mine with Rare Earths as a by-product, making the investment decisions also conditional on the prices for iron and thereby somewhat exogenous.

Rare Earths are traded on a bilateral basis. No commodity exchanges for them exist. Price data are collected by private companies relying on industry sources. Prices underlying the model are supplied by asianmetal.com and are accessible via Thomson Reuters Datastream.

To calibrate the demand and trade of Rare Earths in the base year, a dataset is needed that can be expressed as a three-dimensional matrix. The use of each metal in each application in each region is needed. USGS (2011) presents a dataset displaying how much of every metal is used in the application. In 2011, 67% of all Rare Earths were consumed in China (Kingsnorth, 2012). It is assumed that this share applies for all Rare Earth metals.

The future development is based on scenarios. Two approaches to construct them can be chosen. The first one is relying on prognoses for the overall demand for Rare Earths such as Kingsnorth (2012). The overall growth rate than has to be split to determine growth rate for each application. An alternative is to assume specific growth rates for each application based on prognoses for the products without fixing an overall growth rate initially. So far, the first approach is chosen.

To date, no significant amounts of Rare Earths are recycled. For a long time, low prices made recycling of rare earths uneconomic. In addition to that, Rare Earths are employed in dissipative manner in many applications, which further limits the prospects for recycling (for further information, see Schüler et al. 2011). Therefore, no published information about costs of recycling is available currently. Recycling needs to be analyzed using scenarios exploring which level of costs needs to be reached for recycling to contribute to the future supply of Rare Earths. A focus should be put applications where Rare Earths are employed in relatively high concentrations, e.g. permanent magnets and batteries.

5 Preliminary Results

The preliminary results generally suggest that the high price level which was seen the last years will not sustain. New mines enter the market and the new supply will drive the prices down. The development differs by metals, with some seeing quickly deteriorating prices and some not. The results of specific scenarios are not discussed here due to their preliminary nature.

6 Conclusions

The recently evolving interest for Rare Earth elements has led to a very diverse discussion about the future development of their markets. This work aims at contributing to the discussion by constructing quantified scenarios using disclosed methodology.

The model is designed to depict the life cycle of Rare Earths from the extraction of ores to disposal or recycling. It is developed as a dynamic partial equilibrium model, encompassing the whole world. Data of the model is to a large extent based on industry data and engineering estimates.

Due to the preliminary nature of all results, no definitive conclusions can be drawn so far.

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Annex A: Considered Applications of Rare Earths

Catalysts
Glass
Metallurgy
Phosphors
Ceramics
Magnets
Batteries
Other