Regulating the Electricity Industry

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Abstract

This paper reviews some of the major insights of the economics literature regarding regulation of the electricity industry. We start with a brief review of the theory of natural monopoly. Then, as the most popular pricing method, peak-load pricing is assessed for the U.S. and Chile. Next, the three most commonly used regulation methods in the electricity industry are reviewed and the problems of these regulation methods are summarized. Ramsey-pricing regulation is subject to a series of unrealistic assumptions and highly depends on the availability of good information about price elasticity. Price-cap regulation, on the other hand, is subject to quality issues. Rate of return regulation has a negative impact on innovation. The paper further discusses the supply quality (reliability) issue. The impact of different regulation methods on welfare is reviewed. Lastly, the relationship between investment and market power is addressed in detail.

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1 Introduction

With the development of the world economy, the electricity industry is playing a more and more important role. Due to its natural monopoly properties, national electricity giants could use this advantage to extract consumer surplus. For that reason, many countries regulate the electricity sector. In Canada, the constitution assigns jurisdiction over electricity regulation to the provinces.

The purpose of this paper is to review some of the major regulation issues regarding the electricity industry. In section 2, we will briefly discuss the properties of natural monopoly and to what extent they apply to the electricity industry. In section 3, a prevailing pricing method to the electricity industry—peak-load pricing will be analyzed particularly in the U.S. and Chilean cases. Section 4 will make a detailed review of three major regulation methods—Ramsey-pricing, price-cap regulation and rate-of-return regulation. Some important issues—supply quality, welfare, and investment and market power will be reviewed in sections 5, 6 and 7 respectively. Finally, section 8 will conclude.

2 General issues regarding natural monopoly

An industry is a natural monopoly when a single firm can supply a good or service to an entire market at a smaller cost than could two or more firms. When a firm's ATC (Average Total Cost) curve continually declines, the firm has a natural monopoly. When production is divided among more firms, each firm produces less, and ATC rises. In other words, natural monopoly will arise if there exist economies of scale over a large range of production.

More precisely, and especially for the multiproduct case, let's define $Q = Q' + Q''$, where $Q' and\ Q''$ are both sub-quantities of the total fixed production quantity Q. If $C(Q') + C(Q'') > C(Q)$, there exists natural monopoly[1] (Baumol et al., 1982).

Most of the recent literature treats the electricity industry as a natural monopoly. But there is no universal agreement on the natural monopoly property of the industry, especially after deregulation.

Studying the Swiss electricity industry, Filippini (1998) concluded for the existence of economies of scale only for small and medium-sized electricity utilities. Moreover, the generation and distribution systems have changed from natural monopoly to competition because of the restructuring process in the U.S. since the 1990s (Gans and King, 2000).

Gunn and Sharp (1999) argued for the weakening of natural monopoly in New Zealand after deregulation. They showed that some potentially competitive elements embedded in the electricity industry will be released after effective deregulation. Gunn and Sharp (1999) found that due to the financial principle[2] in the regulatory regime, the electricity industry may induce unsustainable cost structures and unintentional contestability, which is inefficient, into the market. Moreover, they indicated that regulation will not necessarily push the price towards marginal cost and restrict the company's ROR (Rate-of-Return).

[1] The cost function is subadditive.

[2] If the ARP (Accounting Rate of Profit) exceeds the post-tax WACC (Weighted Average Cost of Capital), then the firm is considered to be abusing its monopoly power and will face regulation in the form of price control (Gunn and Sharp, 1999).

3 Peak-load pricing – Price discrimination over time

3.1 Analytical background

In many cases, the monopolist will try to sell the same good or service to customers for different prices in order to take advantage of its monopoly position in the market. Theoretically, if the firm can practice perfect price discrimination, it can extract all consumer surplus. If the firm sets a uniform monopoly price, some potential customers who value the good at more than marginal cost will not buy it. So a DWL (Dead Weight Loss) occurs when a uniform price is charged. However, if the monopolist has the ability to discriminate among consumers and charge their different willingnesses to pay, it will extract the entire consumer surplus.

Braeutigam (1988) provides a basic model of peak-load pricing based on Steiner (1957). Assume we have n demand periods, and the peak period pays the capacity cost. Let us further suppose that:

a) $y_{t,\ t=1,\cdots,n}$ is the demand for each period (including the demand for the peak period y_{peak} and the demand for the other non-peak periods $y_{non-peak}$).

b) Variable cost is b.

c) Unit capacity cost is β.

d) W is total consumer net welfare.

e) A is total consumer gross welfare and $A_{t,\ t=1,\cdots,n}$ is consumer gross welfare in different periods (including the consumer gross welfare in the peak period A_{peak} and the consumer gross welfare in the other non-peak periods $A_{non-peak}$).

f) TC is total cost.

So, the problem is:

$$\max_{y_1 \cdots y_n} \quad W = A - TC = A_1 + A_2 + \cdots \cdots A_n - b \sum_{t=1}^{n} y_t - \beta y_{peak}$$

$$\begin{cases} \dfrac{\partial W}{\partial y_{non-peak}} = \dfrac{\partial A_{non-peak}}{\partial y_{non-peak}} - b = p_{non-peak} - b = 0^3 \\ \dfrac{\partial W}{\partial y_{peak}} = \dfrac{\partial A_{peak}}{\partial y_{peak}} - b - \beta = p_{peak} - b - \beta = 0 \end{cases}$$

$$\rightarrow \begin{cases} p_{non-peak} = b \\ p_{peak} = b + \beta \end{cases}$$

So theoretically, it is socially optimal to have the peak period bear all capacity costs. The effect of peak-load pricing strategy is to create a demand shift from the peak period to non-peak periods and consumers will benefit from the lower price, which in turn makes more efficient use of existing capacity.

Newsham and Bowker (2010:3290) summarized four kinds of common pricing strategies:

a. Time-of-Use (TOU): the day is divided into contiguous blocks of hours. The price of a kWh varies between blocks, but not within blocks, with the highest price for the on-peak block.
b. Critical Peak Pricing (CPP): this is a similar concept to TOU, except that it is only applied on a relatively small number of “event” days. These event days are commonly advertised by the utility a day in advance. The ratio of on-peak to off-peak price is higher on CPP event days than in a TOU program.

[3] See appendix.

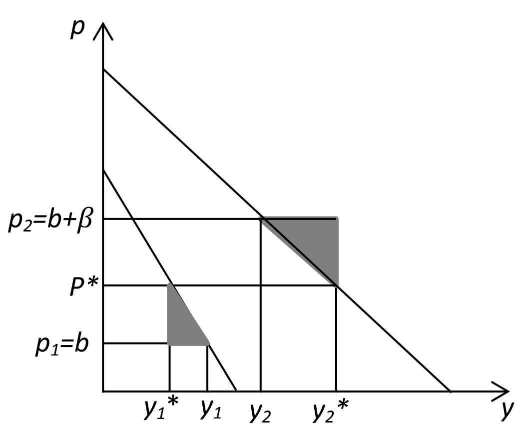
c. Real Time Pricing (RTP): the price may vary hourly and is tied to the real market cost of delivering electricity. Thus, the price is not known far in advance, no two days have the same rate structure, and there can be much greater extremes of on-peak to off-peak price compared to CPP.

d. Peak Time Rebates (PTR): Customers receive electricity bill rebates for not using power during peak periods.

3.2 Analysis and discussion

Because Newsham and Bowker (2010) have grouped some major peak-load pricing strategies, our discussion in this section will mainly be based on their work. We will add some other important studies in order to expand Newsham and Bowker's review.

Peak-load pricing is one special category of price discrimination in that it discriminates between consumers across time periods. One major effect of this pricing method is the deviation of consumption away from the period of peak demand towards periods of lower demand. Thus, consumers will benefit from the lower price. Consumers are encouraged to use electricity when there is excess capacity, which improves efficiency. If a uniform price is charged, a DWL will inevitably occur.



Source: Adapted from Corton (2008)

Figure 1—DWL from Peak-load pricing

If the electricity company sets a uniform price $p*$ instead of price discrimination (p_1 for non-peak period and p_2 for peak period), a DWL will occur, represented by the shaded areas.

As we can see from figure 1, the quantity demanded deviates from the original one. That is to say, the uniform pricing strategy encourages electricity consumption during the peak period and discourages it during the non-peak period. This result is certainly not desirable from the point of view of consumers or producers. However, peak-load pricing is not always fair to consumers by taking advantage of consumers' inability to switch their electricity consumption according to price. For example, most consumers have to pay higher price during the peak period because they can't just avoid using electricity during that period, i.e. the switching cost is fairly high.

3.2.1 Welfare analysis based on U.S. peak-load pricing experiments

Aigner (1984) addressed the TOU strategy in terms of welfare, that is to say, do the benefits to society of placing households on TOU rates outweigh the cost of implementation? There are several papers discussing the social cost-benefit problems. Originally, the TOU welfare analysis was conducted based on U.S. Department of Energy (DOE)-sponsored pricing experiments. Aigner (1984) found that consumers may have a net benefit or a net loss under a mandatory TOU rate scheme in that this type of TOU rate scheme will force customers to respond whereas there is no obvious efficiency implication for an optional TOU rate scheme.

Acton and Mitchell (1980) analyzed the effect of implementing a TOU pricing scheme instead of a uniform pricing strategy[4] in Los Angeles. They indicated that the TOU pricing scheme will not affect revenues. They argued that social welfare should include only consumer welfare, given the reasonable assumption that the TOU prices will be

[4] In this article, a TOU pricing scheme of 9 cents/kWh for peak and 3 cents/kWh for off-peak is implemented instead of a uniform price of 5 cents/kWh.

equal to the long-run marginal cost. In terms of the cost-benefit analysis, they calculated that the break-even electricity consumption is around 800 kWh/month.

Parks and Weitzel (1984) also provide a detailed cost-benefit analysis based on Wisconsin and Illinois. The authors argued that the TOU prices generate too much costs compared to their benefits. The revenue losses for consumers from TOU are much greater than the benefits to producers. But as Lillard and Aigner (1984) indicate, the data in this article is from weekdays, so the results may be biased in that they do not take weekend data into consideration.

Gallant and Koenker (1984) used the Leontief utility function and data from North Carolina to conduct the analysis. Aigner (1984) pointed out that, unlike other comparable works, they used a continuous model to conduct the research and constructed an optimality problem to solve for an optimal pricing scheme. Aigner noted that (1984:7) *"their best set of results for a continuously-varying price schedule they achieve net welfare gains of up to 17.7 cents/day/customer. Limiting attention to pricing mechanisms which preserve a three-part energy charge, in which case the optimization exercise solves for the pricing period definitions too, they still demonstrate a substantial welfare gain of 10.8 cents/day"*. Finally, Gallant and Koenker (1984) pointed out that the most important result of this paper is the huge sensitivity of the estimated long-run welfare gain to different pricing policies. But Gallant and Koenker (1984) also admitted that their work relied heavily on a continuous-time framework and assumed a Leontief utility function, which may be arbitrary to some extent.

3.2.2 U.S. Peak-load pricing from a historical perspective

In spite of the wide use of peak-loading pricing in the electricity industry nowadays, the principle of peak-load pricing has been misused as a demand-charge rate structure for a long time in American history. Neufeld (1987) provided two possible explanations. The first is that demand-charge rate structure is a "second-best" form of peak-load pricing. And this is plausible especially for the industrial electricity users because industry electricity users' peak is likely to occur at the same time as the system peak.

The second explanation provided by Neufeld (1987) was purely from the historical perspective of regulation. He stated that the demand-charged rate system became widely-used since 1906. And the electricity industry was facing state price regulation from 1906 to 1915. So he argued that it would be better to view the demand-charged rate system at that time as a special price discrimination instrument rather than as an application of peak-load pricing. The author also indicated that the reduced price in the demand-charged system was aimed at those consumers who have the alternative to purchase electricity from other self-generation isolated electricity plants. Thus, the major electricity producers facing fierce competition had to respond to the factors which determine the cost of the alternative supply instead of their production cost.

3.2.3 Peak-load pricing in Chili

Raineri and Giaconi (2005) analyzed the Chilean electricity pricing model. In the model[5], they measured net consumer surplus as:

[5] In this model, the authors assumed that there are three independent markets: a residential market with tariff p_1 and quantity q_1, an industrial market with tariff p_2 and quantity q_2, and an access services market

$$W_c = V\big(q_1(p_1), q_2(p_2), q_3(p_3)\big) - p_1 q_1(p_1) - p_2 q_2(p_2) - p_3 q_3(p_3)$$

Then, they measured the electricity producer's profit[6] as:

$$\pi = p_1 q_1(p_1) + p_2 q_2(p_2) + a q_3(p_3) - C_D\big(f_1 q_1(p_1) + f_2 q_2(p_2) + f_3 q_3(p_3)\big) - C_p(f_1 q_1(p_1) + f_2 q_2(p_2))$$

The broker's peak-load purchase cost C_E is:

$$C_E = c_E f_3 q_3$$ [7]

So the social planner's problem is:

$$Max\ W_S = V\big(q_1(p_1), q_2(p_2), q_3(p_3)\big) - C_D\big(f_1 q_1(p_1) + f_2 q_2(p_2) + f_3 q_3(p_3)\big) - C_p\big(f_1 q_1(p_1) + f_2 q_2(p_2)\big) - C_E(f_3 q_3(p_3))$$ by choosing q_1, q_2 and q_3.

Because of the pressure from the competitive fringe, the electricity distribution firm will have an incentive to achieve cost efficiency. However, the authors indicated that this model requires the allocation of a common cost among the markets based on a fully distributed cost criteria that is not necessarily efficient from an economic point of view. In addition, this article offered three alternative regulated contract structures: Ramsey-pricing, physical-cap and price-cap. We discuss these methods in the next section.

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with tariff a and quantity q_3. Each customer is present in only one of the three markets. In addition, zero cross-elasticity is assumed for simplicity.

[6] The authors assumed that C_p is the purchase cost of peak power and C_D is the producer's peak-load power distribution cost, which depends on Q, the peak-load of the distribution system. Also, the authors define the coincidence factor as $f_i = \frac{q_i^c}{q_i}$, where q_i^c is the consumer contribution to the distribution system peak.

[7] In this article, there is a competitive fringe. The behaviour of the competitive fringe that contracts access service is exemplified by a broker firm who sells peak-load q_3 at tariff p_3, with a cost of c_E per unit and an access charge a paid to the producer.

4 Regulation methods

4.1 Ramsey-pricing

Ramsey-pricing is a regulation rule considering what price a monopolist should set in order to maximize social welfare, subject to a constraint on profit. For a monopolist, the price markup should be negatively related to the price elasticity of demand[8]. Ramsey (1927) first determined the socially optimal price subject to a series of firm profit constraints. Raineri and Giaconi (2005) indicate that in recent years, various solutions based on Ramsey-pricing have been suggested for setting prices in regulated industries.

Back to the Chilean case[9], Raineri and Giaconi (2005) implemented Ramsey-pricing to obtain the socially optimal access charge. By solving the FOCs of the maximization problem, the authors obtained the following necessary conditions:

$$\begin{cases} p_1 - \left(C_D^Q + c_P\right) f_1 = \frac{\lambda_S}{1+\lambda_S} \frac{p_1}{\eta_1} \\ p_2 - \left(C_D^Q + c_P\right) f_2 = \frac{\lambda_S}{1+\lambda_S} \frac{p_2}{\eta_2} \\ p_3 - \left(C_D^Q + c_E\right) f_3 = \frac{\lambda_S}{1+\lambda_S} \frac{p_3}{\eta_3} \end{cases}$$

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[8] $Max\ W = \int_0^q p(q)dq - C(q)\ s.t. \pi = p(q)q - C(q) = 0.$
$Max\ \mathcal{L} = \int_0^q p(q)dq - C(q) + \lambda[p(q)q - C(q)].$
$\frac{\partial \mathcal{L}}{\partial q} = p - MC + \lambda[p(q) + qp'(q) - MC] = 0$ and we let price elasticity of demand $\eta = -\frac{p}{qp'(q)}$.
Finally we will obtain the Ramsey price: $\frac{p-MC}{p} = \frac{\lambda}{1+\lambda}\frac{1}{\eta}$. Thus we can see that the price markup $p - MC$ is inversely related to the price elasticity of demand.

[9] In the Chilean case, Raineri and Giaconi (2005) indicated the distribution and peak power prices are $p_D\ and\ p_P$ respectively. As a result, the producer's prices become $\begin{cases} p_1 = \alpha_1 f_1 p_D + f_1 p_P \\ p_2 = \alpha_2 f_2 p_D + f_2 p_P \\ a = \alpha_3 f_3 p_D \end{cases}$, where $\alpha_1, \alpha_2\ and\ \alpha_3$ are choice variables. Finally we maximize W_S subject to $\pi \geq 0$ by choosing the values of $\alpha_1, \alpha_2\ and\ \alpha_3$.

where $C_D^Q = \frac{\partial C_D}{\partial Q}, c_P = \frac{\partial C_P}{\partial Q_P}, \frac{\lambda_S}{1+\lambda_S}$ is the Ramsey number, and $p_1, p_2\ and\ p_3$ are the Ramsey prices. In addition, the optimal access charge is $C_D^Q f_3 + \frac{\lambda_S}{1+\lambda_S}\frac{p_3}{\eta_3}$.

From the above equation system the authors further calculated the reduced form from the equation system above:

$$\begin{cases} \frac{\left[p_1 - \left(C_D^Q + c_P\right) f_1\right]/p_1}{\left[p_2 - \left(C_D^Q + c_P\right) f_2\right]/p_2} = \frac{\eta_2}{\eta_1} \\ \frac{\left[p_2 - \left(C_D^Q + c_P\right) f_2\right]/p_2}{\left[p_3 - \left(C_D^Q + c_P\right) f_3\right]/p_3} = \frac{\eta_3}{\eta_2} \\ \frac{\left[p_3 - \left(C_D^Q + c_P\right) f_3\right]/p_3}{\left[p_1 - \left(C_D^Q + c_P\right) f_1\right]/p_1} = \frac{\eta_1}{\eta_3} \end{cases}$$

It is very clear that the price markup is inversely related to price elasticity of demand for each good.

Although Ramsey-pricing is a classic pricing method in most of the theoretical literature, it is not very popular in the real world. Sheehan (1991) argued that Ramsey-pricing has several problems. In a typical monopoly market, the firm can discriminate between consumers by charging a higher price to those who have a more inelastic demand. By doing so, the monopolist will extract more consumer surplus in order to further maximize its profit. Theoretically, the monopolist can extract the entire consumer surplus if it can perfectly discriminate. Sheehan (1991) concluded that the monopolist still can discriminate between its clients even under Ramsey-pricing regulation due to the fact that utility monopoly is an official monopoly. If there are some potential competitors who want to enter the market by serving those clients who suffer the high price due to their inelastic demand, the government will forbid entry. All in all, although the market may become contestable, the government will prevent entry.

Ramsey-pricing theory is also subject to a series of assumptions. Sheehan (1991) points to some of the assumptions that are not met in the utility industry such as "*There is no taxation, or other government regulation, and no public sector*" and "*Income distribution is optimal*" (p. 25). Moreover, Ramsey-pricing is a static model, which may not be suitable to an environment of rapid technological change. On the other hand, due to the strong dependence of Ramsey-pricing on price elasticity, Ramsey-pricing regulation will be useless unless clear definitions and fairly accurate estimates of the elasticity are feasible (Horowitz et al., 1996:75).

In summary, although Ramsey-pricing sometimes agrees with the government objective to maximize social welfare, it does have a lot of limitations when being considered in a more realistic framework.

4.2 Price-cap regulation

In the 1980s, a Treasury economist from the United Kingdom, Stephen Littlechild, first introduced the concept of price-cap regulation. And since then, it became popular among regulators especially in the electricity and telecom industries. Price-cap regulation allows firms to have more flexibility in terms of their choices of price structure. Firms can adjust their individual prices to reflect costs, demand elasticity, complementarity and substitutability between products, and competitive pressure (Laffont and Tirole, 2001). Furthermore, price caps can encourage firms to reduce costs.

4.2.1 Price-cap regulation and quality

Vickers and Yarrow (1988) pointed out that the regulator should not neglect the effect on supply quality under price-cap regulation. Fraser (1994) analyzed price-cap regulation in the electricity industry with respect to quality by examining the price-cap constraints with and without reliability of electricity of supply. He found that if reliability is excluded from the price-cap constraint, consumers have to suffer the full price increase. On the other hand, if reliability is included, firms have to absorb the incremental cost and consumers will benefit from it. However, if firms have the ability to bypass the incremental cost caused by reliability, they can increase the price which is positively related to the level of reliability. As a result, Fraser (1994) suggested that regulatory authorities might set a low weight to reliability in the price-cap constraint in order to avoid this situation.

4.2.2 Price-cap regulation and investment behavior

In 2003, Ontairo suffered a huge electric power outage. And in the same year, the U.S., Italy, Sweden, Denmark and the UK also suffered electric power outages to some extent. Nagel and Rammerstorfer (2008) argued that underinvestment caused by price-cap regulation plays an important role in this event and should be given more attention. They incorporated price-cap into a dynamic investment model in order to determine the effect of price-cap on investment. A short call position is embedded in the optimal regulated cap problem and the authors performed a comparative sensitivity simulation to show that even a slight deviation of the actual regulated cap away from the optimal regulated cap will lead to underinvestment. What's more, Kearney (2008) proved that investment under price-cap regulation is much lower than under other kinds of regulation methods such

ROR regulation and incentive-based regulation. Therefore, he proposed a new price-cap mechanism with incentive-based components in it. However, lack of reliable data makes it fairly difficult to determine the factors that affect the investment behaviour in each country. As a result, a proxy named "unavailability of electricity" is used in empirical works[10].

4.2.3 Price-cap regulation in the Chilean case

Raineri and Giaconi (2005) proposed some regulation methods other than the somewhat "unrealistic" Ramsey-pricing method. Apart from the price-cap, they also proposed an alternative similar to the price-cap, which is a physical-cap. Unlike pricing-cap, the physical-cap is a constraint in terms of quantity. In the Chilean Case, the physical-cap is stated as:

$$\alpha_1 f_1 q_1 + \alpha_2 f_2 q_2 + \alpha_3 f_3 q_3 = Q$$

Then the authors maximized profits subject to this physical-cap constraint. Let λ_h be the shadow price for the physical cap constraint. If we solve the FOCs by choosing α_1, $\alpha_2\ and\ \alpha_3$, we get the following necessary conditions and optimal access charge:

$$\begin{cases} p_1 - \left(C_D^Q + c_P\right) f_1 = \frac{p_1}{\eta_1} + \frac{\lambda_h}{1+\lambda_h}(p - C_D^Q - c_p) f_1 \\ p_2 - \left(C_D^Q + c_P\right) f_2 = \frac{p_2}{\eta_2} + \frac{\lambda_h}{1+\lambda_h}(p - C_D^Q - c_p) f_2 \\ p_3 - \left(C_D^Q + c_E\right) f_3 = \frac{p_3}{\eta_3} + \frac{\lambda_h}{1+\lambda_h}(p_D - C_D^Q) f_3 \end{cases}$$

$$a = C_D^Q f_3 + \frac{p_3}{\eta_3} + \frac{\lambda_h}{1+\lambda_h}(p_D - C_D^Q) f_3$$

[10] Nagel and Rammerstorfer (2008) highlight the minutes of unavailable electricity in selected European countries and find that countries with incentive-based regulation have lower levels of unavailable electricity than those with price-cap regulation.

Let us come back to the price-cap regulation in the Chilean case. The price cap is expressed as:

$$\alpha_1 p_D f_1 \overline{q_1} + \alpha_2 p_D f_2 \overline{q_2} + \alpha_3 p_D f_3 \overline{q_3} = \bar{Q} p_D$$

Thus the constraint can be further expressed as[11]:

$$\alpha_1 p_D f_1 \overline{q_1} + p_P f_1 \overline{q_1} + \alpha_2 p_D f_2 \overline{q_2} + p_P f_2 \overline{q_2} + \alpha_3 p_D f_3 \overline{q_3} = \bar{Q} p_D + \overline{Q_P} p_P$$

The authors maximized profits subject to this price-cap constraint. Let λ_c be the shadow price for the price cap constraint. If we solve the FOCs by choosing $\alpha_1,\ \alpha_2\ and\ \alpha_3$, we get the following necessary conditions and optimal access charge, which are exactly the same as the Ramsey-pricing problem:

$$\begin{cases} p_1 - \left(C_D^Q + c_P\right) f_1 = (1 + \lambda_c) \frac{p_1}{\eta_1} \\ p_2 - \left(C_D^Q + c_P\right) f_2 = (1 + \lambda_c) \frac{p_2}{\eta_2} \\ p_3 - \left(C_D^Q + c_E\right) f_3 = (1 + \lambda_c) \frac{p_3}{\eta_3} \end{cases}$$

$$a = C_D^Q f_3 + (1 + \lambda_c) \frac{p_3}{\eta_3}$$

4.3 Rate-of-return (ROR) regulation

Rate-of-return regulation is another regulation method, which sets a limit on a firm's operating rate-of-return[12]. Averch and Johnson (1962) found that the capital-labor ratio will be higher under ROR regulation because the firm can increase its profit by raising more capital. This is called the "A-J" effect.

[11] Adding to both sides of the equation the constant term and the peak power value.

[12] Let us define R as gross revenue, wl as the wage expenditure, k as capital. Then the operating rate-of-return is $\frac{R-wl}{k}$.

4.3.1 Rate-of-return regulation and innovation

There are many empirical papers regarding the impact of ROR regulation on innovation. For instance, Nelson (1984) conducted an empirical research based on a sample of 40 privately owned electricity firms during the period from year 1951 to year 1978. According to the statistical test in his paper, ROR regulation has limited impact on innovation.

In order to further study the effect of ROR regulation on technological change, Frank (2003) wrote an empirical paper about the Texas electricity industry. He found that costs have increased dramatically after the implementation of ROR regulation in Texas in 1975. In other words, the Texas electricity industry has experienced a so called "technological regress" during the regulation period. Two translog models, pre-ROR regulation and post-ROR regulation were used to construct estimation equation systems. In addition, five hypotheses were tested in this article:

- H_1: did the presence of ROR regulation have an impact on the firm?
- H_2: whether technological change, be it positive or negative, occurred over each time period.
- H_3: did ROR regulation have an impact on the rate of technological change?
- H_4: the presence of the Averch-Johnson effect.
- H_5: the selection of factor augmenting technology.

The results suggest that:

- ROR regulation did have a significant impact on firms and their technological change[13].
- ROR regulation had a significant negative effect on the rate of technical change[14].
- ROR regulation increased the capital share significantly[15].

Hence, the literature agrees with the negative effect of ROR on innovation, but there is divergence regarding the magnitude of the effect.

4.3.2 Rate-of-return regulation and fair return

Recent studies show that ROR regulation reduced the earnings of public utilities. Ruggles (1924) introduced the concept of "fair return", indicating that the demand of public utilities, especially electric utilities, for a "fair return" has been increasing since the implementation of ROR regulation. Many electricity firms in the U.S. have negotiated with the regulating authorities that they should be ready to make necessary rate adjustment when the regulated rate-of-return falls below what is considered to be fair.

But the issue is that it is hard to define the "fair return". Moreover, several factors might affect the "fair return". Ruggles (1924) listed some of these factors: (1) Changes in economic conditions which affect the cost of operation and the rate of interest on capital, (2) the degree to which utility facilities may be duplicated or overbuilt, (3) deficits incurred by the utility in certain years or unusual earnings enjoyed in others, (4) the character of the service and the efficiency or inefficiency of the management and (5)

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[13] The author rejected H_1: ROR regulation is ineffective and H_2: ROR regulation does not affect technical change.

[14] The author failed to reject H_3 and obtained $\frac{\partial lnC^{post}}{\partial x} > 0$.

[15] The author failed to reject H_4 and obtained $\frac{\partial S_k^{post}}{\partial s} > 0$.

elements of risk peculiar to the utility or to the conditions under which it operates. Despite many other factors, the hottest issue that is still debated is whether the rate base (capital) is properly measured or not. Theoretically, as Ruggles (1924) stated, if the base can be enlarged by the regulatory authorities, then the reported rate-of-return will become smaller, which is preferred by the utility firm. The U.S. has witnessed a debate on the proper rate base between utility firms and the United States Supreme Court for a long time. The main conflict between firms and courts is whether the private properties for public use and the original cost of investment should be considered when calculating the base of "fair return", but the United States Supreme Court has made objection to that until now.

5 Quality and Reliability

The reliability of electricity supply is of great importance to firms and consumers. Amin (2004) pointed out that according to NERC[16] and EPRI[17], nearly 700,000 customers had been affected by electricity supply outage annually on average from 1984 to 2004. Some large supply failures even caused millions of people to suffer outages for extended periods. For instance, in July 1999, a New York City blackout caused 300,000 people to be without power for 19 hours.

5.1 Optimal reliability

Ravid (1992) determined an optimal level of supply reliability in electric utilities through a theoretical approach. He emphasized the fact that welfare increases with reliability. What makes Ravid's approach different from others is the introduction of a market and a

[16] North American Electric Reliability Council.
[17] Electric Power Research Institute.

price scheme for electricity, where “reliability” is treated as a tradable good just like electricity. In his model, an optimal pricing scheme for electricity and reliability was derived from welfare maximization, which also determined the optimal level of electricity supply and reliability[18]. Because of the introduction of the market for reliability, the author was also able to analyze the trade-offs between the electricity product market and the reliability market quantitatively. He used the examples of computers and hospital machinery, where reliability is critical: “*Examples include computers and hospital machinery, which consume little electricity and hence are relatively insensitive to prices charged for electricity, but whose users are willing to pay high prices so as to avoid service interruptions*.” Before the establishment of a market for reliability by Ravid (1992), a reliability constraint of the electric utility was analyzed by Meyer (1975).

Munasinghe (1981) argued that the optimal quality of supply is reached by improving the supply system until the marginal cost of these improvements exactly offsets the marginal benefits realized by consumers because of the enhanced quality of supply. If the optimal level of supply quality is not met or the level of supply quality changes, consumers will adjust their behavior accordingly. A model for the estimation of the changes in electricity consumption in the long-run was established by Munasinghe (1981), while many previous papers have already addressed this issue in the short-run. In his model, the improvement of electricity supply quality is a factor that can significantly increase the demand for electricity. As a result, the demand curve for electricity will shift to the right dramatically due to the increasing quality of electricity supply. Compared to other

[18] Ravid (1992) defined the level of reliability as the probability of being cut off from electric service.

common studies of electricity demand which are not based on utility maximization theory, the demand functions for electricity (which contain the price of substitute energy) in his paper were totally based on explicit maximizing theory.

The Interruptible Rate (IR) option was introduced by Woo and Toyama (1986) when addressing the optimality problem in terms of reliability. Compared to a unique reliability level given by the electricity firm, the introduction of an IR option provided consumers with a linkage between their preferences and supply quality level. In this paper, they were able to prove that the optimal electricity firm service rate [19] is the summation of interruptible rate (IR)[20] and marginal value of additional capacity.

Conducting an economic cost-benefit analysis, Sanghvi (1983) was able to determine the optimal level of reliability through customer shortage costs[21], whereas many studies at that time only considered the customer outage costs[22], which were extended by the author in his paper. In addition, instead of taking one single factor (such as only price or level of reliability) into account when maximizing social welfare, Sanghvi (1983) suggested that system capacity, reliability and prices should be determined jointly and in a mutually consistent manner.

[19] The firm service rate is the sum of the fuel cost and the expected shadow value of additional available capacity, weighted by customer price responsiveness (Woo and Toyama, 1986).
[20] The interruptible rate is essentially the unit fuel cost.
[21] Customer shortage costs reflect the short-run and long-run costs of electricity supply reliability (Sanghvi, 1983).
[22] Customer outage costs reflect short-run costs only and ignore long-run effects such as the shift of demand curve (Sanghvi, 1983).

5.2 Quality and incentive regulation

Apart from the three regulation methods discussed above (Ramsey-pricing regulation, price-cap regulation and rate-of-return regulation), there is another widely-used regulation method in the electricity industry: incentive regulation, and it is highly popular especially in the U.S. Incentive regulation that uses rewards and penalties to encourage better performance in the regulated industry, especially in energy sectors. However, this regulation method has been recognized as having an adverse impact on electricity supply quality since its implementation.

Ter-Mairosyan and Kwoka (2010) analyzed the U.S. electricity distribution utilities during the period of 1993-1999, concluding that incentive regulation will lead to long periods of electricity supply outage, and the decrease of supply quality can be remedied by embedding the supply quality standard into incentive regulation. Furthermore, this paper also concluded that careful design of quality standards can allow incentive regulation to achieve cost savings without quality deterioration. With regard to the service quality dimensions, the authors argued that two dimensions should be considered: the frequency as well as the duration of service interruptions. The analysis in this paper indicated that the declining electricity supply quality was reflected in the longer duration of supply outage, rather than increased frequency of supply outage.

Before Ter-Mairosyan and Kwoka (2010), the impact of incentive regulation on quality of electricity service had already aroused some discussions in the literature. Spence (1975) illustrated that the consumers' marginal valuation of quality (on which the monopolist's decision depends) is not equal to their average valuation (which defines the social optimum). In addition, he showed that the social optimum of service quality cannot be reached if reliability is chosen by the monopolist. He also showed that while incentive regulation can prevent the society from reaching its optimum, rate-of-return regulation might rebuild the social optimum theoretically, which, however, may not work in reality.

As discussed above, the empirical study done by Ter-Mairosyan and Kwoka (2010) on the U.S. electricity industry indicated that incentive regulation will decrease the supply quality, which can be effectively prevented by incorporating a supply quality standard into incentive regulation. Before Ter-Mairosyan and Kwoka (2010), another empirical paper written by Giannakis et al. (2005) on UK electricity distribution firms indicated that it will make a huge difference in company's performance if the production cost can be adjusted for supply quality and if the incentive regulation scheme can be amended with the integration of electricity supply quality. So both empirical studies based on different countries agreed that the regulator should take electricity supply quality issue or standard into consideration when implementing incentive regulation in order to decrease the negative effect[23].

5.3 Investment in quality

By analyzing various types of incentive regulation, Weisman (2002) found that investment in quality will change accordingly. In particular, he found that profit-sharing regulation can make the electricity company largely increase the investment in supply quality because the company needs to bear only a proportion of investment costs, whereas the firm has to absorb all the quality costs under revenue-sharing regulation,

[23] However, a literature survey conducted by Sappington (2005) formed quite mixed views regarding the impact of incentive regulation on electricity supply quality.

which discourages electricity firms from investing in supply quality. Before the supply-side reliability investment issue was explored by Weisman (2002), Andrews (1992) used an end-use approach to analyze consumption-side reliability investment. He also argued that the determination of the socially optimal level of reliability could be further improved by the emphasis on consumption-side reliability investment.

5.4 WTP and supply quality

As reviewed before, incentive regulation can severely deteriorate the supply quality (Ter-Mairosyan and Kwoka, 2010) and may lower the investment in electricity service quality (Weisman, 2002). Thus, it is necessary for the regulation authority to regulate the supply service quality as well. In terms of electricity supply quality, there are three major areas: voltage quality, commercial quality and continuity of supply reliability (CEER, 2008). Growitsch et al. (2010) addressed the last area, indicating that two dimensions should be further discussed: the availability of energy to consumers and the consumers' preference for continuity which is measured by their willingness-to-pay (WTP) for different levels of quality. By analyzing the case of Norway, the author unexpectedly found that the effect of WTP-based service quality regulation on the socially desired quality level is not significant for the period 2001-2004. Brekke (2007) provided a possible explanation that the actual level of supply quality has already been close enough to the social optimum level before quality regulation. Growitsch et al. (2010) also mentions issues relating to data availability for a long time horizon and the time lag between the introduction of quality regulation and its impact on the investment decisions of the electricity firm.

As indicated by Weisman (2002) and Growitsch et al. (2010), the reliability of electricity supply is affected by consumers' WTP. However, just like the empirical result obtained from the empirical study of Norway (Growitsch et al., 2010), consumers' WTP or preferences have played a limited role in establishing standards and incentives regarding quality.

In terms of the WTP of households, only a few studies have analyzed its relationship with improved quality of electricity supply (e.g. Doane and Hartman, 1988; Goett et al., 2000; Carlsson and Martinsson, 2008). Using the choice modelling method together with a mixed logit estimation, Abdullah and Mariel (2010) identified different types of demographic and socio-economic features that determine the WTP of households for improved electricity supply quality. Specifically, the authors pointed out that those who are unemployed, older tend not to pay more to improve the service quality and whose who are employed (steady cash inflow into a bank account), involved in farming activities and have a big family tend to pay more in order to improve the service quality.

With regard to the WTP of businesses for improved quality of supply, Morrison and Nalder (2012) first used choice modelling with random parameters logit models to identify the WTP of business for various quality-related characteristics[24]. The results indicate a selective feature of the WTP of businesses to different kinds of electricity supply quality attributes. They concluded that: "*In particular, manufacturing businesses*

[24] Morrison and Nalder (2012:130) state that "*Most previous studies have focused on examining the willingness to pay of households for improved quality of supply, despite businesses often comprising a larger proportion of electricity demand*" and their paper was the first to analyze the WTP of businesses for electricity supply quality.

are not willing to pay to reduce the frequency of outages" (p. 131), which is surprising because supply outages should be very disturbing in manufacturing.

6 Welfare

Aigner (1984) pointed out that the issue that should be focused on at present is consumer welfare. In particular, for time-of-use (TOU) pricing strategy, what we should consider is whether the benefits to society of placing households on TOU exceed the implementation costs. He also concluded that the welfare of consumers during the peak period is lower than that under the off-peak period because of the higher price during the peak period.

When the regulation authorities try to maximize social welfare, they will use their information to separate firms with high cost from those with low cost, which may lead to adverse selection problems. By using a rate-of-return regulation scheme, this adverse selection problem can be solved, which will cause another problem, "moral hazard". Then, if some form of incentive regulation such as price-cap regulation is used, the moral hazard problem can be solved. However, the problem of adverse selection will occur again (Kopsakangas-Savolainen and Svento, 2010). In order to solve this recurring problem, Laffont and Tirole (1986) introduced Menu-of-Contracts regulation. By using Finnish data, Kopsakangas-Savolainen and Svento (2010:7370) found that "*welfare can be improved by changing the Rate-of-Return regulation scheme to the Menu of Contracts regulation and welfare also increases in the case of Fixed price regulation and Simple Menu of Contract regulation*".

As peak-load pricing is the most prevailing pricing scheme in the electricity industry, many articles discussed its impact on welfare. In the first place, Wenders and Taylor

(1976) wrote a paper on seasonal-time-of-day pricing of electricity to residential users, providing a theory of the estimation of net welfare gain related to demand meters. But the problem is that they did not go on to illustrate how such a pricing strategy should be compared with other alternatives (Renshaw, 1980:37). Renshaw (1980) further illustrated this welfare gain issue by examining a two-period case with two types of consumers and one type of generating technology.

Under the context of increasing non-TOD[25] price of electricity, Wenders (1981) argued that many consumers will be forced to switch to TOD scheme even when it is not desirable from the perspective of welfare. Moreover, as demonstrated by Wenders (1981), if all the customers were free to choose between TOD tariff and non-TOD tariff, there must be some portion of customers who chose a tariff when it is not desirable. Although more and more customers will shift to TOD tariff with continuously increasing non-TOD tariff, Wenders's (1981:104) paper indicated that "*TOD tariff may be beneficial for only the largest 25% or so of the residential and small commercial classes*". Based on this result, he suggested that only those consumers can (and must) use TOD tariff.

By analyzing the impact of different pricing schemes[26] on welfare based on the Wisconsin Power and Light Company, Dimopoulos (1981) found that declining block pricing scheme and lifeline pricing scheme will increase consumer's welfare theoretically. However, regarding to lifeline pricing scheme, the author argued that there is almost no practical significance. What is worthy of being mentioned is that after comparing these

[25] Time-of-day (TOD).
[26] Average cost pricing, two-part tariff, declining block and lifeline pricing.

four pricing schemes, the author concluded that apart from those four schemes, time-of-day pricing will largely improve efficiency and welfare.

7 Investment

7.1 General issues regarding investment

In recent years, the European Union's Emissions Trading System (ETS) and many other countries in the world required electricity firms to invest in low CO_2-emitting technology. As a result, many studies analyzed this type of investment in various kinds of technologies (e.g. Yang et al., 1996; Paul, 2002). By imposing an additional CO_2 price to the consumer, Castillo and Linn (2011) analyze the incentive for investment in different low CO_2-emitting technologies, which are nuclear, wind and solar photovoltaic (PV). Moreover, the simulation model indicated that the increase in electricity prices[27] is positively correlated with output from a typical wind unit but the correlation is much weaker for nuclear and photovoltaic. As a result, they concluded that the investment incentive for wind technology is greater than for solar photovoltaic and nuclear.

Another pricing method, congestion pricing[28], was used to make the access to electricity more efficient. In addition to the achievement of short-run economic efficiency, Matsukawa (2008) also pointed out that congestion pricing also leads to long-run efficiency in certain situations[29]. Joskow and Tirole (2003) pointed out that the revenue

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[27] The increase in electricity prices is the result of the imposition of the additional CO_2 price to the consumer.

[28] Congestion pricing sets transmission prices equal to nodal price differences between regions sending and receiving electricity respectively and is expected to achieve short-run economic efficiency in competitive electricity markets (Matsukawa, 2008).

[29] Matsukawa (2008:697) indicates that this will happen "*if a congestion price reflects the marginal benefit of capacity expansion and transmission capacity is expanded to the point where the unit price of congestion is equal to the marginal cost of capacity*."

from congestion pricing is not enough for moderate capacity expansion under increasing returns to scale technology, while Vogelsang (2001) examined the impact of price-cap regulation on the access to electric transmission network. Later on, Kiesling and Wilson (2007) summarized that price-cap regulation, as a traditional regulation method in the electricity industry, has undesirable impacts on the investment in capacity and technology as well as on long-run prices. Due to the fact that the prices in the wholesale electricity market are very volatile, it is better for the regulatory authority to implement a market mitigation mechanism than a traditional price-cap. Then, by using an Automated Mitigation Procedure (AMP)[30], Kiesling and Wilson (2007) found that the AMP has nearly no effect on the overall investment in new capacity, which is the most important factor affecting long-run electricity wholesale prices. Specifically, through this experimental analysis in terms of the impact of AMP on the investment incentives together with the long-run prices in electricity wholesale market, Kiesling and Wilson (2007) concluded that the difference between the investment levels before and after the AMP is not statistically significant, and the prices in the long-run will not be affected[31], although the AMP may slightly decrease the investment incentives in the short-run.

Compared with the price-cap regulation scheme presented by Vogelsang (2001), the average revenue regulation mechanism presented by Matsukawa (2008) has an information advantage over a price-cap scheme, which requires the regulatory authority to get precise information on the weights used for the price index (Matsukawa, 2008).

[30] According to the author, AMP is a form of historically-based price cap on supplier's offers, implemented as a set of pre-clearing screens on submitted offers when prices are expected to exceed pre-defined thresholds.

[31] It is a reasonable result because the objective of AMP is to stabilize the long-run wholesale price of electricity.

Moreover, average revenue regulation will also decrease the access fee and increase investment as well as consumers' welfare (Cowan, 1997).

In contrast to Ordover and Panzar (1982) who proposed that a two-part tariff is not as good as a uniform price system under increasing return to scale in terms of consumers' welfare, Matsukawa (2008) showed that a two-part tariff is more desirable than a uniform price system under average revenue regulation.

Particularly, Matsukawa (2008) showed that efficiency is much higher under average revenue regulation than under a Coasian two-part tariff[32], although it is widely accepted among many scholars that a Coasian two-part tariff is the most efficient form of cost-of-service regulation in the electricity industry. However, it was also mentioned by Matsukawa (2008) that if the access fee to the electric network is too high to attract potential entry of new electricity generators, average revenue regulation will be inferior to cost-of-service regulation due to the high electricity prices and low consumer surplus.

7.2 Investment in the transmission sector

Normally, there are three sections in the electricity industry: the generation section, the distribution/transmission section and the retailing section (Gans and King, 2000). Due to the restructuring process in the U.S. since the 1990s, the generation and distribution systems have changed from natural monopoly to competition whereas transmission has remained a natural monopoly. As a result, the transmission system lacked incentives for development, which will cause congestions in various areas.

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[32] A Coasian two-part tariff sets unit price equal to marginal cost, extracting all profits through access fixed charge.

Several papers discussed the incentive issue in electricity transmission investment. In terms of regulatory approach, Vogelsang (2001) established a balanced system between the fixed part and the variable part of the price-cap tariff in order to efficiently increase the investment and expand the transmission network. However, Hogan (2002) pointed out that this regulatory system only works with smoothly behaved production and cost functions, which is unrealistic. Besides the criticism of this balanced system, Hogan (2002) proposed a merchant approach by incorporating the FTR (Financial Transmission Right) into the process of transmission expansion through the introduction of competition. Another regulatory approach established by Léautier (2000) compensated the electricity transmission company if the transmission capacity was increased through investment. Later on, Hogan et al. (2010) successfully combined the regulatory and merchant approaches, making it possible to embed the FTR instrument into the two-part tariff balance system designed by Vogelsang (2001). In order to establish a mechanism to promote the investment of transmission network expansion, Rosellón et al. (2010) used PJM region[33] in the U.S. as a benchmark case of the application of merchant-regulatory mechanism (Hogan et al., 2010) to demonstrate how to improve the congestion situation caused by the investment shortness in electricity transmission section. With regard to their model, a price-cap regulated electricity transmission firm in a competitive wholesale market with nodal price setting and FTRs was simulated. As indicated in this paper, "*regulation is applied through a price cap imposed on a two-part price tariff that the Transco can charge to users of the transmission network. The regulatory constraint allows for the rebalancing of the variable and fixed parts of the fee in order to let the*

[33] PJM stands for Pennsylvania, New Jersey and Maryland, which are operated by PJM Interconnection.

Transco[34] *preserve its benefits when congestion rents decrease due to the increased transmission grid capacity*" (p. 11). Through the convergence of nodal prices which can be arbitraged, a steady-state equilibrium was created with lower congestion rents and higher total welfare.

By using a static model containing a two-part tariff with variable congestion price as well as endogeneity of the number of electric generators, Matsukawa (2008) analyzed the impact of average revenue regulation on the investment in the transmission system as well as the welfare change for consumers. In his analysis of the monopolist's choice of transmission capacity, Matsukawa (2008) put emphasis on the endogenity of the number of electric generators in that "*a relatively high access fee that is needed to cover a large amount of the fixed costs in transmission investment is expected to reduce the number of users of the transmission facility, thereby discouraging the expansion of transmission capacity in the long run*" (p. 697).

Like the electricity restructuring process in the U.S. since the 1990s, in Australia, the generation section and retailing section can be viewed as competitive activities while the transmission section barely has the potential of competition. As the connection part of the whole electricity system, the transmission section is of great importance as it can influence the decisions of both upward streams (electricity generators) and downward streams (retailers & consumers). Gans and King (2000) pointed out that the current prevailing regulation options regarding the access price to electricity transmission

[34] Another name for transmission firm.

network in Australia[35], such as those options based on nodal pricing and the assignment of transmission right contracts, did not perform very well in terms of investment in electricity transmission. For example, the current transmission pricing regulations may not send the correct economic signals so that generators and retailers/consumers as well as the electricity transmission companies themselves will be misled. Furthermore, Gans and King (2000) also showed that the nodal pricing regulation method will lead to the best investment in transmission only if the transmission participants are price takers. If the power of these participants is big enough to distort nodal prices, the investors' decision may not be socially optimal anymore. Instead, on the basis of the idea by Sappington and Sibly (1988) that an incremental surplus subsidy (ISS) regime can align the private and social incentives, Gans and King (2000) designed an alternative regulation scheme, which may generate first-best investment results for the electricity transmission section in Australia. In the ISS scheme, the natural monopolist in the transmission section will benefit from gaining the whole social surplus only in one period and will be regulated based on costs in the other periods. According to Gans and King (2000:154), the logic behind the ISS scheme is that "*optimal decisions are often based on marginal gains and losses and so long as the monopolist faces the correct marginal incentives then it will make socially desirable decisions*".

7.3 Investment and market power

In the first place, the AMP was designed to limit the market power of those electricity generators in the wholesale market. And before Kiesling and Wilson's (2007) discussion of the relationship between investment and the wholesale price as well as another

[35] According to the author, in the Australian National Electricity Market (NEM), transmission prices are set by regulation under the *National Electricity Code*.

experimental analysis which talked about the interactions between market power and investment incentives (Williamson et al., 2006), there already existed many research papers focusing on the market power issue in electricity markets. According to Holt's (1989) definition, market power exists if the market participants are able to perform profitably and unilaterally by raising the market price. Borenstein (2000) also regarded the ability to increase market price unilaterally as an indication of market power. By applying this definition, Kiesling and Wilson's (2007) stated that "*if, for a given distribution of ownership of capacity, a firm profitably and unilaterally can submit an offer schedule above its marginal cost such that the market price rises above the competitive level, then a firm is said to be able to exert market power in a sealed bid-offer market*" (p. 315). Borenstein (2000) then claimed that electricity generators do not need to exercise their market power to invest in new capacity.

Apart from market power, there still exist other reasons that can lead to price increases. Analyzing data from the California price spikes 2000-2001, Borenstein et al. (2002) found that approximately 59% of the price spikes from June 1998 to October 2000 were the outcome of the exercise of market power while the other 21% and 20% were due to production cost inflation and scarcity rents respectively. Similar to Kiesling and Wilson's (2007) application of the definition of market power regarding the offer schedule from Borenstein (2000), Puller (2007) analyzed the five largest electricity generators supplying the California electricity market during the California price spikes from 1998 to 2000 by examining the hourly offer schedules. His results suggest the market operated more like a Cournot oligopoly, rather than like a natural monopoly or a perfectly competitive market.

Since the restructuring process of the electricity wholesale sector towards competition, private investment has become an essential factor to ensure a successful competitive electricity generation market. Due to the high level of investment uncertainty and risk, the new entrants need some kind of contracts to protect themselves. However, due to the fact that it is impossible for a single contract to cover all types of investment risks, which can lead to market inefficiency, Onofri (2003) indicated that there is always a trade-off between the reduction of investment risk through contracts and the improvement of electricity generation efficiency. In his paper, Onofri (2003) used a theoretical contractual model incorporating the trade-off between the investment risk and the power generation efficiency to derive three kinds of contracts: "take-or-pay" contracts, economic dispatch contracts and competitive pool contracts. Onofri (2003) found that the "take-or-pay" contracts have the highest, and the competitive pool contracts have the lowest investment incentives, while the economic dispatch contracts are in the middle. As a result, the "take-or-pay" contracts cannot achieve system efficiency because only those firms who gained profit got motivated, whereas the competitive pool contracts can lead to high levels of system efficiency due to the generators' consistent pressure to maintain low costs.

De Hauteclocque and Rious (2011) pointed out that MTI[36] are remunerated by the congestion rent arising from the spot price differential between the export and import zones or by the sale of FTR, whereas other regulated transmission investments are remunerated with a regulated access tariff. Joskow (2006) and others argued that MTI are usually regarded as a second-best solution when other regulated transmission investments

[36] Merchant transmission investments (MTI) are profit-motivated investments in cross-border infrastructure undertaken by non-regulated market players.

fail to develop at a suitable pace. Followed by Hogan's (2002) idea of FTR in electricity transmission markets, recently, the wide implementation of FTR in the U.S. has largely accelerated the decentralized development of MTI. Moreover, this MTI system based on FTR in the U.S. has effectively eliminated the regulation bias against dominant generators because both state and federal levels of regulatory authorities in the U.S. are able to detect and mitigate market abuse.

However, although MTI can mitigate the under-investment problem in transmission, they may increase the risk of anti-competitive effects, which is even worse if the MTI investor is a dominant electricity generator under improper regulatory power. Apart from the U.S. market with proper MTI regulation under which potential abuses of dominant electricity generators are mitigated, De Hauteclocque and Rious (2011) analyzed the European Union (EU) market in which the regulatory framework of MTI is weak due to improper regulatory decisions made by the new Agency for the Cooperation of Energy Regulators (ACER) created at the EU level. As a result, unlike the U.S., there existed a strong bias against dominant electricity generators in the development of MTI in the EU market and it is still very difficult for the EU to incorporate FTR in the electricity market for several reasons, such as the inefficiency of regulatory supervision over cross-border infrastructure (ENTSO-E, 2010a,b). Nevertheless, De Hauteclocque and Rious (2011) still argued that the EU should allow MTI by dominant generators with an enforcement regime based on a clear border between transparency monitoring by ACER and antitrust enforcement by the European Commission (EC)[37]. Moreover, as is stated by De

[37] De Hauteclocque and Rious (2011) recognize that "*it is true that allowing MTI by dominant generators indeed means creating a position of dominance in the cross-border transmission markets, but as long as*

Hauteclocque and Rious (2011), "*having a more integrated approach to competition policy, in order to leverage the complementarities between ACER and the antitrust powers of the EC, appears to be a way to bring a new impetus to interconnection investment in Europe*" (p. 7077).

8 Conclusion

Apart from the review of peak-load pricing, this survey also summarized three common regulation methods: Ramsey-pricing regulation, price-cap regulation and rate-of-return regulation. So one of the contributions of this survey is the emphasis on the potential problems of these regulation methods reviewed above. In summary:

Ramsey-pricing has little effect under official monopoly and also is subject to a series of unrealistic assumptions and the availability of information about price elasticity. In other words, the regulatory authority prohibits the potential entrants from setting contestable lower prices to attract the electricity consumers with higher elasticity, even though the objective of the authority is to maximize welfare. Price-cap regulation is affected by the quality ("reliability") of electricity supply. Consumers benefit from the increasing "reliability" of electricity supply whereas the electricity producer may increase their profit in this situation only if they can bypass the incremental cost caused by "reliability". In addition, the electricity producer suffers from underinvestment during the implementation of price-cap regulation. Rate-of-return regulation has a negative impact on innovation, although there is disagreement about the strength of this effect. In extreme cases, a technical regression (opposite to technical progress) may happen under rate-of-

potential market abuses can be mitigated this is an acceptable improvement of regulation and probably the best way today to regulate MTI" (p. 7077).

return regulation. Furthermore, the controversial concept of "fair return" is also an issue under rate-of-return regulation.

In terms of quality issue, "reliability" can be treated as a tradable good in the optimization problem, which leads to a trade-off between the "reliability" market and the electricity product market (Ravid, 1992). From some more traditional points of view, optimal reliability can be achieved if the marginal cost (MC) of the reliability improvement equals the marginal benefit (MB) gained by the customers from the improvement of supply quality (Munasinghe, 1981). Moreover, Sanghvi (1983) offered a cost-benefit approach, which is based on customer shortage costs, to determine the optimal level of supply quality. As another regulation method in the U.S., incentive regulation will have severe negative impacts on the supply quality (Ter-Mairosyan and Kwoka, 2010). This situation could be improved if the incentive regulation regime and production costs can be adjusted according to the supply quality (Giannakis et al., 2005). As different types of incentive regulation, profit-sharing regulation will encourage the investment in quality while revenue-sharing regulation will discourage the investment in quality. Regarding the WTP (Willingness to Pay), there is some kind of agreement among the literature that the WTP has only limited or little effect on the reliability regulation setting (Growitsch, 2010; Weisman, 2002). However, people with various social demographic features have different attitudes towards the improvement of supply quality (Abdullah and Mariel, 2010) and different types of firms will also have different attitudes towards the improvement of supply quality (Morrison and Nalder, 2012).

Regarding welfare, generally, consumers' welfare is lower during the peak period and higher during the off-peak periods due to the higher price charged to consumers during the peak period (Aigner, 1984). Before that, Wenders (1981) was able to show that only a limited portion of consumers can benefit from the TOD pricing schedule. Later on, by studying the relationship between welfare and different types of regulation methods based on Finnish data, Kopsakangas-Savolainen and Svento (2010) pointed out that welfare can be improved if the regulatory authority can make a change from rate-of-return regulation to menu-of-contacts regulation.

Reviewing the relationship between investment and various kinds of technologies, Castillo and Linn (2011) argued that firms with wind technology will have the largest investment incentive. By introducing the concept of congestion pricing and using a static two-part tariff model, Matsukawa (2008) found out that a high access fee will substantially reduce investment. Another balanced two-part tariff system was proposed by Vogelsang (2001) so as to increase investment. However, Hogan (2002) criticized this balanced two-part tariff system by introducing a merchant approach with the concept of FTR. Afterwards, by using price-cap regulation and the concept of FTR, Hogan et al. (2010) demonstrated how to improve the congestion situation caused by the investment shortness. As far as the electricity transmission network in Australia is concerned, those regulation methods based on nodal pricing and the assignment of transmission right contracts did not encourage the investment activities very well unless the transmission firms are price takers. Gans and King (2000) also showed that first-best investment results could be possible by using the concept of ISS (Sappington and Sibly, 1988). However, the AMP, which is used to mitigate the wholesale electricity market, has little effect on the overall investment and the long-run wholesale prices (Kiesling and Wilson, 2007). And due to the restructuring of the wholesale market towards competition, a trade-off between investment risk and market inefficiency occurs because a high level of investment (high level of investment risk) can ensure a competitive wholesale market (Onofri, 2003).

Although there are many papers discussing the issue of regulating the electricity industry, not many papers has successfully analyzed the interaction between the demand and supply side in the electricity market from a game-theoretic perspective. With the increasing complexity of the market and the interaction between the demand and the supply side, using game theory to analyze the electricity market will be a potentially promising area to explore.

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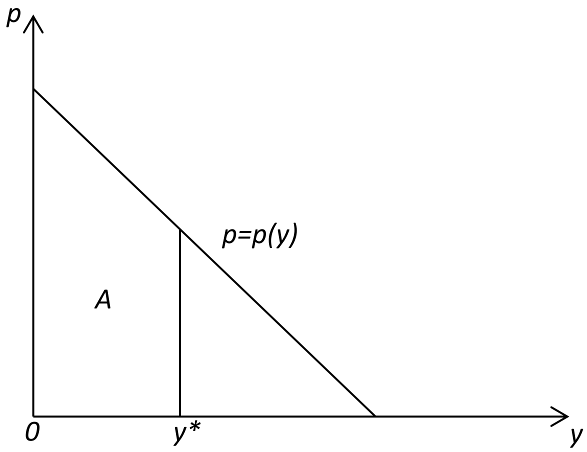
Appendix



$A = \int_{y=0}^{y=y^*} p(y)dy \rightarrow p = \frac{\partial A}{\partial y}$ for all periods.

So $\begin{cases} \frac{\partial A_{non-peak}}{\partial y_{non-peak}} = p_{non-peak} \\ \frac{\partial A_{peak}}{\partial y_{peak}} = p_{peak} \end{cases}$