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How does coal-electricity price linkage impact on the profit of enterprises in China? Evidence from a Stackelberg game model

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ABSTRACT

To mitigate the serious conflicts between market-driven coal prices and state-administered electricity prices in China, two kinds of mechanism of coal-electricity price linkage (CEPL) policies were proposed by the Chinese government in 2004 and 2012, known as CEPL-2004 and CEPL-2012 respectively. The present study proposes a Stackelberg game model to investigate the profit changes of two CEPL mechanisms caused by different production strategies of coal mining enterprises and coal-fired power plants when coal prices rise. The findings show that CEPL policy is conducive to reducing profit loss during coal price rises for coal-fired power plants. However, the equilibrium profit of coal mining firms will decrease without CEPL policy if coal prices rise. Furthermore, the equilibrium profit of the coal-fired power plants will decline when coal prices rise by 5–10% but profit decline is less than in the case of maintaining electricity production.

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1. Introduction

Constricted by the coal-dominated energy resource endowment, coal took 77–82% of China's total primary energy production and 72–80% of its total primary energy consumption during 1990–2012 (National Bureau of Statistics, 2013). The larger endowment of coal also determined the composition of secondary energy production, with coal-fired power generation accounting for approximately 80% of electricity generation during 1990–2012 (National Bureau of Statistics, 2013; Yu et al., 2014; Zhang et al., 2015). The codependent dynamics is widely recognized between the coal mining industry and electricity generation industry, being located within the same production-supply chain. In a competitive market, coal price changes directly affect the input costs of coal-fire electricity generation, thereby affecting the supply of electricity, and cause a new equilibrium point reflecting an equilibrium price and equilibrium quantity in the electricity market. At present, coal price in China is basically determined by the fundamental supply and demand of the market, forming a competitive coal market. However, electricity prices, including on-grid and final consuming prices (such as residential and industry use prices), are still controlled by the Chinese government in order to avoid negative effects on producers, and household consumption and living standards, when facing high fuel costs.[1] As a result, coal price variations from the downstream coal enterprises fail to be delivered to the upstream output price of electricity generation. Therefore, it is easy to understand the resultant conflict between coal mining firms and coal-fired power firms, especially when coal prices rise. On the one hand, coal producers desire premium coal prices so as to increase profits (with or without speculators); on the other hand, coal-fired electricity enterprises have to accept the government regulated electricity price (the on-grid price), which is relatively sustained. This situation directly aggravates enterprises' burden by reducing their profits and causing additional losses. In practice, some electricity enterprises would rather give up generation than buy expensive coal, which causes adverse impacts on the supply of power and energy security in the short term. For example, during the year 2003, 22 provinces took the action of switching off power and limiting electricity supply during peak electricity consumption

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[1] Under this regulation, perfect competition mechanism of electricity market is destroyed, inevitably leading to efficiency loss. Nevertheless, regulation on electricity market did make end-users benefit from relatively low electricity price as a result of government's subsides.

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in summer, seriously affecting household and production activities (Xinhua, 2004; Cong and Wei, 2010).

To alleviate the contradiction between coal firms and electricity firms, the National Development and Reform Commission of China (NDRCC) proposed a coal-electricity price linkage mechanism in 2004, known as CEPL-2004. The proposal declared that on-grid electricity prices would be adjusted in accordance with the price of coal in order to make up for the increased cost of power plants themselves. Furthermore, if the average coal price increment reached or exceeded 5% of that seen in a cycle period of six months, NDRCC would be required to adjust the corresponding electricity price to the level where the power enterprise digests 30% of costs induced by the coal price increment (National Development and Reform Commission, 2004). However, the actual implementation effect of the CEPL-2004 policy turned out not to be ideal. During the period 2005–2008, there occurred three opportunities when the conditions of CEPL-2004 were met. Unfortunately, the prices failed to link thoroughly, or in time, and failed to fully achieve the initial purpose of the CEPL-2004 policy due to several external factors, such as inflation. In consequence, the price of coal used for power generation continued to rise by more than 150% from 2003 to 2010, while on-grid electricity prices only rose by 32% during the same period (Jiang et al., 2012). The rising coal prices led to serious deficits for coal-fired power plants, forcing them to limit the electricity supply by switching off power generation. As a result, the relationship between the coal-fired power plants and coal mining firms deteriorated further. In order to improve the coal price linkage mechanism, a new proposal, *opinion on deepening the marketization reform on coal used for power generation*, known as CEPL-2012, was issued by the China State Council in 2012. The new document states that the on-grid electricity price should be correspondingly adjusted when coal prices fluctuate by more than 5% within a cycle period of one year, and meanwhile the electricity firms' digesting ratio should be altered from 30% to 10% (China State Council, 2012). The new proposal makes the mechanism more thorough, which could introduce new opportunities for the marketization reform on coal-fired electricity prices. It is thus likely to relieve the current conflict between electricity firms and coal firms.

Electricity market reform in developed countries has received much attention in recent years due to its significant effects on electricity pricing, which in turn affects economic development. Some studies focus on the developments and barriers of electricity market reforms. For example, Woo, Lloyd analyzed the electricity market reform failures that had already taken place in the UK, Norway, Alberta and California, stating that an electric market reform can be extremely risky, and may lead to disastrous outcomes (Woo et al., 2003). Kuleshov, Viljainenexamined how far the reforms have advanced in the Russian retail electricity market and discussed social, political and technological barriers to market liberalization (Kuleshov et al., 2012). By studying the Greek electricity market reform, Danias, Swales pointed out that fundamental political economy issues need to be further addressed in order for liberalization to progress, to which the financial crisis in Greece added extra challenges (Danias et al., 2013). Peng argued that the market-oriented and decentralized reforms in the coal sector of China were influenced by the changes in state energy investment priorities as well as the relationship between the central and local governments in the context of broader reforms within China's economy (Peng, 2011).

However, most researchers have proposed various models on electricity market reform and its effects. For example, Gunn and Sharp developed a network model of a representative New Zealand distribution business, which suggested that the current light-handed regulatory regime on electricity supply distorts costs and introduces elements of contestability into the market for distribution services (Gunn and Sharp, 1999). Akkemik and Oğuz analyzed the electricity market reform in Turkey using a CGE (computable general equilibrium) model, and the results indicated that full liberalization enhances GDP and national welfare by 0.5%–1.1% of GDP (Akkemik and Oğuz, 2011). From a panel data analysis for OECD countries, Hattori and Tsutsui found that expanded retail access is likely to lower the industrial price and increase the price differential between industrial customers and household customers, as expected (Hattori and Tsutsui, 2004). In addition, the short-term forecasting of electricity prices under the condition of market liberalization by applying various models also attained significant attention (Yu et al., 2015; Amjady and Keynia, 2009; Anbazhagan and Kumarappan, 2014; Osório et al., 2014; He and Zhang, 2015; Wei et al., 2015; Tang et al., 2016).

Aiming to control the conflicts of market-driven coal prices and state-administered electricity prices in China, many quantitative models have been proposed (Zhao et al., 2012; He et al., 2010; Liu et al., 2013; Mou, 2014; Cong and Wei, 2012). Among them, the Game model, which is a discipline used to analyze problems of conflict among interacting decision makers, has been one of the most popular models for dealing with the issue in recent years. For example, Jiao et al. investigated the impact of the coal-electricity price linkage mechanism on the profit margin of the Chinese power generation companies based on a game model (Jiao et al., 2010). Wang et al. analyzed the inevitability of CEPL using a game theory and they found that CEPL might ease the contradiction between coal enterprises and electric power enterprises effectively (Wang et al., 2007). Similar studies can be found from Li et al. (2011), Zhao and Qi (2007) and Tan (2010). These studies are very useful in terms of understanding the necessity and feasibility of the implementation CEPL in China. However, the impact on profits of coal mining enterprises and coal-fired electricity plants caused by CEPL implementation should be further investigated.

Therefore, the present paper proposes a Stackelberg game model, which reflects the economic behaviors of coal mining enterprises and coal-fired electricity enterprises based on their game relationship in the upstream and downstream. The model can explore the profit changes caused by different production strategies of both coal mining and coal-fired electricity enterprises when coal prices rise, using two CEPL mechanisms (CEPL-2004 and CEPL-2012).

2. Methodology

2.1. The economic linkage between coal price and coal-electricity price

According to the theory of market demand in economics, we generally characterize the economic behavior of two markets (here, the coal market and coal-electricity market) and their relationship is highly simplified, as shown in Fig. 1. In a completely competitive market, the equilibrium price is determined by supply and demand. That is, the supply and demand curves describe the relationship between price and supply/demand. The price where the two curves intersect is the equilibrium price, while the quantity at the intersection is the equilibrium quantity (Gans et al., 2011).

On the one hand, the benefits for coal producers would change if the coal price is changed. Supply and demand theory assumes that coal supply reduction (one of the causes of coal price rises) leads to the movement of the original equilibrium point M_0 along the demand curve of coal, generating a new equilibrium M_1. Accordingly, the equilibrium quantity reduces from QC_0 to QC_1 and the equilibrium price increases from PC_0 to PC_1. Thus, the revenue of coal enterprises ($P * Q$) changes from the area $A + B$ into $A + C$. It also determines that the net change of revenues is $C - B$, as shown in Fig. 1(a).

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