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Coal lumps vs. electrons: How do Chinese bulk energy transport decisions affect the global steam coal market?☆

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ABSTRACT

This paper demonstrates the ways in which different Chinese bulk energy transport strategies affect the future steam coal market in China and in the rest of the world. An increase in Chinese demand for steam coal will lead to a growing need for additional domestic infrastructure as production hubs and demand centers are spatially separated, and domestic transport costs could influence the future Chinese steam coal supply mix. If domestic transport capacity is available only at elevated costs, Chinese power generators could turn to the global trade markets and further increase steam coal imports. Increased Chinese imports could then yield significant changes in steam coal market economics on a global scale. This effect is analyzed in China, where coal is mainly transported by railway, and in another setting where coal energy is transported as electricity. For this purpose, a spatial equilibrium model for the global steam coal market has been developed. One major finding is that if coal is converted into electricity early in the supply chain, worldwide marginal costs of supply are lower than if coal is transported via railway. Furthermore, China's dependence on international imports is significantly reduced in this context. Allocation of welfare changes particularly in favor of Chinese consumers while rents of international producers decrease.

1. Introduction

Steam coal sourcing and costs have not presented a real challenge during the last decades. However, this situation could change. The center of gravity and price setting in the global steam coal trade market have been shifting to Asia since 2005 (Ritschel, 2009a). An important driver for the future evolution of steam coal market economics will be China as Chinese demand today already makes up 45% of the global market volume. Established energy projections show that Chinese demand will rise by 80% to 130% until 2035 compared to 2007 levels (EIA, 2010b).

In addition to the challenges of providing an additional 2 billion tons of steam coal mining capacity until 2030 and significantly increasing exploration efforts to generate proven, marketable reserves, the main challenge is that steam coal supply and demand are spatially separated in China (Minchener, 2007). The majority of the country's coal reserves lie in the North-central Chinese provinces of Shaanxi, Shanxi and Inner Mongolia as well as far in the west, in the province of Xinjiang. Inland transport distances from these regions to the coastal demand centers around Beijing, Hong Kong and Shanghai total up to 3500 km. Coal transport in China mainly takes place by rail, river barges and coastal shipping, which significantly increases costs of supply to the coastal demand centers. Approximately 60% of Chinese coal output was hauled via railway along distances of more than 500 km to coal-fired power plants in 2005 (CIRI, 2006). Transport costs make up more than half of delivered costs for domestic coal in the southern provinces. Chinese demand centers are located along the coast and have the opportunity to procure steam coal volumes on the global trade market. Thus, high domestic transport costs combined with rising mining costs have recently led to an increase in foreign steam coal imports (Ritschel, 2010).

Future Chinese steam coal demand can be satisfied either through additional domestic steam coal production or by significantly increasing steam coal imports. One important driver for determining the Chinese supply mix is the future domestic transport costs between the coal-bearing regions in North-Central China and the coastal areas.

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[1] Steam coal is hard coal of bituminous and sometimes subituminous or anthracite quality which is almost exclusively used in electricity generation.

[2] The global steam coal market is defined as total global steam coal production and demand worldwide including domestic markets. The global steam coal trade market on the other hand consists of the internationally traded volumes (mostly by sea transport) which only make up a small fraction of the global market. The global steam coal trade market volume was 658 Mt while the global steam coal market volume was5000 Mt in 2009 (IEA, 2009).

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The primary energy carrier coal can be transported via railway or can be converted on-site to electricity which is then transported via HVDC lines to the main consuming regions. Currently, China mainly relies on railway expansion projects to significantly increase its coal transport capacity (Sagawa and Koizumi, 2007; Minchener, 2004) from the West to the Eastern regions. Even though China has been able to rapidly expand its railway infrastructure during recent years to cope with the majority of the rising coal transport, railway transport is comparatively expensive (Minchener, 2004).

Another transport option for China is investment into large-scale HVDC transmission in combination with mine-mouth coal-fired power plants in the North-Central coal-bearing provinces. Such an energy transport system could significantly reduce variable transport costs and could supply coal-based energy to the Chinese coastal demand centers. Unfortunately, large-scale deployment has so far been hindered by weak central energy planning institutions as well as regulatory schemes that provide few incentives for Chinese grid companies to invest in power transmission (Fedor, 2008; MIT, 2007).

Nevertheless, the need for a coherent domestic energy transport strategy remains pressing, particularly regarding the continuing consolidation process in the Chinese coal industry (Peng, 2011). Initiated by national reform efforts to enhance work safety and efficiency of the entire industry, recent policy implementation has led to the closing or merging of small and inefficient coal mines, thus improving economies of scale (ESMAP, 2008; NDRC, 2007). Consequently, the share of small coal mines in total domestic production dropped significantly from 19.9% (342 Mt) in 2003 to 2.1% (55 Mt) in 2008 (CIRI, 2008). In addition to the permanent increases in national coal trade volume in recent years, this might have proven to be an additional burden to the prevalent energy transport system, since the restructuring process results in a concentration of production in remote regions in the North and North West of China (Lester and Steinfeld, 2006). Taking these implications of the policy of increased efficiency in the coal industry into account, setting up HVDC transmission lines might as well be regarded as a logical extension in an overall strategy for improvement of energy efficiency.

The analysis focuses on the two effects of the two outlined bulk energy transport investment strategies in China: firstly, how is the future Chinese steam coal supply mix affected by different bulk energy transport modes? Secondly, what are the implications of the change in the Chinese coal supply mix for the world steam coal market? Hence, the paper will look at the future Chinese coal supply mix, at the global long-run marginal costs of steam coal in China and several important world market regions, at the worldwide mining investments and utilization as well as at the global welfare effects. To analyze these parameters, a spatial equilibrium model which minimizes total costs of global steam coal demand coverage is developed and presented. This global modeling approach makes it possible to obtain answers to the proposed research questions, including feedbacks and interdependencies between worldwide market actors. The model is validated for reference years 2005 and 2006. Then, two scenarios for possible future transport infrastructure investment decisions in China are investigated: one scenario assumes further investment in railroad transport to move coal energy to the demand centers. The second scenario assumes large-scale investment in HVDC transmission lines combined with mine-mouth coal-fired power plants and transmission of electricity to the demand hubs. Then, steam coal flows and marginal supply cost patterns for both scenarios are projected up to 2030.

The remainder of the paper is structured to include seven sections: after a round-up of relevant literature regarding supply cost modeling and coal market analyses in Section 2, the current situation in the steam coal trade market will be shortly described in Section 3. Then, the model is introduced in Section 4. Section 5describes the underlying dataset. Section 6 depicts the scenario assumptions, and Section 7reports model results. Section 8 concludes the paper.

2. Related literature

The most obvious characteristic of the steam coal world market is its spatial structure. Steam coal demand regions are not necessarily at the location of the coal fields (Ritschel, 2010). Coal fields are dispersed widely over the globe, and internationally traded coal is usually transported over long distances to satisfy demand.

Researchers have scrutinized the economics of such spatial markets in depth. In an early approach, Samuelson (1952) combines new insights from operations research with the theory of spatial markets and develops a model based on linear programming to describe the equilibrium. Using marginal inequalities as first-order conditions, he models a net social welfare maximization problem under the assumption of perfect competition. Based on Samuelson's findings, Takayama and Judge (1964) developed an approach that uses quadratic programming. Moreover, they present algorithms that are able to efficiently solve such problems also in the multiple commodity case. Harker (1984, 1986) is particularly concerned with imperfect competition on spatial markets. He extends the monopoly formulation as presented by Takayama and Judge to a Cournot formulation which yields a unique Nash equilibrium and suggests algorithms to solve the generalized problems. Yang et al. (2002) develop conditions for the Takayama-Judge spatial equilibrium model to collapse into the classical Cournot model. They demonstrate that, in the case of heterogeneous demand and cost functions, the spatial Cournot competition model is represented by a linear complementary program (LCP).

One research venue on steam coal market economics has centered on analyzing market conduct either in the global trade market (which only accounts for a fraction of the total world wide market) or in regional markets. Abbey and Kolstad (1983) and Kolstad and Abbey (1984) analyze strategic behavior in international steam coal trade in the early 1980s. In both articles, the authors' model demonstrates an instance of a mixed complementary problem (MCP), derived from the Karush–Kuhn–Tucker conditions that the modeled market participants face and a series of market clearing conditions. In addition to perfect competition, they model different imperfect market structures. Labys and Yang (1980) develop a quadratic programming model for the Appalachian steam coal market under perfectly competitive market conditions including elastic consumer demand. They investigate several scenarios with different taxation, transport costs, and demand parameters and analyze the effect on steam coal production volumes and trade flows. Haftendorn and Holz (2010) developed a model of the steam coal trade market where they model exporting countries in a first scenario as Cournot players and in a second scenario as competitive players. They found no evidence that exporting countries exercised market power in the years 2005 and 2006.

Literature on how bulk energy transport modes influence underlying resource or electricity markets is scarce, at best. However, related analyses of such effects on a regional level exist: Quelhas et al. (2007a,b) develop a multi-period network flow model for a one-year time period in the integrated energy system in the United States. They model system-wide energy flows, from the coal and natural gas suppliers to the electric load centers and identify the actors that can increase energy system efficiency if they overcome informational and organizational barriers. Empirical studies include for example Bergerson and Lave (2005), who investigate in a case study the lifecycle costs and environmental effects for transporting coal-based energy between the Powder River Basin (Wyoming) to Texas. They discovered that,