Competitive Entry In Ontario's Deregulated Power Generation Industry

Xiaoting Wang, Acadia University, Canada
Jun Yang, Acadia University, Canada

ABSTRACT

In this paper we investigate the issues involved in the deregulation of an electricity market. The paper focuses on efficiency considerations, comparing the gap between the socially efficient outcome and that achievable by a market. We model this problem with two-sided uncertainty: the uncertain market demand and the uncertain cost of production. In each case, we find the social optimum and the equilibrium outcome of the deregulated market. Conditions when deregulated industry cannot generate the socially optimal number of firms are identified. The relationship between market demand, the degree of risk-aversion of private firms, and the equilibrium number of firms is investigated.

Keywords: Power Generation; Deregulation; Efficiency; Entry of New Firms; Risk Aversion

1 INTRODUCTION

Shortly after the deregulation of its electricity market, Ontario experienced shortage of power and soaring electricity prices in the summer of 2002. There has been a huge debate on the issue of deregulation of the power industry. Most economists support the idea of liberalization, as it will enhance market efficiency and allocate market resources in a better way. However, the implementation of a restructured electricity market has not been a smooth process in most pioneer countries.

The causes of the power crisis are many, from both the demand side and the supply side of the market. The demand for electricity is volatile and hard to predict because of unpredictable weather conditions and the variability in the speed of economic growth. Moreover, the retail price of electricity to most residential customers and small business is not on an hourly basis, but rather on a monthly average rate. The hourly price of electricity is a piece of hidden information to those consumers. The supply of electric power, due to the capacity constraint of the generation plants, is known to be very inelastic to price changes (Borenstein 2002). So there are fundamental difficulties in pricing and supplying electric power efficiently.

The supply of power, from the generating companies to the end users, is composed of three parts: generation, transmission and distribution. The transmission part has the properties of a natural monopoly, and remains regulated in the restructuring process in Ontario¹. The distribution market has been partly opened to competition, but still under price regulation. Power generation and the wholesale electricity market have been deregulated and opened to competition since May 2002.

Given these characteristics of the electricity market, we develop a model where demand is fluctuating and unpredictable. Both the social optimum outcome and the market equilibrium are affected by this structure, and the prevailing belief that market equilibrium always generates less than the socially efficient number of firms is not necessarily true under fluctuating market demand. When market equilibrium does generate less firms than the social optimum, the higher the mean level of market demand, the larger the welfare gap between the social optimum and market equilibrium. In a market that firms can enter freely but facing uncertain demand, high expected market demand will bring in more competitors and thus the total output will increase. However the firms won't operate at the most efficient level of production. We show that the loss from the added fixed costs outweighs the gain from the intensified competition.

Besides the random shocks to market demand, the fixed cost of power generation is hard to predict too. A nuclear power plant needs to wait for two to five years in order to get operating permission from the regulatory agencies. During this period the owners must pay financing costs without a clear sense of completion date. In the second part of this paper, we add this feature into the model, i.e. allowing uncertainties from both demand and supply side of the market. We compare the social optimum outcome with the market equilibrium when firms are risk-neutral, and when firms are risk-averse. With risk-neutral firms, the condition is determined when market equilibrium cannot generate the social optimum number of firms. With risk-averse firms, we find the relationship between the degree of risk-aversion of private firms and the market equilibrium number of firms under different phase of the demand. This extended model shows some important features of the market equilibrium. When the expected market demand is strong, despite their risk aversion firms are more willing to enter the market and compete. When the expected market demand is weak, however, risk-averse firms would tend to shy away from the market. In practice, since existing firms have occupied the majority of the market, entering firms are essentially going to compete for the residual demand. Residual demand is highly uncertain and volatile as it is affected by both market demand uncertainty and the existing firms' supply uncertainty. Thus new potential competitors are extremely cautious to enter the market.

The results of this paper have strong implications for public policy. Soaring wholesale prices and unplanned power outage (black-out) happened in both California and Ontario after the deregulation of electricity market. As a result, both states incurred loss of billions of dollars and had to hold back their steps towards a competitive electricity market. This paper shows that when there is uncertainty in demand and in the cost of private firms, regulatory agencies should not take it for granted that private sector will build new power plants under the deregulated system. To reach the desired sufficiency of power supply under deregulation, there has to be some way through which private investors could insure against the uncertainty.

Paul Joskow (2008) gives a thorough overview of the status of electricity market liberalization. Lessons are learned from the experiences in electricity restructuring in England and Wales, the Nordic countries, Argentina, Australia, California, and Ontario. He points out that system reliability is of great concern to policymakers in almost every country. Even relatively short blackouts carry high political (if not economic) costs. However, agreement has not been reached among economists on whether or how competitive power markets can stimulate levels of investment in new generating capacity in the right places at the right time. In the U.S., over 220,000 MW of new generating capacity went into service between 1999 and 2006. In England and Wales about 40% of the stock of generation plants in service was replaced with modern efficient combined cycle gas turbine (CCGT) technology between 1990 and 2002. Other countries, including Argentina, Chile, and Australia, also attracted significant new generating capacity after the market reforms were initiated.

However, in places like Ontario, California, and New Zealand, great concerns have been expressed about incentive for private investment in additional generating capacity. According to Trebilcock and Hrab (2005), only two new private-generation projects amounting to 620 MW became operational during the first year of the open market in Ontario, while almost all existing generation capacity will be retired from service or require substantial refurbishment over the next 30 years.

Iacobucci, *et al.* (2006) suggests the following elements (among others) to be essential for the transition from monopoly provision to competitive markets: significant generation market restructuring to encourage entry; sufficient transmission and generation capacity to deal with exogenous (demand) shocks; and integration of larger regional markets (*e.g.* Quebec, Manitoba, Ontario, and the North-east of the U.S.) to even out fluctuations in local demand and supply.

A Brief History

In order to understand Ontario's road to power deregulation, let us first look at the market demand and generation capacity since the 1980's.

Figure 1: Annual Peak Demand 1984-2002

Figure 1 illustrates the peak market demand in Ontario from year 1984 to 2002². Figure 2 shows the peak demand in each month of 2008³. From these figures we can observe the fluctuation in peak demand from year to year, and the seasonal fluctuation within a year.

As part of the introduction of a new electricity market, Ontario Power Generation (OPG) is to decontrol⁴ a portion of its electricity generation, so that OPG would represent no more than 35% of the provinces electricity supply 10 years after the market opens (Iacobucci, *et al.* 2006). This decontrol will result in substantial competition and customer choice.

OPG's first decontrol transaction is the long-term lease of the Bruce nuclear stations to Bruce Power, which is 80% owned by British Energy. Cameco has a 15% ownership in Bruce Power, and the other 5% of the equity is held by the two major employee unions at the Bruce stations. In May 2002, OPG completed the sale to Great Lakes Hydro Income Fund of four hydroelectric generating stations and related water storage facilities located on the Mississagi River, east of Sault Ste. Marie in Northern Ontario, for the price of \$340 million. In year 2007, OPG owns about 75% of the 30,662 MW installed generation capacity in Ontario.

Before the 1980's, generation of electricity was a state-owned industry, possessing huge market power. Most cities were served by a few large stations. Since the 1980's, the emergence of combined cycle gas turbines (CCGT) has allowed the production of electricity more efficient and on a much smaller scale than the traditional coal-fired plants. As noted in Gillen and Wen (2000), estimates of the cost of gas-powered generation lie between 4 and 4.5 cents/kWh. Unit costs of producing electricity with nuclear-based and thermal-based generation are about 5.1 cents/kWh and 6.7 cents/kWh respectively. CCGT plants also face less environmental objections. As CCGT became the preferred new source of power, competitive generation of electricity became possible.

Figure 2: Monthly Peak Demand in 2008

The Ontario government's plan for power supply was based on the expectation that the private sector would build new plants under a deregulated system. But prices soared after the electricity market opened in May 2002, then the government shut down the experiment after only six months. In December 2002, Ontario Energy Board capped the retail price of electricity at 4.3 cents/kWh for residential and small business customers. With market reform on hold, the private sector has withdrawn many of its investment plans. Ontario's tight capacity became a focus of attention when the power system failed in Ontario and seven U.S. states in Mid-August of 2003.

A wide array of issues holds back private investment in power generation in Ontario. The uncertain future of electricity deregulation is only one of them. There are problems with the market perspective of building new gas-fired power plants, as well as major uncertainties about the future competitive landscape in the province. In Ontario, hydro-electricity has largely been tapped to its maximum potential, and it is difficult to get approval to build new coal or nuclear plants. Private companies like TransAlta find it hard to forecast Ontario's electricity supply for the future, because there is significant uncertainty about the province's nuclear plants. Once those dormant nuclear units are restarted, the price of electricity may go down; therefore the profitability of investing in new gas-fired plants has been questioned by most private companies. Apparently, in Ontario the major deterrence to investing in power generation is not the incumbents' predatory behaviour, but the fluctuation in market demand and in the cost of production. Deregulation can lead to an inefficient number of firms in the market equilibrium.

The rest of this paper is organized as follows. Section 2 models the problem of power generation with market demand uncertainty, and compares the market equilibrium outcome with the social optimum. In section 3, we relax the assumption of constant fixed cost, and study the model with uncertainty from both demand and supply sides of the market. Section 4 concludes.

2 TWO STATES OF DEMAND AND CONSTANT FIXED COST

In this section, we model the electricity market with a random demand function, and see how the fluctuation in demand affects the equilibrium outcome. We first look at the ideal supply situation, i.e. the social optimum. Then we investigate the market equilibrium with and without free entry conditions.

2.1 Social Optimum

Suppose there are n generation plants in the market, producing identical products. All plants are symmetric with cost function given by⁵

$$C(q) = \alpha q^2 + F + \beta \quad (1)$$

F is the fixed cost of production. β is a random shock to the fixed cost. We assume $\beta = 0$ in this section; the situation $\beta \neq 0$ (uncertain fixed cost) will be examined in Section 3.

There are random shocks to the market demand curve. The inverse market demand function is given by

$$P(Q) = \bar{a} - bQ \quad (2)$$

when demand is high; or

$$P(Q) = \underline{a} - bQ \quad (3)$$

when demand is low, where $\bar{a} > \underline{a} > 0$, $b > 0$. Assume demand is low with probability p and high with probability $1 - p$.

The social optimum (first-best outcome) is obtained by maximizing consumer surplus net of producers' costs, by choosing the optimal number of plants and output level. Here it does not matter if the social planner sets price equal to marginal cost or average cost of production, since price only determines who get the larger share of the total surplus, producers or consumers.

We all know that social surplus is maximized where marginal willingness to pay equals marginal cost, i.e. at the intersection of the demand curve and the marginal cost curve. This is the first best outcome when the social planner has perfect information about the cost function and the market demand function. However, when demand is random and the social planner has no ability to perfectly forecast (due to unexpected weather conditions, for example), the optimization problem takes a different form.

Let $\bar{W}$ be the total surplus when demand is high and $\underline{W}$ be the total surplus when demand is low. The social planner's optimization problem becomes,

$$\max p\underline{W} + (1 - p)\bar{W} - TC_n(q)$$

by choosing q , the amount of total output, and n , the number of generation plants. Here $\underline{W} = \int_0^q (\underline{a} - bQ)dQ$; $\bar{W} = \int_0^q (\bar{a} - bQ)dQ$. $TC_n(q)$ is the total cost of production, when n plants are in the market. Given that all plants have the same cost functions, the social planner will split the total output equally to each plant (Viscusi, *et al.* 2000). Therefore,

$$\begin{aligned} TC_1(q) &= C(q) \\ TC_2(q) &= 2C(q/2) \\ TC_n(q) &= nC(q/n) \end{aligned}$$

If there is only one plant in the market, the most efficient level of production occurs where $MC(q) = AC(q)$, i.e. $q^* = \sqrt{F/\alpha}$. When there are two plants in the market, the most efficient level of production occurs at $q_2^* = 2q^* = 2\sqrt{F/\alpha}$.⁶

Optimal n under Discrete Choices of Quantity

Suppose the set of quantities to choose from is composed only of the most efficient levels of production, i.e. $q \in \{q^*, 2q^*, 3q^*, \dots, mq^*\}$, then the social planner's choice variables are reduced to one.⁷ As long as the optimal number of generation plants is determined, the output level will be q^* multiplied by that number. The social planner's optimization problem now takes the form of

$$\max_n p \int_0^{nq^*} (\underline{a} - bQ) dQ + (1-p) \int_0^{nq^*} (\bar{a} - bQ) dQ - n(\alpha q^{*2} + F)$$

by choosing n .

First order condition gives the optimal value of n ,

$$n^* = \frac{[p\underline{a} + (1-p)\bar{a}]q^* - \alpha q^{*2} - F}{bq^{*2}}$$

Substitute in $q^* = \sqrt{F/\alpha}$ and let $E(a) = p\underline{a} + (1-p)\bar{a}$, the expression can be simplified to

$$n^* = \frac{E(a)\sqrt{\alpha/F} - 2\alpha}{b} \quad (4)$$

The second order condition is satisfied for a maximum. Given that n has to be an integer, we will compare the two integers that are adjacent to n^* . In general, we compare the social welfare levels at $[n^*]$ and $[n^*]$,⁸ and determine the optimal number of plants. To simplify notations, we will continue using n^* as the benchmark for the following analysis.

2.2 Market Equilibrium

Now we investigate the market equilibrium under two circumstances. First we look at the equilibrium with fixed number of firms and then we allow free entry by firms and compare the equilibrium outcome with social optimum.

2.2.1 Fixed Number of Firms

As noted in Ventosa *et al.* (2005), most studies on the imperfect competition in electricity market are based on Cournot competition, in which firms compete in optimal output. We adopt this assumption here as well. In the real world, all generating companies bid in price and conditions of availability in the power pool. However, the assumption that firms engage in Cournot competition is justified by the fact that every power plant has capacity constraint. Kreps and Scheinkman (1983) offers an elegant theoretical support for this idea.

Suppose there are n^* plants operating in the market. They compete in their quantities of production. The price is determined by the market demand curve. Assume firms are risk neutral. Each firm i chooses its own quantity q_i to

$$\max q_i p(\underline{a} - bQ) + (1-p)(\bar{a} - bQ)q_i - C(q_i)$$

where $Q = \sum_{i=1}^{n^*} q_i$.

The Cournot outcome follows.

$$q_i^C(n^*) = \frac{E(a)}{(n^* + 1)b + 2\alpha} = \frac{1}{\sqrt{\alpha/F} + b/E(a)}$$

$$Q^C(n^*) = n^* q_i^C = \frac{n^* E(a)}{(n^* + 1)b + 2\alpha}$$

$$P(a = \underline{a}) = \underline{a} - \frac{bn^* E(a)}{(n^* + 1)b + 2\alpha}$$

$$P(a = \bar{a}) = \bar{a} - \frac{bn^* E(a)}{(n^* + 1)b + 2\alpha}$$

It is obvious that $q_i^C(n^*)$ is less than the most efficient level of production $q^* = \sqrt{F/\alpha}$, and the total output level is also less than the social optimum. These results are not surprising. Cournot outcome only approaches the results of perfect competition when n gets large.

2.2.2 Free Entry

Now we will investigate the market equilibrium with free entry and find out the equilibrium number of firms in the market. Assume that firms are symmetric in the sense that they all face the entry problem. There are no incumbents in the market.

Consider the following 3-stage game: in the first stage, firms simultaneously determine whether to enter the market and pay the fixed cost F if entry occurs;⁹ in the second stage, firms that had entered the market compete in their quantities of production; in the last stage, the actual market demand is realized and price is determined by the demand curve.

There are pure strategy subgame perfect equilibriums for this game, where firms keep entering the market until the expected profit for entering equals zero.¹⁰

Applying the results from “Fixed Number of Firms” (Section 2.2.1), a private firm’s expected profit from the subgame after entry is

$$E(\Pi) = \left[\frac{E(a)}{(n+1)b + 2\alpha} \right]^2 (b + \alpha) - F$$

Set $E[\Pi]$ equal to zero, we will get the equilibrium number of firms in the market.

$$\tilde{n} = \frac{E(a)}{b} \sqrt{\frac{b+\alpha}{F}} - \frac{2\alpha}{b} - 1 \quad (5)$$

Consequently, the market equilibrium prices are

$$\bar{P}_m = (\bar{a} - \underline{a})p + (2\alpha + b) \cdot \sqrt{\frac{F}{b+\alpha}} \quad (6)$$

$$\underline{P}_m = -(\bar{a} - \underline{a})(1-p) + (2\alpha + b) \cdot \sqrt{\frac{F}{b+\alpha}} \quad (7)$$

where $(\bar{a} - \underline{a})$ is the fluctuation in market price.

Comparing $\tilde{n}$ with the social optimum n^* , we get the following result.

Proposition 1: $\tilde{n} < n^*$ if and only if the following condition holds,

$$F > \underline{F} = \left[\frac{E(a)}{b} \cdot (\sqrt{b+\alpha} - \sqrt{\alpha}) \right]^2$$

or in terms of p ,

$$p > \underline{p} = \frac{1}{\bar{a}-\underline{a}} \cdot [\bar{a} - \sqrt{F}(\sqrt{b+\alpha} + \sqrt{\alpha})] \quad (8)$$

This proposition tells us that market equilibrium (with free entry condition) generates less than socially optimal number of firms, as long as fixed cost is beyond a certain point, or the probability of having low demand is higher than a certain value.

Suppose condition (8) is satisfied. We know that market equilibrium cannot replicate the social optimum outcome. The question is how the welfare gap varies with the uncertainty in market demand. Next we will calculate the total welfare level at the social optimum and at the market equilibrium, and then find out the relationship between the difference in welfare and the uncertainty in demand. Let W_{sp} be the maximized value of the social planner's total surplus. Let W_m be the surplus from the market equilibrium with free entry.

Proposition 2: The gap between W_{sp} and W_m is a decreasing function of p (probability of low demand).

Proof:

From the social planner's optimization problem, we can get

$$W_{sp} = p \int_0^{n^* q^*} (\underline{a} - bQ) dQ + (1-p) \int_0^{n^* q^*} (\bar{a} - bQ) dQ - n^* (\alpha q^{*2} + F)$$

Substitute in the values of n^* and q^* , the above expression can be simplified to

$$W_{sp} = \frac{[E(a)]^2}{2b} - \frac{2E(a)}{b} \cdot \sqrt{\alpha F} + \frac{2\alpha F}{b} \quad (9)$$

From the market equilibrium, we can get

$$W_m = p \int_0^{Q^C(\tilde{n})} (\underline{a} - bQ) dQ + (1-p) \int_0^{Q^C(\tilde{n})} (\bar{a} - bQ) dQ - \tilde{n} [\alpha q_i^C(\tilde{n})^2 + F]$$

Substitute in the values of $\tilde{n}$ and $q_i^C(\tilde{n})$, the above expression can be simplified to

$$W_m = \frac{[E(a)]^2}{2b} - E(a) \cdot \left(\frac{2\alpha}{b} + 1 \right) \cdot \sqrt{\frac{F}{b+\alpha}} + \frac{F(2\alpha+b)^2}{2b(b+\alpha)} \quad (10)$$

Subtract equation (10) from (9),

$$W_{sp} - W_m = E(a) \cdot \frac{\sqrt{F}}{b} \cdot \left[\frac{2\alpha+b}{\sqrt{b+\alpha}} - 2\sqrt{\alpha} \right] + \frac{2\alpha F}{b} - \frac{F(2\alpha+b)^2}{2b(b+\alpha)} \quad (11)$$

The difference between W_{sp} and W_m is an increasing function of $E(a)$, since $\frac{2\alpha+b}{\sqrt{b+\alpha}} > 2\sqrt{\alpha}$.

$E(a) = \bar{a} - (\bar{a} - \underline{a})p$, is decreasing in p . Therefore the gap between W_{sp} and W_m is a decreasing function of p .
Q.E.D.

When $E(a)$ increases, i.e. the average level of market demand increases, the loss of total welfare from the market equilibrium increases as well. One might argue that when market demand is high, the competition among private firms becomes intense. It is true. In the market equilibrium with free entry, both the number of firms and the total output level increase in $E(a)$, which helps to reduce the welfare gap between the social optimum and the market equilibrium. However, none of the private firms operate at the most efficient level of production. From the social planner's point of view, the private investors overreact to market signals by too much entry. The positive effect from intense competition is overrun by the negative effect from the added fixed costs of production. Overall the welfare gap will increase.¹¹

3 TWO STATES OF DEMAND AND RANDOM FIXED COST

Waiting for approval from the environmental authorities adds great uncertainty to the fixed cost of power generation for both nuclear and fossil-fuelled power plants. In addition, the construction costs are also volatile and unpredictable. As an example, when returning to service in September 2003, the refurbished first unit at Pickering A nuclear power station was more than two years behind schedule and \$800 million over budget.

In the previous section, we assumed that β , the random shock to fixed cost, equals zero. Now we will change this assumption to a uniformly distributed β in the range of $[0, F/2]$. Let $G(\beta)$ and $g(\beta)$ be the CDF and PDF of β respectively. For a uniform distributed variable, $g(\beta) = 2/F$, $G(\beta) = 2\beta/F$. The unconditional expectation of β is $F/4$. Assume β and p are independently distributed.

We will first look at the social optimum outcome under uncertainties, both to the market demand and to the fixed costs of production.

3.1 The Social Optimum

A risk-neutral social planner will choose n to

$$\max \int_0^{nq^*} (E(a) - bQ)dQ - n[\alpha q^{*2} + F + E(\beta)]$$

Note that the only difference between this optimization problem and the social optimum from Section 2 is this term: $-nE(\beta)$.

Let n_{RF}^* be the optimal solution, we can get

$$n_{RF}^* = \frac{E(a)\sqrt{\alpha/F} - 9\alpha/4}{b} \quad (12)$$

Next we will look at the market equilibrium with risk-neutral firms and with risk-averse firms.¹²

3.2 Market Equilibrium with Risk Neutral Firms

A risk-neutral private firm chooses its quantity of production to

$$\max \int_0^{F/2} [p(\underline{a} - bQ)q_i + (1-p)(\bar{a} - bQ)q_i - (\alpha q_i^2 + F + \beta)]dG(\beta)$$

The Cournot outcome gives

$$q_i = \frac{E(a)}{(n+1)b + 2\alpha}$$

Substitute the optimal level of production¹³ into the objective function and set that equal to zero. We can get the equilibrium number of firms with free entry, denoted by $\tilde{n}_{RF}$,

$$\tilde{n}_{RF} = \frac{2E(\alpha)}{b} \cdot \sqrt{\frac{b+\alpha}{5F}} - \frac{2\alpha}{b} - 1 \quad (13)$$

Comparing $\tilde{n}_{RF}$ with the social optimum n_{RF}^* , we have the following result.

Proposition 3: $n_{RF}^* > \tilde{n}_{RF}$ if the following conditions hold,

$\alpha < 4b$, and $F > F_{RF} = \left[\frac{E(\alpha)}{b-\alpha/4} \cdot (2\sqrt{(b+\alpha)/5} - \sqrt{\alpha}) \right]^2$, or in terms of p ,

$$p > p_{RF} = \frac{1}{\bar{a}-\underline{a}} \left[\bar{a} - \sqrt{F} \left(\sqrt{\frac{5}{4}(b+\alpha)} + \frac{5}{4}\sqrt{\alpha} \right) \right]$$

Recall that without random shock to fixed costs, $\underline{p}$ is the minimum level of p above which market equilibrium generates less than socially efficient number of firms. The expression of $\underline{p}$ is given in equation (8). Comparing the values of p_{RF} and $\underline{p}$, we get

$$\underline{p} - p_{RF} = \frac{\sqrt{F}}{\bar{a}-\underline{a}} \left[\left(\frac{\sqrt{5}}{2} - 1 \right) \sqrt{b+\alpha} + \frac{1}{4}\sqrt{\alpha} \right]$$

This value is always positive; in other words, $\underline{p} > p_{RF}$. With the random shock β to fixed costs, market equilibrium generates less than socially optimum number of firms for a wider range of p . In other words, when taking into account of the uncertain fixed cost, the number of firms in the market equilibrium is even less likely to be the social optimum.

3.3 Market Equilibrium with Risk Averse Firms

Now suppose private firms are risk averse. They are still expected utility maximizers, but their utility functions have to be concave in the profit levels. Their objective functions will now take the following form,

$$\max E[\Pi^\theta]$$

where $0 < \theta < 1$.¹⁴ In order for this problem to have valid mathematical meanings, we confine the value of θ to the reciprocal of odd numbers, i.e. $\theta \in \left\{ \frac{1}{3}, \frac{1}{5}, \frac{1}{7}, \dots \right\}$.¹⁵

In our particular case, the objective function of each private firm can be written as

$$\max \int_0^{F/2} \left\{ p[(\underline{a} - bQ)q_i - (\alpha q_i^2 + F + \beta)]^\theta + (1-p)[(\bar{a} - bQ)q_i - (\alpha q_i^2 + F + \beta)]^\theta \right\} dG(\beta)$$

By solving the maximization problem and using the zero-profit condition, we get the following result.

Proposition 4: When private firms are risk-averse, the market equilibrium number of firms ($\hat{n}$) and the degree of risk-aversion (θ) satisfy the following relationship: when $p \in (\frac{1}{2}, 1)$, $\hat{n}$ is increasing in θ ; when $p \in (0, \frac{1}{2})$, $\hat{n}$ is decreasing in θ .

Proof:

First order condition of the private firm's optimization problem yields

$$-\frac{p}{1-p} = \left(\frac{\Pi}{\underline{\Pi}} \right)^{\theta-1} \cdot \left[1 + \frac{\bar{a}-\underline{a}}{\underline{a}-bQ-(b+2\alpha)q_i} \right] \quad (14)$$

where $\underline{\Pi} = (\underline{a} - bQ)q_i - C(q_i)$; $\overline{\Pi} = (\overline{a} - bQ)q_i - C(q_i)$.

Equation (14) defines the optimal q_i as a function of n . We know that under free-entry condition, the expected profit of each firm is zero,¹⁶ which means

$$p \int_0^{\frac{F}{2}} \underline{\Pi} dG(\beta) + (1-p) \int_0^{\frac{F}{2}} \overline{\Pi} dG(\beta) = 0$$

or equivalently,

$$-\frac{p}{1-p} = \frac{\overline{\Pi}}{\underline{\Pi}} \quad (15)$$

Substitute equation (14) into (15), we have the following condition:

$$1 + \frac{\overline{a} - \underline{a}}{\underline{a} - b\hat{n}\hat{q}_i - (b+2\alpha)\hat{q}_i} = \left(-\frac{p}{1-p}\right)^{2-\theta} \quad (16)$$

The left hand side of equation (16) is increasing in $\hat{n}$ (given α is relatively small). The right hand side can be decreasing or increasing in θ , depending on the value of p .

Given θ being the reciprocal of an odd number, the right hand side of equation (16) can be transformed to

$$-\left(\frac{p}{1-p}\right)^{2-\theta}, \text{ the derivative of which with respect to } \theta \text{ is then } \left(\frac{p}{1-p}\right)^{2-\theta} \cdot \ln\left(\frac{p}{1-p}\right).$$

When $0 < p < \frac{1}{2}$, i.e. $0 < \frac{p}{1-p} < 1$, the R.H.S. of (16) is an decreasing function of θ . When $\frac{1}{2} < p < 1$, i.e. $\frac{p}{1-p} > 1$,

it is an increasing function of θ . Combined with the result that the L.H.S. of (16) increases in $\hat{n}$, our proposition follows immediately. **Q.E.D.**

Intuitively, when the market demand is on average high, i.e. p is less than a half, the more risk-averse the private firms are, the higher the number of firms entering the market in equilibrium. When the demand is on average low, i.e. p is greater than a half, the more risk-averse the private firms are, the lower the number of firms entering the market in equilibrium. In other words, the expected market demand directly affects risk-averse firms' attitude towards risk in entry. The second scenario explains why there has been lack of private investment in Ontario since the market was opened in 2002. From the viewpoint of private investors, the demand they face will be the difference between the market demand and the supply from OPG's existing power plants. This residual demand is even more volatile as it is affected by both demand uncertainty and other firms' supply uncertainty. When expecting the residual demand being low, either due to slowing down of economic growth or restarting of OPG's dormant nuclear plants, risk-averse private investors tend to shy away from this market.

Solving for $\hat{n}$ from the equilibrium conditions is quite complicated and has little analytical meaning. Thus we do not compare market equilibrium with the social optimum for risk-averse private firms here.

4 CONCLUSIONS

In this paper we evaluate the performance of deregulated power generation industry, under the assumptions of random demand and random fixed costs. We find that the fluctuation in demand affects not only the social planner's optimal choice, but also the relative performance of market equilibrium. When there is random shock to fixed costs, entry behaviour of potential firms is further deterred. For risk-averse private firms, the degree of risk-aversion also affects entry and the performance of market equilibrium. The intention of this paper is not to answer the question whether the power generation industry should be opened to competition. Allowing for private investment in power generation is a common practice nowadays. However, the deregulated industry has not done a good job in adding more capacity to the power pool. This paper explains the underlying reason from both demand and supply sides of the market.

The results of this paper can be applied to the question of how a social planner should set the ratio between nuclear and gas-turbine power plants. Nuclear power is associated with high fixed cost and low variable cost. Gas-turbine generation plants cost much less to construct, but the input price is high. The ideal solution is to let nuclear power fulfill the regular demand, and to let gas-turbine power generation fill the gap between high and low demand. Our model can also be applied to the problems resulted from asymmetric information. Incomplete information regarding the fluctuations in construction costs along with the complicated process of getting regulatory approval can deter interested parties from entering the market. Social welfare would be improved if asymmetric information can be reduced.

Zareipour, *et al.* (2007) examines the operation of Ontario's competitive electricity market, including several programs introduced by the Independent Electricity System Operator (IESO) to improve electricity market stability and efficiency. Among these programs, the Spare Generation On-line program (SGOL) and the Market Power Mitigation Agreement (MPMA) are directly related to the supply side of the market.

The SGOL program launched in August 2003 was mainly designed to improve market reliability by offering eligible generators a guarantee of their start-up costs. While this objective has been met, market efficiency has been reduced by the payment of more than \$33 million to eligible generators. MPMA was put in place by the Ontario government before opening the market in May 2002. Effective April 2005, generation from OPG's base load hydroelectric and nuclear facilities was capped at \$33/MWh and \$49.5/MWh respectively. OPG's revenue from its unregulated assets, *i.e.* non-base load hydroelectric, coal and gas-fired stations, were capped at \$47/MWh. The Market Surveillance Panel so far has not found any exercise of market power by OPG or any other market participants. However, as pointed out in Zareipour *et al* (2007), the MPMA resulted in inefficient operation of OPG and subsidized electricity prices for consumers.

The Ontario Power Authority has also been negotiating contracts with both supply and demand sides to ensure availability of reliable power. Given these contracts and new capped prices over most of OPG's output, only about 25% of the total Ontario generation capacity is truly open to market competition.

The tradeoff between market efficiency and system reliability seems hard to avoid in the short-run of electricity market deregulation. Overtime, investment in additional capacity should be made as long as the incremental value of the investment exceeds the incremental cost of the investment. As vividly described in Dewees (2001), over time competitive prices in a market in which new investment is not small relative to installed capacity may follow a sawtooth pattern, rising until a new plant comes on line, then falling, only to rise again as demand grows.

NOTES

1. For readers interested in the reform of transmission networks, Littlechild (2008) offers a good survey on the challenges faced by policymakers and private investors in transmission expansions and interconnection.
2. Data source: http://www.ieso.ca/imoweb/pubs/marketReports/10Year_ODF_2004jan_20030526.pdf
3. Data source: <http://www.ieso.ca/imoweb/marketdata/marketSummary.asp>
4. "Decontrol" means selling, leasing, or swapping generation, or using other mechanisms that result in yielding control over operations and power marketing to others.
5. We assume quadratic cost function for the reasons that it captures the main characteristics of electricity supply and allows for potential competitiveness in theory (Borenstein 2002; Viscusi, *et al.* 2000).
6. The social planner will divide the total output equally between the two plants, therefore the average cost curve is obtained by doubling the output level at each average cost level.
7. For an optimization problem where the social planner chooses both the number of plants and the output level, optimal output level is proved to be q^* multiplied by the number of plants. So even though we confine the social planner's choice variable to one, the results are the same as in a multi-variable optimization problem.
8. $[n^*]$ is the smallest integer that is greater than or equal to n^* . $\lceil n^* \rceil$ is the largest integer that is less than or equal to n^* .
9. F can be explained as construction costs.

10. Mixed strategy equilibrium also exists. For example, all potential entrants enter the market with probability λ , and stay out of the market with probability $1 - \lambda$.
11. Comparative static analysis shows W_{sp} is not monotonic in $E(a)$. Neither is W_m monotonic in $E(a)$. Moreover, the conditions under which W_{sp} increases in $E(a)$ don't imply that W_m increases or decreases in $E(a)$. So it is not true assuming that the increase in welfare gap is merely a result of the expansion in the market size.
12. We investigate the two types of firms separately, because closed form results can be obtained in the model with risk-neutral firms, but not with risk-averse firms. The model with risk-averse firms is appealing and can serve as the foundation of future research.
13. For risk-neutral firms, the expressions of q_i are the same with or without the random shock to fixed costs.
14. We can think of risk-neutral firms as having θ equal to 1. The closer is the value of θ to 1, the less risk-averse private firms are; the closer is the value of θ to 0, the more risk-averse they are.
15. Free entry condition ensures that sometimes profits are negative, and the square root of a negative number does not exist. As only the trend in θ matters in the analysis that follows, this assumption on θ is legitimate.
16. One can as well set the expected utility $E(\Pi^\theta)$ equal to zero. The main results are not affected.

AUTHOR INFORMATION

Dr. Xiaoting Wang is an Assistant Professor at Department of Economics, Acadia University, Canada. She received her Ph.D. in economics from Queen's University, Canada. Her research interests include industrial organization and microeconomic theory. E-mail: xiaoting.wang@acadiau.ca. Corresponding author.

Dr. Jun Yang is an Associate Professor of finance at the F.C. Manning School of Business Administration, Acadia University, Canada. He received his Ph.D. in finance from Queen's University, Canada. His research interests include corporate governance, asset pricing, and risk management. E-mail: jun.yang@acadiau.ca.

REFERENCES

1. Borenstein, S. 2002. "The Trouble with Electricity Markets: Understanding California's Restructuring Disaster." *Journal of Economic Perspectives* 16(1):191-211.
2. Dewees, D.N. 2001. "Price and Environment in Electricity Restructuring." Working Paper, Department of Economics, University of Toronto, Toronto.
3. Gillen, D. and J.F. Wen. 2000. "Taxing Hydroelectricity in Ontario." *Canadian Public Policy* 26(1):35-49.
4. Iacobucci, E., M. Trebilcock, and R.A. Winter. 2006. "The Canadian Experience with Deregulation." *University of Toronto Law Journal* 56:1-74.
5. IESO. 2003. "Ontario Demand Forecast from January 2004 to December 2013." at http://www.ieso.ca/imoweb/pubs/marketReports/10Year_ODF_2004jan_20030526.pdf
6. Joskow, P.L. 2008. "Lessons Learned from Electricity Market Liberalization." *The Energy Journal* 29 (Special Issue 2):9-42.
7. Kreps, D. and J. Scheinkman. 1983. "Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes." *Bell Journal of Economics* 14:326-337.
8. Littlechild, S. 2008. "Some Applied Economics of Utility Regulation." *The Energy Journal* 29 (Special Issue 2):43-62.
9. Trebilcock, M.J. and R. Hrab. 2005. "Electricity Restructuring in Ontario." *The Energy Journal* 26(1):123-146.
10. Ventosa, M., A. Baillo, A. Ramos, and M. Rivier. 2005. "Electricity Markets Modeling Trends." *Energy Policy* 33(7):897-913.
11. Viscusi, W.K., J.M. Vernon, and J.E. Harrington. 2000. *Economics of Regulation and Antitrust*. Cambridge: The MIT Press.
12. Zareipour, H., C.A. Canizares, and K. Bhattacharya. 2007. "The Ontario Competitive Electricity Market: Overview, Experiences, and Lessons." *IEEE Transactions on Power Systems* 22(4):1782-1793.

NOTES