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A portfolio theory based optimization model for steam coal purchasing strategy: A case study of Taiwan Power Company

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ABSTRACT

The price of coal has fluctuated dramatically in recent years, resulting in the uncertainty of the coal purchasing decision. As a result, reducing costs and managing risk are issues of tremendous importance to power companies. This study developed a model for the purchase of steam coal, taking into account the risks associated with fluctuations in the price of coal. The proposed model combines portfolio theory with conventional mathematical programming. The model also considers limitations in the demand for coal, the upper limit of imports from specific sources, power plant operational requirements, and environmental constraints. Scenario analysis was conducted to simulate changing patterns in the factors influencing the purchase of coal. Simulation results reveal that incorporating the dimension of price risk within a conventional coal purchasing model shifts purchasing decisions toward contracts with long-term suppliers, thereby reducing susceptibility to fluctuations in coal prices. However, the case study in this paper is a state-owned company; therefore, its coal purchasing portfolio lacks flexibility due to complex prequalification requirements. Related restrictions (e.g. strict qualification requirements) must be relaxed to increase the number of available sources and take advantage of the benefits provided by the proposed model.

1. Introduction

In recent years, coal-fired power plants have been facing many challenges related to fluctuations in fuel prices and environmental protection. For example, the monthly price of Australian thermal coal (steam coal) skyrocketed to USD 192.86 per metric ton in July 2008, representing a USD132.86 increase (221%), compared to the USD60 per metric ton in May 2007 (Index Mundi website, 2012). Generally speaking, coal has been regarded as a cheaper and stable-pricing energy among other forms like crude oil or natural gas. However, according to Bacon and Kojima (2008), the volatility of spot Australian coal prices[1] was much lower than that of spot crude oil prices until 2004. Since then, the volatility of both fuels has been almost the same. It means the volatility of coal price has been catching up to with other energy forms since the beginning of 2004 and shows that coal prices have been fluctuating dramatically in recent years. Hence, determining how best to distribute the price risk and reduce costs are issues of great importance to power companies. The issue of environmental protection is also under the spotlight. The introduction of environmental restrictions to reduce output levels of sulfur dioxide, nitrous oxide and greenhouse gas emissions, have added additional constraints that further complicate the purchase of coal.

Coal is one of the most important energy resources in Taiwan. Due to continued economic growth and development, the demand for electricity has been rapidly increasing with an average annual growth rate of 4.89% in the past two decades (BOE, 2012). A large and growing percentage of electricity, which is mostly provided by the state-owned Taiwan Power Company (TPC), is generated by imported coal. Hence, an electric utility company (e.g. TPC) faces the coal procurement decisions of source, method, and order set selection in an environment where multiple sources, periods, multi-mode procurement methods, multiple power plants, emission constraints and plant operational constraints exist. Thus, a robust coal procurement strategy can not only reduce the risk of a power shortage but also reduce costs and assure the quality control of imported coal.

The conventional approach to the purchase of coal is the least-cost method, in which quantities of coal purchased are determined without assessing risks associated with the price of coal (Kondragunta and Walker, 1984; Lyu et al., 1995; Lai and Chen, 1996;

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[1] Standard deviations of fuel price volatility are calculated on returns on logarithms of monthly prices expressed in nominal USD per unit of energy. Coal is Australian coal. Oil is the average of Dubai, Brent, and WTI crudes.

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Shih, 1997; Liu and Sherali, 2000; Liu, 2008; Yucekaya, 2013). Furthermore, the quality of coal can vary widely with regard to heating value, sulfur content, and ash content. The heat content ranges from low to high which affects the energy amount gained when the coal is burned. On the other hand, the ash content of each coal type is also different and less ash is desired from the burned coal. Another issue is the gaseous emissions from coal-fired power plants which have been an important problem since the 1990s. Sulfur dioxide emissions that are produced from the burning of coal in the power plants cause the acid rain problem in nature. Hence, blending various grades of coal fuel is necessary to maintain reliable boiler operations, while satisfying environmental restrictions.

This study applied portfolio theory to the conventional purchasing approach and employed TPC as a case study. The proposed model was designed to minimize the purchasing cost of steam coal after adjusting price risk by considering both the present value of purchasing cost as well as variance in the purchasing cost. The model also considers limitations in the demand for coal, the upper limit of imports from specific sources, power plant operational requirements, and environmental constraints. Scenario analysis was performed using the proposed model, while taking into account a variety of factors. Finally, suggestions are provided according to the simulation results.

The paper is structured into seven sections. The following section provides a review of relevant literature. Section 3 introduces the current status and future trends related to coal in Taiwan. Section 4 provides a description of the model. Section 5 describes data sources. Section 6 presents the simulation results and the final section provides our conclusions.

2. Literature review

Early research efforts related to the purchase of coal concentrated on the optimal acquisition and blending of coal using linear programming, goal programming, and mixed integer programming techniques. Kondragunta and Walker (1984) demonstrated the use of linear programming to determine the coal acquisition requirements from multiple sources in order to generate the power required to serve load requirements. The objective was to serve the load at minimum cost, while satisfying SO_2 emissions and inventory constraints. SO_2 emission constraints were met by blending high and low sulfur coal. The linear programming approach can be used to determine the coal requirements in a cost effective manner. Lyu et al. (1995) presented a coal blending management system, which calculates the quantities of coal required from different stockpiles to maintain a consistent feed of blended coal, while meeting environmental and boiler performance requirements. Lai and Chen (1996) proposed a cost minimization model for the import of steam coal to Taiwan. The objective was to satisfy coal usage requirements at a minimum cost, subject to the company's internal policy, boiler requirements, and environmental standards, while reflecting actual operational constraints. That study demonstrated the use of mixed 0–1 integer programming to determine the coal acquisition requirement from multiple sources. Shih (1997) proposed a mixed integer programming model that plans and schedules coal imports from multiple suppliers. The objective was to minimize total inventory costs by minimizing costs for procurement, transportation, and holding. Constraints included company procurement policy, power plant demand, harbor unloading capacity, inventory balance equations, blending requirements, and safety stock.

Liu and Sherali (2000) presented a mixed 0–1 integer programming model for determining optimal shipping and blending combinations using coal from overseas suppliers. That study developed a procedure using heuristic rules in conjunction with branch-and-bound methods. The practicality of this approach was illustrated using real-world data collected from an electric power company. Liu (2008) proposed a coal blending and inter-modal transportation model to find optimal blending and distribution decisions for coal fuel from overseas contracts to domestic power plants. The objective was to minimize total logistics costs, including procurement cost, shipping cost, and inland delivery cost. The developed model was mixed 0–1 integer programming problem. A real-world case problem was presented using the coal logistics system of a local electric utility company to demonstrate the benefit of the proposed model. Results from this study suggested that the obtained solution was better than the rule-of-thumb solution and the developed model provided a tool for management to conduct capacity expansion planning and power generation options. Yucekaya (2013) developed a multi-objective model that considers multimode transportation alternatives, multiple coal products with different price and quality, and multiple suppliers for efficient coal supply of an electric power company with more than one plant at different locations. Constraints included the capacity limitations on transportation routes, supplier capacity for a particular product, product emission specifications, emission costs, and plant burn capability. Multi-objective linear programming and analytic hierarchy process were employed to solve the problem. The solution methodology was applied to a case study in the Midwestern United States. That study demonstrated that the proposed model can be used by the power companies to find a desired solution for their coal supply and hence generate power with coal of lower cost, lower emission, and ash.

These references used a variety of programming techniques to optimize the acquisition and blending of coal from multiple sources based on the least-cost approach. Recent price volatility in fossil fuels underlines the importance of price risk; however, none of these studies take into account the enormous price fluctuations to which the purchase of coal is subject.

One way to quantitatively determine the price risk is by means of portfolio theory. Portfolio theory has been used for decades in the financial sector to identify portfolios of bonds or assets capable of minimizing risk for a given level of profit (Roques et al., 2010). The foundation of portfolio theory was laid by Markowitz (1952). The basis of the theory states that by diversifying a portfolio of assets, the overall risk can be lowered compared to the risk of the individual assets (Delarue et al., 2011). A number of researchers have applied the theory of risk analysis to the energy market. One early application to the electricity sector was presented by Bar-Lev and Katz (1976). Awerbuch and Berger (2003) utilized this portfolio approach to consider an optimal generation mix for the European Union. They used an expected rate of return [MW h/€] (as an inverse of cost) and a given standard deviation (i.e. risk) on that return [MW h/€]. The authors further assumed a total amount of installed capacity and test different scenarios. Other examples that followed this approach have been presented in different countries, including the EU (Awerbuch and Berger, 2003; Awerbuch and Yang, 2007), Switzerland, the United States (Krey and Zweifel, 2006), Japan (Bhattacharya and Kojima, 2012), Italy(Arnesano et al., 2012), Spain (Muñoz et al., 2009), Turkey (Gökgöz and Atmaca, 2012) and China (Zhu and Fan, 2010).

The utilization of portfolio theory in a liberalized electricity market environment was described by Roques et al. (2008). Another example of making use of portfolio theory in the purchase of electricity was presented by Huisman et al. (2009). Other applications in the energy market have included marine technologies (Allan et al., 2011), cogeneration technologies (Westner and Madlener, 2010), and wind power (Roques et al., 2010; Rombauts et al., 2011). Despite the growing number of studies using portfolio