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The spark spread and clean spark spread option based valuation of a power plant with multiple turbines

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ABSTRACT

This paper offers a novel study of two key factors that affect the valuation of a natural gas-fired power plant having multiple turbines: carbon allowance prices and the ability to switch among turbines. Amid stricter environmental rules on CO_2 emissions, a power plant operator needs to be able to judge how the purchase of carbon allowances affects the plant's expected value; and whether the plant's value rises from switching among turbines. This paper presents a model analysis of a spark spread and clean spark spread option-based valuation of a power plant with multiple gas turbines — using a bivariate and a tri-variate lattice, respectively. Results demonstrate that the purchase of CO_2 allowances lowers the plant's expected value. Conversely, when operations of turbines are switched in response to price movements, the plant's value increases. This outcome has implications for plant management decisions: when to switch among turbines and how the purchase of CO_2 allowances affects the plant's value.

1. Introduction

A natural gas-fired power plant burns natural gas to produce electricity and bears price risks from both purchasing natural gas and selling electricity. Until the 1990s, most power plants had been state-owned and allowed earning a return above the cost of generation, transmission, and distribution. Deregulation, in many countries, has led to competition and price uncertainties. In a competitive electricity market, it is important to know the value of a power plant.

Valuation is the process of estimating the market value of an asset, i.e., the price at which an asset can be traded in a competitive setting. The goal is to create a reference point for plant owners and prospective buyers and sellers, and reduces the likelihood of overpaying or underselling (Wang and Min, 2013). A power plant owner/operator has to know the value of the plant in order to understand its status, to mitigate financial risk, and to decide whether to run or shutdown the plant or to switch its operating mode. Moreover, recent restrictions on CO_2 emissions have forced power plant operators to include emission costs in their plans. Since 2013, power generators in many countries in Europe have been required to purchase carbon allowances for their CO_2 emissions (Heydari and Siddiqui, 2010; Abadie, 2015). Operators will thus benefit from a study, given here, that models the valuation of a natural gas-fired power plant with multiple gas turbines in light of CO_2 emission restrictions.

The existing literature, to the best of the authors' knowledge, contains few models that take carbon emission allowances into account for valuing a merchant power plant based on clean spark spread (CSS) options. Abadie (2015), for example, proposes a valuation model for coal and natural gas-fired power plants incorporating carbon emission costs based on a single turbine.

A power plant can possess one or multiple generators. According to the US Energy Information Administration, there are approximately 19,000 individual generators at around 7000 power plants in the USA (EIA, 2015). While studies in the literature consider power plants with a single turbine operating at a constant heat rate, this research examines the valuation of a natural gas-fired power plant with multiple turbines, each of them having different power generation capacities, input–output characteristics, and carbon emission rates. This study also investigates the effect of flexibility of switching from one turbine to another based on price movements in response to carbon allowance prices. For example, a merchant power plant

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having two gas turbines may operate only Turbine 1, or only Turbine 2, or both Turbine 1 and Turbine 2 in accordance with profitability. Therefore, the power plant possesses an internal operational flexibility insofar as it can switch one turbine to another according to the price movements of electricity and natural gas in the case of spark spread (SS) option, and according to the price movements of electricity, natural gas, and carbon allowance in the case of CSS option. Overall, the paper seeks (1) to determine and compare the SS and CSS values of a power plant with and without operational flexibility; (2) to assess the operational flexibility of having multiple turbines with different heat rates, emission rates, and generation capacities; and (3) to investigate the effect of modeling carbon allowance prices on the CSS value of the power plant in two different processes, as a mean-reverting process and as a geometric Brownian motion. These aspects are important for researchers, power plant investors and operators. Researchers will now have access to a proposed valuation model based on a multi-state, multi-period framework and with a pragmatic scenario wherein a power plant has multiple turbines rather than a single turbine with a constant heat rate. Investors and operators can benefit from the model in making decisions to address the impact of carbon allowance prices on the value of the power plant. Results show that with CO_2 allowance costs factored in, depending on the turbine efficiencies and emissions, the plant operator might be better off running with only one turbine.

A natural gas-fired power plant bears price risks from both purchasing natural gas and selling electricity. The spread or difference between the prices of electricity and natural gas is known as the spark spread (SS). If P_e is the electricity price per MWh and P_n is the natural gas price per MMBtu, the SS is expressed as $(P_e - H \times P_n)$, where H is the average heat rate in MMBtu/MWh. The lower the heat rate, the less natural gas is required to burn to produce 1 MW of electricity per hour, resulting in a more efficient power plant. A positive spark spread implies that the electricity generation is potentially profitable. A power plant owner in a deregulated electricity market is free to operate the plant – which gives it the status of a "merchant power plant" – since it sells power without any obligation (Wang and Min, 2013). Therefore, operating a merchant power plant can be viewed as a series of SS options of $\max(0, P_e - H \times P_n)$. It also implies operational flexibilities of operating and shutting down the power plant depending on the profitability. Quick startup and shutdown characteristics of gas turbines make them suitable for such operations of power plants. Considering the operational and maintenance cost, v, per MWh of the plant, the SS options can be expressed as: $\max(0, P_e - H \times P_n - v)$. Since owning a merchant power plant is like owning a series of SS options, the value of a power plant can be estimated as a sum of SS options over a planning period (Heydari and Siddiqui, 2010; Wang and Min, 2013).

Recent stricter environmental rules on CO_2 emission force power plant operators to buy carbon allowances from carbon markets. Power plants covered by the Emissions Trading Scheme (ETS) have to consider the cost of carbon dioxide emission allowances (Abadie, 2015). The spark spread minus the carbon price is known as the clean spark spread (CSS). If P_c is the cost of carbon emission per ton of CO_2 (tCO_2) and R is the emission rate in tCO_2/MWh, the CSS options are calculated as $\max(0, P_e - H \times P_n - RP_c - v)$.

The remainder of the paper is arranged as follows. Section 2 presents the literature review. Power plant characteristics, SS option and CSS options are discussed in Section 3. Section 4 presents price processes and Section 5 describes the lattice representation. Results are discussed in Section 6. Section 7 concludes the paper.

2. Literature review

There are two basic approaches to power plant valuation. One is to view a power plant as a physical asset where the owner may choose to operate the plant according to spark spread options. In the literature, it is mentioned as 'a merchant power plant' (Wang and Min, 2013). Another is to consider a power plant as a financial asset; that is, one may virtually own a power plant as a tolling agreement under which a buyer pays the fuel price and owns the power generated by the plant. Various versions of such agreements may exist. Such a power plant, in the literature, is referred to as 'a synthetic power plant' (Li and Kleindorfer, 2009).

For a synthetic power plant, the value of the SS option at each interval is usually priced in light of the Margrabe (1978) analysis of exchange option, and the overall value of the plant is calculated as a sum of these individual SS options over the valuation period. Studies by Deng et al. (2001), Näsäkkälä and Fleten, and Fleten and Näsäkkälä (2009) fall into this category. While Deng et al. (2001) use separate price processes for electricity and gas, Näsäkkälä and Fleten model the SS itself as a single price process in light of the Schwartz and Smith (2000) model. Fleten and Näsäkkälä (2009) use the same methodology to analyze operational flexibilities and the opportunity to abandon capital equipment in gas-fired power plants. On the other hand, studies by Gardner and Zhuang (2000), Tseng and Lin (2007), Heydari and Siddiqui (2010), and Wang and Min (2013) use the real options merchant power plant approach. They price the SS option by deducting the fuel price directly from the electricity price. Table 1 provides a brief literature review on the valuation of gas-fired power plants. Inclusion of operational constraints, for example, startup and shutdown costs, makes the valuation problem both interesting and challenging. Lattice approaches are useful in this regard. Though a Monte Carlo (MC) simulation can easily adopt different types of price processes, incorporating operational constraints in an MC simulation is computationally intensive. Tseng and Barz (2002) utilize the MC simulation with dynamic programming for a short-term valuation of a gas-fired power plant. The lattice approach of Gardner and Zhuang (2000) incorporates operational constraints, such as the minimum on-and-off times, ramp times, and the minimum dispatch level. Tseng and Lin (2007) propose a lattice framework to value a power plant by discretizing correlated electricity and fuel prices processes. A comparison of SS options based valuation under different price processes is studied by Heydari and Siddiqui (2010). Cassano and Sick (2013) analyze optimal operating policies for a power plant, which is operated by General Electric's LM6000 gas turbine, based on the market heat rate, i.e., the ratio of prices between electricity and natural gas. The plant is said to be 'out of the money' if the market heat rate is below the plant's operational heat rate. The value of the plant is obtained by multiplying the market heat rate by the natural gas price forward curve.

For a combined heating and power (CHP) system, Smith et al. (2011a) propose an SS based model that compares the economic viability of a CHP system with a system that produces heating and power separately. They also extend the concept of SS in terms of the emission spark spread (ESS) and the primary energy spark spread (PESS) in order to measure the reduction in CO_2 emissions and primary energy consumption required for a CHP system (Smith et al., 2011b). Wood (2016) presents a comparison of SS with respect to various fuels, such as coal, gas, and fuel oil, in some significant power consuming markets in Asia, Europe and North America. For valuing CSS options, Carmona et al. (2012) propose a structural approach in which electricity demand is modeled by an Ito process represented by a stochastic differential equation. The fuel price is also modeled by an Ito process. The electricity prices are derived from a bid-stack based structural model, and the emission allowance prices are modeled as a function of electricity demand and fuel prices. An elaborated discussion on the structural and reduced-form models on pricing financial instruments in emission markets can be found in Howison and Schwarz (2015).

Abadie (2015) addresses the valuation of coal-fired and natural gas-fired power plants considering emission costs due to coal and