A Proposal for Inverse Demand Curve Production of Cournot Model for Application to the Electricity Market

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Abstract: At present, the Cournot model is one of the most commonly used theories to analyze the gaming situation in an oligopoly type market. However, several problems exist in the successful application of this model to the electricity market. The representative one is obtaining the inverse demand curve able to be induced from the relationship between market price and demand response. In the Cournot model, each player offers their generation quantity to obtain maximum profit, which is accomplished by reducing their quantity compared with available total capacity. As stated above, to obtain the probable Cournot equilibrium to reflect the real market situation, we have to induce the correct demand function first of all. Usually the correlation between price and demand appears over the long-term through statistical data analysis (for example, regression analysis) or by investigating consumer utility functions of several consumer groups classified as residential, industrial, and commercial. However, the elasticity has a tendency to change continuously according to the total market demand size or the level of market price. Therefore it should be updated as the trading period passes by. In this paper we propose a method for inducing and updating this price elasticity of demand function for more realistic market equilibrium.

Keywords: Cournot model, inverse demand curve, oligopoly market, price elasticity

1. Introduction

At present, the Cournot model is one of the most widely used models to analyze strategic interaction or gaming situation in electricity markets. The major difficulty in modeling a competitive electricity market using the Cournot model is to induce (inverse) demand curve reflecting the relationship between demand and market price. We assume demand response to market price in the Cournot model, therefore each market participant (especially supply side) attempts to determine the output level to maximize its profit. In this situation, generators usually reduce their generation quantity to a certain level; thereby rising market price could increase the profit for those generators. This is a representative example of market power exercising known as capacity withdrawal or physical withholding in an oligopoly type market. The oligopoly model is suitable for the market having several large-scale companies as its market participants. At present, six large generating utilities compete with each other in the Korean electricity market, which can be considered to be an oligopoly market. The Cournot model is preferred to any other model for modeling a competitive electricity market because of its simplicity on mathematical formulation and its similarity with real results. In order to obtain correct results using the Cournot model, first of all, we have to define the most probable demand curve reflecting the demand response in the real electricity market regardless of whether that kind of demand response exists or not. However, it has been observed that the electricity market also has a demand response even though it is somehow weaker than that in any other market. And the demand response in the electricity market has the tendency to be observed more on long term than on short term. In previous studies demand curve is usually induced from direct investigation to many customers for collecting their willingness-to-pay functions or from statistical methods like regression analysis based on historical data. But demand curve can change continuously due to many factors such as weather, price and demand level, periodic replacement of electric equipment and the increase of load quantity participating in demand response, etc. Therefore we need continuous or periodic renewal of the demand curve to reflect these kinds of changing environments. In this paper we propose the renewal method of price elasticity periodically or for every trading period.

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2. Main Body

Game theory is a useful model for modeling strategic interaction of the decision process in an electricity market [1, 2]. However, game theory also has several weak points. The first one is that game theoretic approach requires many strict assumptions that we just accept naturally without any doubt. The second one is that there might be additional equilibrium in some games like those in the Nash bargaining game. The third one is that the equilibrium in game theory might be unrealistic because we assume that the players build their bidding strategy only based on the objective function to maximize their profit. For example, in the two player Cournot model (duopoly model), the two firms could maximize their profit by reducing their generation quantity to the half level of the one in a monopoly situation, which is the Cournot equilibrium. However, this kind of Cournot equilibrium is not long-lasting, so two firms get to have the incentive to change their bidding strategy for the purpose of deceiving the other competitor. For this kind of reason, the Cournot model might be not appropriate to the repetitive bidding game involved in the electricity market, though the Cournot model is currently a widely used model to analyze the strategic behaviors of electric power market players. However, there have been no reliable models to replace the Cournot model in the case of the oligopoly electricity market, and it is also true that the Cournot model has been the only verified model among the many market models for a long time. We can't help using the Cournot model until a new model is developed. When we analyze the market using the Cournot model, it is the most important thing to induce the demand function of that market because the Cournot model assumes the demand responding to the changing market price. Conclusively we adopt the Cournot model for the analysis of the electricity market, and propose the method to induce the demand function of the electricity market.

2.1 Cournot Model and Electricity Market

Electricity as a commercial commodity has some problems. The representative problem in applying the Cournot model to the electricity market is that electricity cannot be stored, so supply and demand must be balanced in real time or at every trading period.

(1) Cournot game is the model for static game situation and doesn't consider time-variable components.
(2) Cournot game assumes the demand function responding to price change at every node, which is unrealistic because electricity demand is non-elastic to the market price change in the real market situation.
(3) Cournot game has a difficulty in reflecting many physical constraints like the capacity of the generator and transmission line, as well as energy constraints. In addition, it is also difficult to reflect fringe suppliers and generators in the market.
(4) Generally the problem of generator bidding is modeled as linear programming, but the Cournot model is modeled as quadratic programming. This kind of modeling issue influences the method to obtain the solution or improve the speed of solving the problem.

The clauses of (1) and (2) connote that it might be difficult to apply the Cournot model to the electricity market if there is a probable demand function of that market. Because the demand function in the electricity market is almost non-elastic during one trading period or short duration, demand function generally approaches a vertical line. Most portions of demand bids at the VoLL level, and there exists only a slight portion of load that can be dispatched. Therefore, the finally formed demand function has very low price elasticity.

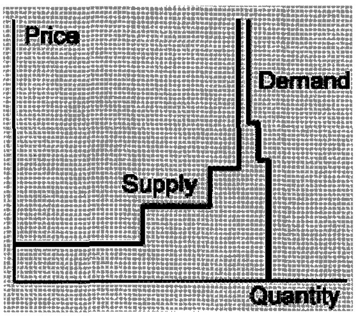

Fig. 1 Demand curve in electricity market

This kind of demand pattern is the step function curve, not the linear function having a constant slope. However, the demand curve in the longer term has a tendency to form a linear slope like in Fig. 2.

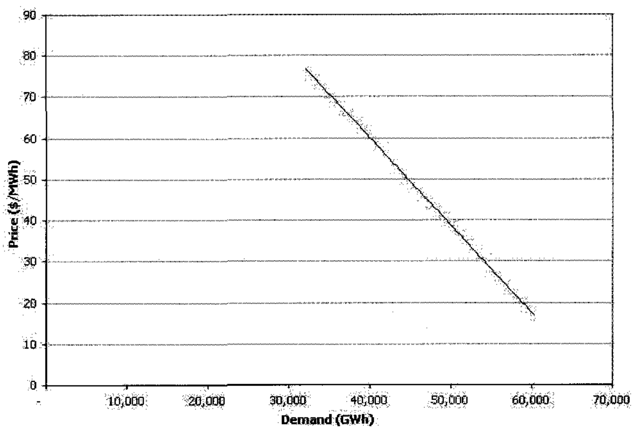

Fig. 2 Inverse demand function

The demand function representing the relationship between supply amount and price level determines the market clearing price dependent on total generation output supplied by all generators participating in the market. This demand function is also called inverse demand function in the perspective of considering the demand (or supply amount) as the variable on the x-axis. Therefore inverse demand function indicates the same function as demand function does. Fig. 2 indicates the example of inverse demand function.

Inverse demand function provides the information of total revenue (P×Q) of market suppliers when suppliers determine their supply amount (Q). Inverse demand function gives us the information of the market clearing price and the suppliers' total revenue based on the supply quantity of all suppliers. Because the supply quantity of suppliers determines the total revenue of all suppliers, suppliers need to forecast the demand function of the market for decision making about profit maximization.

2.2 Inverse Demand Function Estimation in Electricity Market

2.2.1 Case of the NEM market in Australia

In the Australian electricity market, demand elasticity is defined as derivative of market price (P) with respect to generation quantity (Q), which is formulated as . Demand elasticity could be defined for the short-term and the long-term. In most cases of empirical research, price elasticity in the electricity market is almost inelastic with respect to generation quantity for the short-term and even the long-term period. That is the result based on the observation of real market data, and the interaction between price and quantity is usually marginal. In 1999, NIEIR committed to research concerning long-term price elasticity. Based on the research of NIEIR, many countries beside Australia determined to enter into research to estimate price elasticity in the electricity market. The elasticity values proposed by NIEIR are as follows.

Residential Load	-0.25
Commercial Load	-0.35
Industrial Load	-0.38

The research committed by NIEIR shows diverse results dependent on each state. The reasons for these differences are analyzed as follows.

- Different composition rates of energy sources and various different capacity factors on the numerous facilities of each state
- Availability of other energy sources substitute for electrical energy and the price level of the substitute energy source
- Different structures or regulations of electricity market, especially at the final consumer level

The long-term demand elasticity of each state shows as follows.

New South Wales	-0.37
Victoria	-0.38
Queensland	-0.29
South Australia	-0.32
NEM	-0.35

These elasticities are calculated based on the data from 1980 to 1995, in which the electricity market price shows an overall increase. In addition, the demand response curve didn't indicate symmetry in the demand response to price change, which means the elasticity during price increase and decrease were different. The Australian market shows the value between -0.2 and -0.5 whose average is about -0.35. However this value is also changeable dependent on the period of considering market data. For example, price elasticity with respect to demand change could be increased when the next set of conditions are satisfied.

- More than 10~20% of medium scale customers affected by price increase
- More than 5~10% of large scale customers affected by price increase
- More than 20~30% of small scale customers affected by price increase

It is possible for the price elasticity to be increased up to 130~140% of the average value, 0.35. For example, if price goes up by 30~40% when the price elasticity of residential load is -0.25, the price elasticity could be increased to 0.4.

2.2.2 Domestic and international researches

Inverse demand function in the Cournot model is generally defined as the linear function form of $P=C-eQ$ as in Fig. 2. In this case the important thing is to determine C and e. There are several reasons why we introduce linear function as demand function in the Cournot model. Most of all we use linear programming solver for computation of large scale problems. Therefore, we have to formulate the model as a linear form. Secondly linear formulation is helpful for reducing computation speed especially in the case of problems faced by the electricity market in which we have to obtain the optimal equilibrium at every trading period because it is possible for each market participant to build its new strategy period by period.

If there are demand bids in the electricity market it is possible to estimate the demand function from historical data. However, it is difficult to make demand function using this method in the Korean electricity market because there exists no demand bid in the CBP (Cost Based Pool) market. It is also difficult to induce demand function using statistics because the pricing scheme in the Korean electricity market has two different prices, one for industrial load and one for residential load. In addition the averaged price is charged to customers, so the electricity price increases as the load does on the demand function induced from the Korean market.

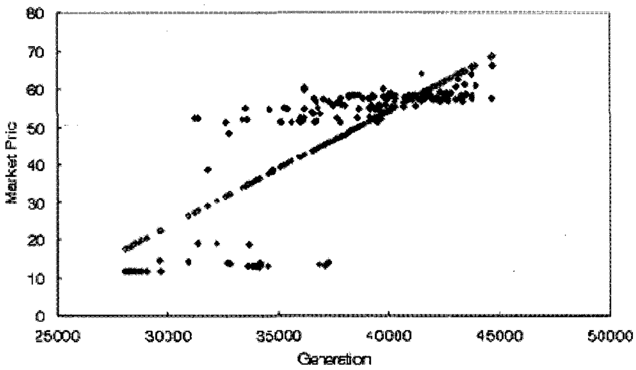

Fig. 3 Correlation between market demand and market price

This indicates that customers don't respond to electricity price changes, which means there is no price elasticity in the market. Nam-il Kim of KEEI induced inverse demand function in the electricity market using the method as follows. If we assume that the elasticity value is given, we can determine that the point P-axis and demand curve intersect each other on the P-axis [5] like in Fig. 4. In the report by Nam-il Kim, inverse demand function is derived by substituting 74.56[won/kWh] and 32,509[MW] for P and Q in the demand curve equation, which are the value of electricity price and demand quantity for the year 2000 respectively.

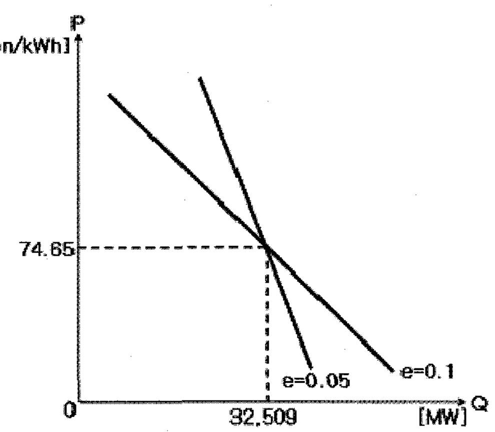

Fig. 4 Demand curve production using price elasticity and equilibrium point

Inverse demand function could be changed at every trading period as the market price, demand quantity, and price elasticity change continuously. Thereby inverse demand function is derived for each trading period like each hour from 8760 hours per year.

2.2.3 Consideration for estimating inverse demand function

The most probable and common method for inducing demand function in general markets (including all different kinds of commodities beside electricity) is regression analysis based on historical data, as in Fig. 3. However the inverse demand curve of the Cournot model in the CBP market demonstrates a proportional relationship between quantity and price because market demand doesn't respond to market price in the current CBP market. This relationship doesn't satisfy the basic requirement of demand curve, which proves the current electricity pricing scheme doesn't reflect the price elasticity of customers.

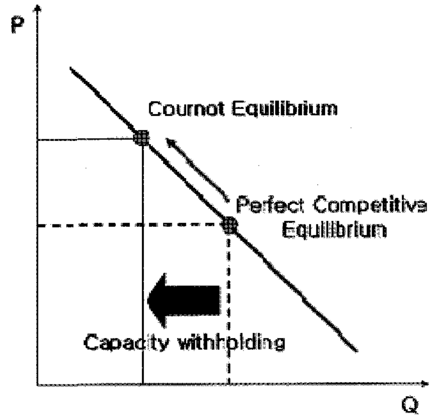

Fig. 5 Cournot Equilibrium and Perfect Competitive Equilibrium

It is possible for (P,Q)=(74.65,32,509) used in section *2)* to be replaced with perfect competitive equilibrium in the CBP or TWBP market. Cournot equilibrium is located on the same demand curve with perfect competitive equilibrium in the aspects that Cournot equilibrium is the moved equilibrium from perfect competitive equilibrium by interaction between price and generation quantity. The market price increase results from physical or economic withholding of generation capacity by generators participating in the electricity market. If there is a demand curve in the market, the demand curve must be unique at the spot time, and two equilibrium points being located on one demand curve is also a natural consequence. In a perfect competitive electricity market the competition between generators is so fierce that all generators should offer their generation quantity at the level of their marginal cost and have no room for gaming like physical or economic withholding, which is a similar situation in the CBP market. However, in the oligopoly market each generator has the incentive to raise market price by capacity withdrawing or to offer price manipulation, which results in higher market price than in the perfect competitive market. Fig. 6 shows the price comparison result between the perfect competetion model, the Cournot model, and the Bertrand model.

This result is produced by PLEXOS, the commercial simulator for the electricity market developed by Drayton Analytics, Australia, and the data for the simulation is the data of the Australian electricity market. Fig. 6 has three different price duration curves, and we can recognize that the price duration curve of the Cournot model is always above that of the perfect competition model during one year. The perfect competition equilibrium was derived through PLEOXS by clicking the "Benefit Maximization" option. In perfect competition, each generator's offer curve approaches the marginal cost curve and merit order for dispatch is determined by that marginal cost curve. In this condition each generator determines its generation quantity for benefit maximization [6, 7].

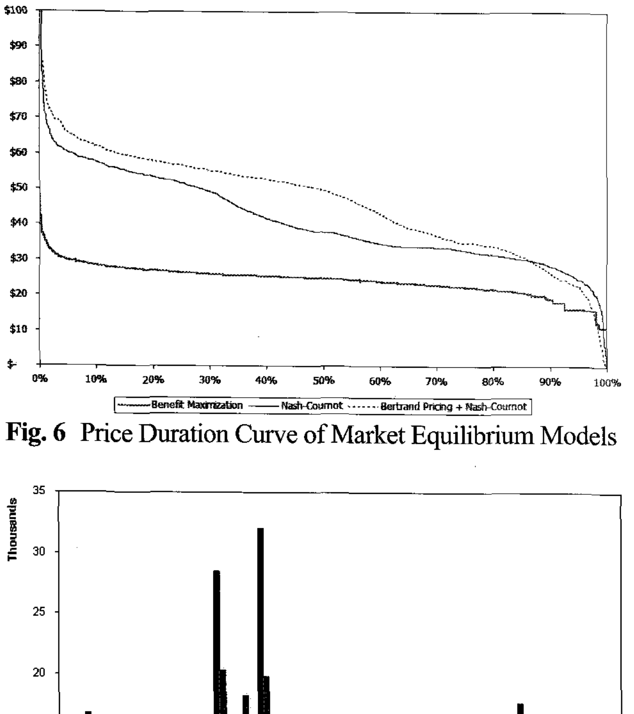

Fig. 6 Price Duration Curve of Market Equilibrium Models

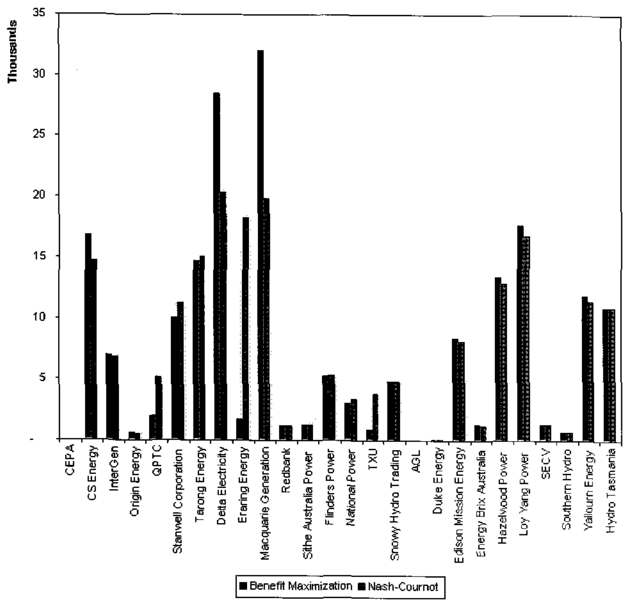

Fig. 7 Generation Comparison of Perfect Competition and Cournot Model

Beside the perfect competition model, PLEXOS has two more options for determining market equilibrium like the Cournot-Nash and Bertrand models. The inverse demand curve of the Cournot model in PLEXOS requires the input values of market constant and price elasticity by simulator user. Despite the fact that PLEXOS is one of the representative commercial simulators, it seems as if there is still a lack of some functions for modeling the gaming situation. Fig. 7 is the result of a comparison between perfect competition and Cournot-Nash equilibrium, which shows the generation quantity in the Cournot model to be less than that in the perfect competition model.

If we apply the Cournot model to the analysis of the gaming situation in the electricity market, price elasticity should be calculated first. One representative method having been used is to derive the price elasticity from the database accumulated over a long period of time, like that being used in Australia, which is explained in Section 2.3.1. In case there is no demand side bid and strict price regulation applied as in the case of the Korean market, we cannot estimate price elasticity from market price and demand variation. Instead we cannot help investigating the utility function of each customer one by one, but this kind of job is too vast to perform on every customer therefore, a sampling process should be done. However, this type of process inevitably accompanies inaccuracy and uncertainty in the procedure of investigating demand utility or response functions. Even if we assume that this kind of investigation of demand function is executed over a long term basis, the likeness of customer changes occurs continuously on spot time and the devices and facilities of consuming electricity are also replaced periodically or randomly. And the number of devices and facilities are too many to model all of them. So the demand function derived at a certain spot time does not guarantee that it is the general demand function able to be applied to all time periods. In addition, the Cournot model requires a new demand function at every trading period to reflect demand response at that time. A similar supply curve with a similar demand function produces the same equilibrium at every trading period. Therefore, to complement the weak points of the previous method for producing the demand function, this paper proposes the structural method for deriving the inverse demand function. The basic concept is that inverse demand function at t period is induced from perfect competition equilibrium and becomes cleared equilibrium at t-1 period. The reason why the information of the t-1 period for deriving the demand function of t period is that t-1 is the closest period of t period and thereby the circumstances are more similar to t period than to any other period. As seen in Fig. 5, perfect competition equilibrium and Cournot equilibrium rely on the same demand function and the slope of the line intercepting two points is the value of price elasticity. As the price elasticity and demand function change continuously, a revision process is required. Once the slope and price elasticity is determined, it is possible for P-axis intercept to be solved by substituting perfect competition equilibrium points for (Q,P) in equation. Through this process the demand function can be updated periodically. The demand quantity used for computing perfect competition equilibrium at t-period is the value forecasted demand by statistics methods. Market price in a perfect competitive model is determined on the condition of this forecasted demand and marginal cost curves generators participating in the market.

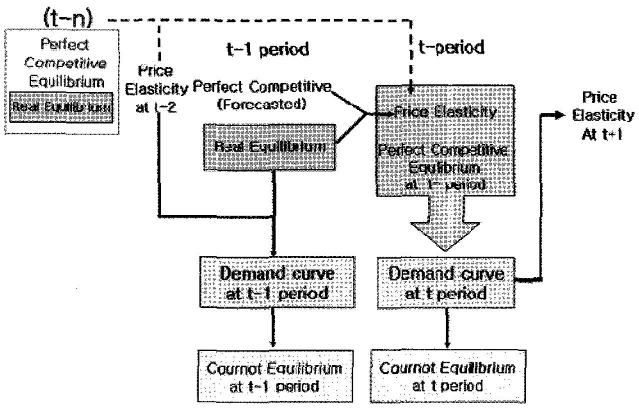

Fig. 8 Algorithm for Estimating Price Elasticity

The algorithm for producing a new demand curve for each trading period is as follows. As seen in Fig. 6, Cournot-Nash and perfect competition equilibrium points are obtained through the simulation in the first stage. In the second stage, one linear demand function is derived by connecting two equilibriums of perfect competition and the Cournot model. To compute price elasticity of t period we can use perfect competition equilibrium and Cournot equilibrium of t-1 period, or just take the price elasticity of t-1 period. When we are lacking information pertaining to market outcomes, the most recent market data like the equilibriums of t-2, t-3, or t-4 can be used for updating the price elasticity.

2.2.4 Case Study

As seen in Fig. 9, we assume a simple electricity market composed of two generators and one demand in the market. The transmission network is not considered and perfect competition and Cournot-Nash equilibrium points are solved under non-constrained dispatch schedules. In this example only two generators are participating in the market, but we assume there are more potential competitive generators. Thereby it is possible for the market to be perfectly competitive.

Utility A has the capacity of 500[MW] and utility B has the capacity of 450[MW]. The cost functions of the two utilities are shown in (3) and (4). The generator of utility A is a coal-fired generator, and the one of utility B is a LNG generator. The fuel cost of the coal-fired generator is fixed as 6.192 [won/Gcal], and fuel cost of the LNG generator is 26.646 [won/Gcal]. Heat rate curves of A and B generators are (1) and (2), respectively. In the CBP market, base-load generator and peak-load generator are compensated with different pricing schemes. The base-load generator is compensated with the BLMP (base load marginal price), which has a price cap currently set as 18.9 [won/kWh]. Base-load generators include nuclear and coal-fired generators, while the other generators are compensated with the SMP (system marginal price). But in this example we assume there is only one market price for simplification.

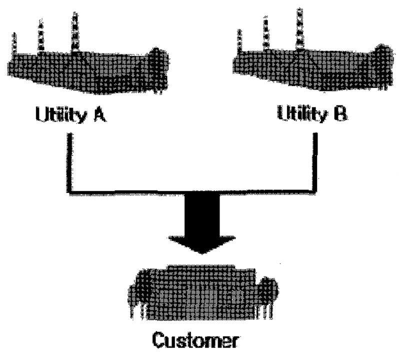

Fig. 9 Electricity Market for Case Study

$$F_A(P_A) = 135.13 + 1.85P_A + 0.000369P_A^2 \quad (1)$$

$$F_B(P_B) = 135.13 + 1.85P_B + 0.000369P_B^2 \quad (2)$$

(1) and (2) are heat rate functions of the two generators. (3) and (4) are generation cost functions obtained by multiplying (1) and (2) by fuel cost. (The unit of cost is [won]).

$$C_A(P_A) = 836.72 + 11.46P_A + 0.002285P_A^2 \quad (3)$$

$$C_B(P_B) = 662.15 + 14.12P_B + 0.049855P_B^2 \quad (4)$$

(5) & (6) are marginal cost functions that are computed by differentiating (3) and (4). The unit of marginal cost is [won/kWh].

$$p_A(P_A) = 11.46 + 0.004570P_A \quad (5)$$

$$p_B(P_B) = 14.12 + 0.099710P_B \quad (6)$$

According to (5) and (6) Generator A has a lower marginal cost than Generator B, which is also shown in Fig.10. In the cost structure of base-load and peak-load generators, peak-load has a lower marginal cost than the base-load generator when generation quantity is small. As the generation increases, the base-load plant has greater economical efficiency than the peak-load plant. But the marginal cost functions are illustrated as in Fig. 10, which is the randomly chosen result among the many cost functions of generators in the database.

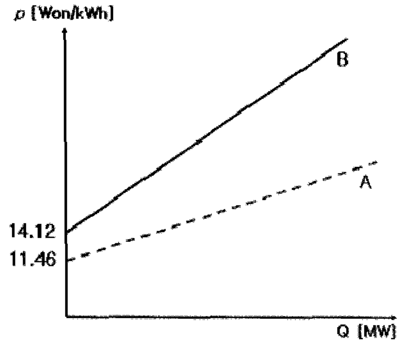

Fig. 10 Marginal Cost Curves of two Generators

Table 1 is the result of forecasted demand data for 5 trading periods.

Table 1 Forecasted Data [MW]

	1h	2h	3h	4h	5h
Demand	400	550	780	890	650

The perfect competitive equilibriums are calculated as indicated in Table 2 when forecasted demand is assumed like in Table 1.

Table 2 Only Variable Cost Compensated

	Generation [MW]	Marginal Cost [Won/kWh]	Generation Cost [Thousand Won]
1h	(400,0)	(13.29, 0)	(5786, 0)
2h	(500,50)	(13.74, 19.11)	(7138,1939)
3h	(500,280)	(13.74, 42.04)	(7138,8972)
4h	(500,390)	(13.74, 53.01)	(7138,14199)
5h	(500,150)	(13.74, 29.08)	(7138,4349)
	Market Price [Won/kWh]	**Revenue [Thousand Won]**	**Net Profit [Thousand Won]**
1h	13.29	(5316, 0)	(-470, 0)
2h	19.11	(9555, 956)	(2417, -983)
3h	42.04	(21020, 11771)	(13882, 2799)
4h	53.01	(26505, 20674)	(19367, 6475)
5h	29.08	(14540, 4362)	(7402, 13)

The profit functions of generators A and B are (7) and (8) respectively. Because this example is using practical data provided by the generating unit in the KPX administered market, the net profit of the peak-load LNG generator is usually a (-) value when the market price is high enough. To reconciliate (-) net profit we include capacity payment to the revenue sources of the utility, because if the payoff is a minus value, it gives generators no incentive to participate in the market. This kind of problem is caused by the simplification of example in that two utilities have only one base-load plant and one peak-load plant respectively. The way to pay off available capacity could have various options like the timely differentiation according to reserve margin. In this paper we assume the timely constant capacity payment as only proportional to capacity quantity, and the amount of capacity payment is calculated by multiplying available capacity by capacity payment per unit like [Won/kW]. Base-load generator A is paid off 21.49 [Won/kW] and the peak-load generator is also paid off 7.17 [Won/kWh]. The capacity revenue of utility A is 21.49×500=10,745 [Thousand Won], and the one of utility B is 7.17×450=3,227 [Thousand Won]. The total revenue of the two utilities is calculated by adding these values to the net profit values on Table 2.

$$PF_A(P_A) = p_A P_A - C_A(P_A) + CP_A \quad (7)$$

$$PF_B(P_B) = p_B P_B - C_B(P_B) + CP_B \quad (8)$$

Table 3 Variable Cost+Capacity Payment Compensated

	Generation [MW]	Marginal Cost [Won/kWh]	Generation Cost [Thousand Won]
1h	(400,0)	(13.29, 0)	(5786, 0)
2h	(500,50)	(13.74, 19.11)	(7138,1939)
3h	(500,280)	(13.74, 42.04)	(7138,8972)
4h	(500,390)	(13.74, 53.01)	(7138,14199)
5h	(500,150)	(13.74, 29.08)	(7138,4349)
	Market Price [Won/kWh]	**Revenue [Thousand Won]**	**Net Profit [Thousand Won]**
1h	13.29	(16061, 3227)	(10275, 3227)
2h	19.11	(20300, 4183)	(13162, 5471)
3h	42.04	(31765, 14998)	(24627, 6026)
4h	53.01	(37250, 23901)	(30112, 9702)
5h	29.08	(25285, 7589)	(18147, 3240)

The next step is to compute the Cournot equilibriums of 5 trading periods as in Table 3. Unlike all values of perfect competition, equilibriums for 5 trading periods are computed simultaneously through one process, and Cournot equilibrium is computed individually after price elasticity is determined in previous trading period.

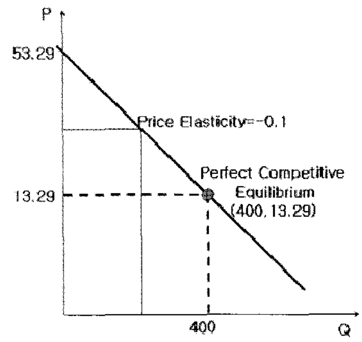

Fig. 11 Inverse Demand Curve

The problem in this process is the price elasticity of inverse demand function in the first trading period. The most probable method is to use the value measured or calculated in the real market, but we substitute -0.1 for price elasticity. We assumed the inverse demand curve in the first trading period as (9). Solving (9) and (Q,P) = (400,13.29), the market constant (P-axis intercept) is calculated as 53.29, and inverse demand function becomes P=-0.1Q+53.29 at the first trading period.

Once the inverse demand function is fixed, it is possible for the Cournot model to be formulated as (9), (10) and (11). Indicated here is the equilibrium market price, and it signifies the generation quantity supplied to the market or market demand formulated as $Q=P_A+P_B$

$$P = -0.1Q + 53.29 \tag{9}$$

$$\frac{dPF_A}{dP_A} = \frac{dP}{dP_A}(P_A + P_B) + P^* - \frac{dC_A}{dP_A} = 0 \tag{10}$$

$$\frac{dPF_B}{dP_B} = \frac{dP}{dP_B}(P_A + P_B) + P^* - \frac{dC_B}{dP_B} = 0 \tag{11}$$

Solving simultaneous equations, (9), (10), and (11), Cournot equilibrium of the first trading period is $(Q^*,P^*)=(355,17.80)$. If the real equilibrium is $(Q_{real},P_{real})=(375,15.45)$ in the cleared market at that period, the new price elasticity to apply to the second trading period is determined by deriving a linear function intercepting two points, which are perfect competition equilibrium (400,13.11) and $(Q_{real},P_{real}) = (375,15.45)$

$$\frac{15.45 - 13.29}{375 - 400} = -0.0864$$

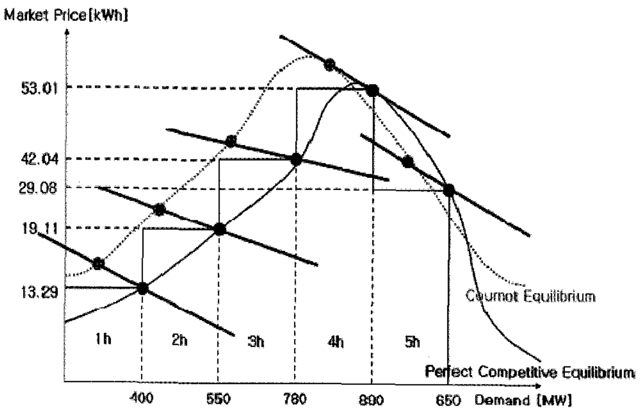

Fig. 12 Continuous Production of Demand Function for Cournot Model

Cournot equilibrium of 2nd trading period is calculated in a similar manner to the 1st trading period. As this process repeats, price elasticity of demand function can be updated by new market data. To reflect changing market conditions and customer activities this update process should be done periodically. However this update doesn't need to be carried out at every trading period. It may be done hourly or on a daily basis, which is dependent on the situation. As price elasticity is updated, demand function for the trading period is produced.

3. Conclusion

Conventionally, price elasticity in the Cournot model is derived from the correlation data between demand and price accumulated in the market. When there is demand side bidding, price elasticity is induced from the historical data of demand bids. In the case in which there is no demand bidding price, elasticity is estimated by investigating the customer's utility or willingness-to-pay function. This kind of method requires a significant amount of effort and time, and its accuracy and propriety are not guaranteed. Moreover the demand function produced at a certain moment does not reflect the universal demand response over the entire time period. In this aspect this paper assumes the outcomes of the market reflect the real market situation at best, and proposes the method for deriving price elasticity based on those market outcomes. The method in this paper shows the algorithm for continuous price elasticity updates for Cournot equilibrium derivation reflecting market outcomes and simulation results. This type of algorithm could give market participants lots of meanings in many aspects like building bidding strategies and understanding market situation. More concretely, comparing perfect competition equilibrium and Cournot equilibrium could be used as a certain standard for the market operator to monitor the competition level of the market. In addition, market participants including both generators and customers could use the information to build their bidding or transaction strategies. In future, further studies are going to be carried out to calculate more accurate price elasticity and determine the method for applying this system to market monitoring schemes. In addition the application of the Cournot model to the electricity market itself should be verified for its reasonability. In spite of the Cournot model's generality on the analysis of a competitive electricity market, it has several weak points not suitable to the electricity market. The representative one might be that the electricity market has little short-term demand response as stated in the main body while the current Cournot model has to assume demand curve responding to price change. So we are trying to develop a new method as well as improve the current Cournot model in future study.

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