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Risk aversion and technology mix in an electricity market

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ABSTRACT

This article analyzes the effect of risk and risk-aversion on the long-term equilibrium technology mix in an electricity market. It develops a model where firms can invest in baseload plants with a fixed variable cost and peak plants with a random variable cost, and demand for electricity varies over time but is perfectly predictable. At equilibrium the electricity price is partly determined by the random variable cost and the returns from the two kinds of plants are negatively correlated. When the variable cost of the peak technology is high the return of peak plants is low but the return to baseload plants is high. Risk-averse firms reduce the capacity of the riskiest technology and develop the capacity of the other, compared to risk-neutral firms. In the particular case where a risk-neutral firm invests heavily in baseload technology and only sparely in peak capacity, a risk-averse firm would invest less in baseload, increase peak capacity, and increase total installed capacity.

1. Introduction

The purpose of this article is to analyze the influence of firms' risk aversion on the technology mix in an electricity market if the variable cost of a technology is random. In the electricity industry, the fundamental explanation for the existence of a technology mix is the great variability of the demand for electricity over the course of a year and the limited potential to utilize intertemporal arbitrage to smooth these variations. To address the time-variable nature of electricity demand, firms invest in several types of technology; baseload technologies are more efficient for frequent production, whereas peak technologies are employed for more sporadic production. In addition to this well-known variability of the electricity demand curve, electricity producers face numerous uncertainties with respect to costs of production. In particular, the prices of fossil fuels and CO_2 emissions are uncertain. These uncertainties are likely to influence the technology mix that is chosen to meet the variable demand, particularly if firms are risk-averse.

A canonical model of an electricity market is used to consider a situation in which the demand curve is variable and two different technologies are available to produce electricity: a baseload technology and a peak technology. The variable cost of the peak technology is random. It is assumed that electricity producers anticipate the variability of the demand curve; moreover, these producers are regarded as risk-averse.

In the risk-neutral benchmark situation, these firms invest in the technology mix that minimizes the expected cost of servicing the electricity demand. We consider how risk aversion modifies the equilibrium technology mix and investigate how this modification is related to the cost structure and the variability of electricity demand.

This study demonstrates that risk-aversion modifies the technology mix in either one of two directions: (i) the baseload capacity is increased, although the peak and total capacity are reduced; or (ii) the baseload capacity is reduced, but the peak and the total capacity are increased. In the latter situation, compared with the risk-neutral benchmark, risk-averse firms over-invest in both the risky technology and their total capacity.

The uncertainty with respect to the variable cost of the peak technology translates into uncertainties in the electricity prices during the fraction of the year in which the peak technology establishes these prices. Both technologies have risky returns. The risk faced by peak units is related to the fraction of the year in which the peak technology is a sub-marginal source of electricity, whereas the risk faced by baseload units is related to the fraction of the year during which the peak technology establishes the price. Thus, the two technologies face negatively correlated risks. In certain circumstances, the baseload technology involves higher risk than the peak technology, and risk-averse firms will therefore tend to decrease their quantity of baseload capacities and increase their capacities of the risky peak technology to hedge against the risk incurred by baseload capacities.

The influence of the cost structure and the variability of electricity demand is also investigated. Among other conclusions, this study demonstrates that over-investment in the peak technology is more likely to arise when demand is less variable. This result is of particular interest if the framework of this study is applied to considerations of environmental policy because in these considerations, the peak technology may represent a polluting method of generating electricity. Thus, the development of renewable intermittent electricity production might induce an increase in peak capacity through increasing the variability of the (residual) load (Lamont, 2008). Our results reveal that this effect could be softened if firms are risk-averse and if the future price of CO_2 emissions is uncertain. However, the environmental benefit from real-

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time-pricing (Holland and Mansur, 2011) might be reduced if producers are risk-averse.

The questions of whether firms are risk-averse and what the consequences of firms' potential risk aversion may be are issues that have received a considerable attention both in the general literature and in studies of energy and resource economics. With a complete set of markets (Arrow and Debreu, 1954), firms' profits are not random and whether they are risk-averse or not does not matter. If markets are incomplete, (Diamond, 1967) suggests that firms should be risk-neutral, and shareholders should use capital–asset markets to hedge their risks.

However, there are several theoretical arguments (for a review, see (Banal-Estanol and Ottaviani, 2006)) and certain empirical evidence that suggest that firms are risk-averse or at least behave *as if* they are risk-averse.[1]

Numerous authors have considered how risk aversion influence production choices in situations that feature random demand and perfect competition (Appelbaum and Katz, 1986; Baron, 1970; Dhrymes, 1964; Sandmo, 1971) or scenarios that involve monopolies (Baron, 1971; Leland, 1972) or oligopolies (Asplund, 2002; Banal-Estanol and Ottaviani, 2006; Wambach, 1999). The assumption regarding the risk aversion of firms has also been used to analyze the firms' use of not only financial futures and option contracts (McKinnon, 1967; Moschini and Lapan, 1995) but also vertical integration (Aïd et al., 2011; Hirshleifer, 1988).

In a situation featuring random input prices, Stewart (1978) demonstrates that a risk-averse firm over-invests in riskless factors.

Input price risks have also been analyzed by Blair (1974) and by Okuguchi (1977), but none of these analyses have addressed the issue of technological diversification. Recently, Meunier (2012) considers the effect of risk aversion on choices between two risky technologies; however, he does not consider the variability of the demand but instead regards risk-aversion as the sole explanation for technological diversification. Furthermore, he assumes the existence of an exogenous correlation that arises endogenously in the current study.

In the electricity industry, the influence of producers' risk-aversion on investment decisions is a central issue because electricity prices demonstrate a high variability and because of the uncertainty that surround the development of fossil fuel markets and environmental regulations.

Neuhoff and Vries (2004) provide a formal analysis of the influences of risk and of electricity producers' risk-aversions on the producers' investment choice with respect to a single technology. Willems and Morbee (2010), who build on the framework of Bessembinder and Lemmon (2002), consider the effect of financial options on both welfare and investment decisions. They do not consider the choice of technology mix but consider the incentive of a risk-averse producer to invest in one plant. They show that the initial development of financial markets can reduce the incentive to invest in peak plants. They do not consider the fact that investment in one type of plant can be used to hedge risks associated with other types of plants.

In the presence of several risky technologies, a financial portfolio framework (à la (Markowitz, 1952)) has been utilized by (Bar-Lev and Katz, 1976) to analyze the "technology portfolio". In particular, Bar-Lev and Katz (1976) evaluate the mix of fossil fuels of regulated electricity utilities.[2] Roques et al. (2008) adopt a more positive perspective and determine the efficiency frontier (the expected return versus variance) of portfolios that are composed of combined cycle gas turbine (CCGT) plants, coal plants and nuclear plants for a price-taking firm that faces random electricity and gas prices. These researchers consider exogenous electricity prices and do not analyze the market equilibrium. In particular, they stress the role of the correlation between electricity and gas prices; however they had to assume this correlation, whereas this relationship arises endogenously in our framework.

Two recent works possess similarities to the present study. Ehrenmann and Smeers (2011) use numerical simulation of an electricity industry equilibrium to assess the influence of electricity producers' risk-aversion on the total capacity that is built and on the producers' technology mix. They consider several sources of uncertainty, including the design of the EU CO_2 permit trading scheme and the evolution of fossil fuel markets. Fan et al. (2010, 2011) also perform numerical simulations of the equilibrium of an electricity industry; they focus on the uncertainty surrounding CO_2 prices and the effect of rules for allocating free allowances. They show that risk-aversion tends to favor investment in peak units (using gas) if permits are auctioned and not grandfathered. Compared with these two articles, we provide a tractable model; this model allows us to perform a formal analysis that contributes to a better understanding of the effects that risk produces on the technological mix and capacity of electricity producers.

The rest of the article is organized as follows: Section 2 introduces the model for this investigation. Subsequently, Section 3 describes the equilibrium in the risk-neutral benchmark situation and in the case of a risk-averse firm. Section 4 provides a generalized version of the model that incorporates more than two technologies. Section 5 considers the normative aspects of the model. Section 6 concludes.

2. The model

We consider a simple electricity system. The demand side is represented by a variable inelastic demand with a year's duration normalized to a value of 1. Electricity demand x is assumed to be distributed in $[0,X]$ with a cumulative distribution function $F(x)$. The function F is positive, increasing and differentiable, and its derivative $F' = f$ is the distribution of the load; in other words, $f(x)$ represents the duration of the year during which the demand for electricity is x. The "load duration curve" is the curve $F^{-1}(1-t)$.[3] The typical shape of a load duration curve is depicted in Fig. 1(b).

The real time demand for electricity is x if the price is below v and 0 otherwise, v is the "value of the lost load" (VoLL). The instantaneous surplus when the demand is x and a quantity $y < x$ (resp. $y > x$) of electricity is served is vy (resp. vx) in \$ per time. The total surplus is the sum over the year of the flow of instantaneous surplus.

There are two technologies to produce electricity; these are labeled $t = b$ and $t = p$ to represent the baseload and peak technologies. As a concrete illustration we have in mind nuclear for the baseload technology and CCGT for peak units. Each technology t is characterized by a variable cost c_t (\$ per W year) and a capacity cost I_t (\$ per W).

The variable cost of the peak technology is assumed to be random at the time of investment. We assume that the variations of c_p are sufficiently small to ensure that $v > c_p > c_b$ for all realizations. Finally, the expected value of c_p is $\overline{c}_p$ and its standard deviation σ.

The baseload technology b provides less costly production per unit of electricity throughout the year than the peak technology p, but the baseload technology is more costly than the peak technology for production over a short period:

$$\begin{array}{ccccc} c_b & + & I_b & < & \overline{c}_p + I_p, \quad \text{and} \ I_p<I_b \\ \$/\text{W.year} & \times 1 & \text{year} & + & \$/W \end{array}$$

The ratio $r = (I_b - I_p)/(\overline{c}_p - c_b)$ is the portion of a year such that technology b is more efficient than p for production over a longer period than r. The ratios $r_p = I_p/(v - \overline{c}_p)$ and $r_b = I_b/(v - c_b)$ are the minimal duration of production with the peak and baseload technologies,

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[1] For instance risk aversion can explain corporate hedging activity (Amihud and Lev, 1981; May, 1995; Nance et al., 1993); (Wolak and Kolstad, 1991) that has empirically investigated how risk aversion can explain Japanese firms' choices of coal suppliers.

[2] This framework has been used by several authors to evaluate national portfolios (Awerbuch and Berger, 2003; Humphreys and McClain, 1998).

[3] The load duration curve is obtained by ranking hourly demands in decreasing order, so that for each date t the corresponding quantity is such that the demand is larger than this quantity during t.