The Modeling of Dynamic Optimal Bidding in Electricity Market of Iran

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Abstract:

The main goal of this paper is to modeling of producers' strategic suggestions for each electricity manufacturer in an oligopolistic structure. According to the proposed structure of the electricity market modeling; this paper uses a dynamic model based on cournot equilibrium. Due to the large volume of required information, the implementation of the model is limited to a regional electricity market and the model is be implemented in such as a way to compare the results for low, medium and peak load consumption. Market actors in the research are active power plants in Isfahan electricity region and MATLAB software has been used for solving the model. The empirical results of model with the actual behavior of actors in selected hours have been compared and finally by comparing the actual behavior of actors with the results of the simulation model, the analysis and results are presented. Accordingly it is clear that the producers did not use cournot strategy. Although the proposed strategy can be more profitable for them.

JEL Classification: D43, L13, L95

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1. Introduction

Power industry as a fundamental industry in the past two decades has been undergoing fundamental changes, these changes are known as restructuring and deregulation. Moving from a centralized structure to a competitive and deregulated system in electricity industry requires the establishment of a competitive electricity market as an essential element of buying and selling system.

Since the early seventies, restructuring was provided and electricity market was born in 1382 in Iran. The electricity market and the profits depending on their performance and their competitors in the market were implemented in real system in 1385.

The deregulation of the electricity market in recent years has opened the way to do research in this area. One of the topics that are frequently considered in various countries is about bidding modeling in the market. The strategy of actors to provide the quantity and price of the electricity market determines the ultimate benefit and the benefits from participating in the market. Every power plant should provide a bidding price and quantity to play in the market. For this purpose it needs a strategy. The manufacturer expects that the strategy be in a way that maximizes the benefit to the plant. There are various strategies for this matter that we can mention cournot, SFE and Bertrand strategies.

In this study the Cournot model has been used with dynamic modeling approach and we try to compare the results of simulating Cournot balance with market actors in the regional strategy.

From the producer point of view the presented modeling in this study is exactly manufacturer's bidding strategy with respect to cost of production, the quantity demanded in the market in every market executive and the behavior of other actors. In other words, expected simulation in the study provides plants optimizing production in an electricity market and from the social perspective of the model made it possible to analyze the behavior of market actors as well as market stability in Iranian power market.

In this modeling optimal bidding, dynamic model was used. In other words, the feedback implementation of market-based in previous market is a base for decision making in similar period. What distinguishes this study from previous studies is considered from two aspects. The first section is article modeling and the second part is model implementation with real data.

The rest of paper has been organized as follows: after the introduction in the first part, second part about theoretical bases and third part on the research literature are given. The forth section is dealt with model explanations and the fifth one with data and experimental results. Summary and suggestions have been provided in the last section.

2. Literature Review

2.1- Electricity Market and Reconstructing

Electricity market is a system to buy and sell power in a way of demand and supply for determining the power price. Unlike the old model that production management- distribution and transferring are all performing as a unit, the mentioned systems work independently. In this way power market acts like an intermediate between the systems (Staft 2002).

Restructuring means changing the structure and organization to increase the system Efficiency and competition. Restructuring in power industry deals with the decomposition of activities that are vertically mixed. In addition it mentions horizontal concentration and tries to be separated in the new structure of activities as much as possible. This process challenges all technical and economic considerations in producing- transferring and distributing electrical energy in traditional systems and provides new concepts in producing- transferring-distributing and taking advantages of power systems.

2.2- Iranian Power Market Characteristics

As mentioned before it's more than a decade from making power market in Iran. Iranian power market is a model of buying agency which presence of all buyers and sellers is a necessity; it means that 100 percent of deals are done by pool. Local power companies are the main parts of this market and distribution companies are known as Iranian wholesale buyers.

From the time and implementation points of view Iranian power market is the next day market and a day before winners and losers of the market and the order of producing units are identified. Payment to the sellers is based on pay as bid method and receiving mechanism from buyers is the uniform method.

2.3- Game Theory, Nash Equilibrium

Game theory has been known as an important tool for analyzing the behavior of firms. The most important feature used in game theory is to assess the impact of decisions on the results and analysis of the interaction between the actors. Any changes in the value and price of oligopoly competition will affect sales and profits so they react and change their prices and quantities. Each firm's decision depends on the reaction of competitors and competitor reaction depends on the firm's decision and action. Accordingly in the firm optimization process, we will face the reaction of firms and competition. So derivation gets hard from the objective function. (Shakeri, 1385, p 234).

To partially solve this problem, economists often assume that each firm with certain assumptions about the behavior and reactions of competitors does the best behavior. The firm has to do the price decisions based on the competitors' behavior and formulate it. This equilibrium behavior is settled in the oligopolistic structure of Nash equilibrium. Nash equilibrium refers to the situation in which a firm with an approval state of its opponents' behavior does the best (The same source).

2.3.1-Cournot Solutions

Cournot solution which is used in this article is an example of Nash equilibrium. According to the theory each firm that maximizes its profits assumed that with changing their behavior (change in price or quantity) the competitor's won't change its product. This means that in situations of price changing - the equilibrium amount- the level of competitor's products are considered as given and exogenous (The same source,235).

3. Empirical Studies

Ruiz and et al in 2008 in an article entitled "Some analytical results pertaining to Cournot models for short-term electricity markets" provides some theoretical results pertaining to the Cournot model applied to short-term electricity markets. Price, quantities and profits are first obtained, and then results related to sensitivities and limit values are derived and discussed. The cases of both several identical Cournot producers and one dominant Cournot producer are analyzed. A case example illustrates the results obtained.

Kamalinejad and et al in 2010 in an article entitled "Cournot games with linear regression expectations in oligopolistic markets" a Cournot game in an oligopolistic market with incomplete information is considered. The market consists of some producers that compete for getting higher payoffs. For optimal decision making, each player needs to estimate its rivals' behaviors.

This estimation is carried out using linear regression and recursive weighted least-squares method. As the information of each player about its rival's increases during the game, its estimation of their reaction functions becomes more accurate. Here, it is shown that by choosing appropriate regressors for estimating the strategies of other players at each time-step of the market and using them for making the next step decision, the game will converge to its Nash equilibrium point. The simulation results for an oligopolistic market show the effectiveness of the proposed method.

Kebriaei and Rahimi in 2010 in an article entitled "Decision making in dynamic stochastic Cournot games the Cournot competition is modeled as a stochastic dynamic game. In the proposed model, a stochastic market price function and stochastic dynamic decision functions of the rivals are considered. Since the optimal decision of a player needs the estimation of the unknown parameters of the market and rivals' decisions, a combined estimation–optimization algorithm for decision making is proposed. The history of the rivals' output quantities (supplies) and the market clearing price (MCP) are the only available information to the players. The convergence of the algorithm (for both estimation and decision making processes) is discussed. In addition, the stability conditions of the equilibrium points are analyzed using the converse Lyapunov theorem. Through the case studies, which are performed based on the California Independent System Operator (CA-ISO) historical public data; the theoretical results and the applicability of the proposed method are verified. Moreover, a comparative study among the agents using the proposed method, naïve expectation and adaptive expectation in the market is performed to show the effectiveness and applicability of the proposed method."

4. Empirical Model and Estimation Method

The research is on the basis of theoretical - descriptive research and library studying method which was developed on English and Farsi books. Later Cournot will be discussed in details in this chapter.

4.1- How to Play Cournot

1. The actors of this game are suppliers.
2. The actor movement in the game is about $x_i$produced quantity choosing.
3. The goal of each actor is to maximize the profit from the sale to the market-clearing price and the cost of production.

Suppliers choose their production quantities. The price is determined according to customer demand and aggregate supply curve. Each of the actors with regard to the assumption that other actors still keep their supply, make their profit maximized and it is assumed that all actors have the same information that the knowledge of the demand and production cost include all the other actors.

Here, based on the above criteria- production quantities for each plant are obtained separately for a base day. So each plant with a fixed amount of competitors' product tries to gain maximum benefit.

But noteworthy point is Cournot solution Dynamism. Since consumer behavior is similar on weekdays at each time so Instead of running Cournot , adjustment coefficient can be used and the mount of the production can be obtained by the amount of the production of the day ahead. After the adjustment, if the obtained amount is higher than the plant capacity- extra amount will be assigned to other plants. The figure below concisely illustrates the implementation process. The following picture briefly shows the process.

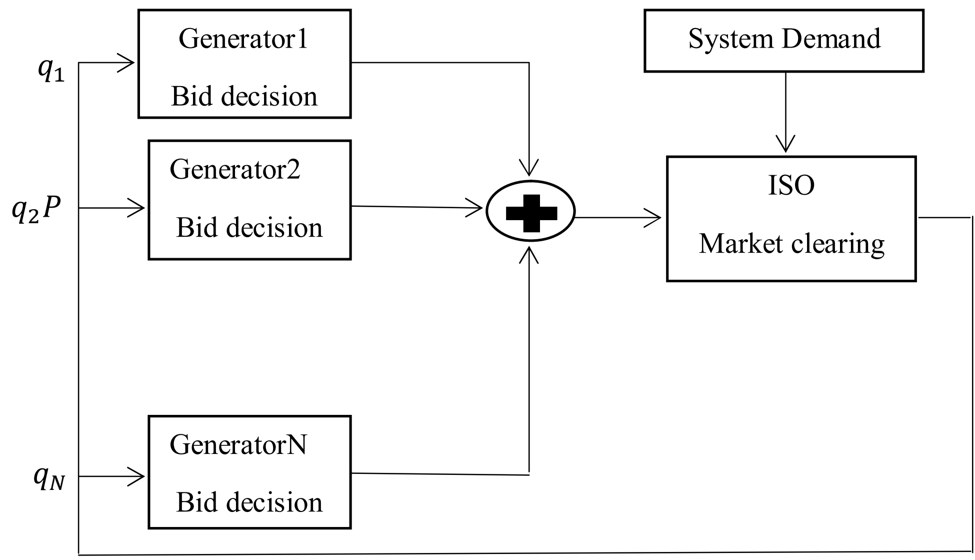

Figure1.System Dynamics Model of the Electricity Market
Source: (Giabardo and Zugno, 2008)

Each generator gives its suggested amount for every hour to independent system operator and the system operator determines prices according to the demanded functions and suggested amount and declares it before the next bidding and this price affects the suggested amount of manufacturing companies.

Now we turn to the description of the model.

In this model, variables are bid quantity (by each plant). For generator i, the amount of bid is indicated with x_i.

In order to identify the actors (plants) functions, the cost function must be estimated. Based on existing literature which is discussed in the next section, the cost of each plant is considered to be a quadratic equation.

Cost function for generator is at time t:

$$C_i\big(x_i(t)\big) = a_i(t) + b_i(t)x_i(t) + \frac{1}{2}c_i(t)x_i^2(t), i = 1,2,\dots,n \quad (1)$$

Equation (1) is a good estimation of actual production cost if the generator is a thermal power plant. In this article thermal plants are considered.

In this model we consider the total demand. The demand side is described as the inverse demand functions.

$$p(t) = e(t) - f(t)D(t) \quad (2)$$

Where $D(t)$is total demand, $p(t)$ is the priceand$f(t)$, $e(t) > 0$ which is a positive decreasing function. Above estimation is simply obtained from the demand function.

Due to this property that electrical energy is not saving at any given time the amount of production and consumption must be equal and the equality of supply and demand is as follow:

$$D(t) = \sum_{i=1}^{n} x_i\,(t)\,, \forall t \quad (3)$$

According to the stated elements the profit of each plant which is obtained by subduction of the cost of revenue is as follow:

$$\pi_i\,(t) = p(t)x_i(t) - C_i\,\big(x_i(t)\big) \quad (4)$$

To find the maximum amount of earnings we derived it from the Profit function and define the zero of derivative function:

$$\frac{d\pi_i(t)}{dx_i(t)} = 0 \quad (5)$$

This process is performed for one round and adjustment factor is used for next round.

It is really hard for a producer to adjust the amount of production that satisfies the above conditions, since it would require changing the energy level in high speed. A realistic strategy for each production unit is based on the adjusted values of the bidding period.

A good model for this is the adjustment for the profit function derived as follow.

$$x_i(t+1) - x_i(t) = k_i(t+1)\left.\frac{d\pi_i(t+1)}{dx_i(t+1)}\right|_{x_i(t+1)=x_i(t)}, \quad k_i(t+1) > 0 \quad (6)$$

Where $x_i(t)$ the amount of time is specified in the current day and $x_i(t+1)$ is the quantity at the same time which is offered the next day. This idea arises from the fact that the consumption pattern of people is the same in the same hour of weekdays.

In this study, the expressed model for the hours of 1, 14 and 22 which respectively represent low, medium and peak load is implemented. The data of workday patterns were used for estimation because the consumption patterns are different in workdays and holidays.

According to this model the behavior of generator, is the adjusted amount of production to increase profit in reality the bid quantity $x_i(t+1)$ increases with respect to $x_i(t)$ if $\frac{d\pi_i}{dx_i}$ at time $t+1$ in the point $x_i(t+1) = x_i(t)$is positive and decrease, if the stated derivation is negative. In other words it is considered how its profit would evolve if the bid quantity at $(t+1)$ is equal with bid quantity in the previous round (t) and after that they decide for the next bid accordingly.

The parameter k_i in the previous equation shows speed of adjustment with which the i-th generator alter its energy production according to the possibility of an increase/decrease in the profit

By (1) and (5) equations we get the following:

$$x_i(t+1) - x_i(t) = k_i(t+1)\left.\frac{d\pi_i(t+1)}{dx_i(t+1)}\right|_{x_i(t+1)=x_i(t)} = \tag{7}$$
$$k_i(t+1)\left[\mathrm{p}(\mathrm{t}+1) + \frac{d\mathrm{p}_i(t+1)}{dx_i(t+1)}x_i(t+1) - \left(\mathrm{b_i} + \mathrm{c_i}x_i(t+1)\right)\right]_{x_i(t+1)=x_i(t)}$$

In equation (7) one round bidding strategy is formulated to maximize benefit of this algorithm. Necessary conditions for using and implementation of this strategy is the knowledge of price system $p(t+1)$ in next round and the derivative of the profit function with respect to$x_i(t+1)$. It is assumed that producers have access to a good estimation of the demand function.

Substituting equation (2) into (7), one gets:

$$\mathrm{x_i(t+1) - x_i(t+1) =} \tag{8}$$
$$\mathrm{k_i(t+1)}\Bigg[\mathrm{e(t+1) - f(t+1)D(t+1) - f(t+1)\frac{dD(t+1)}{dx_i(t+1)}}x_i(t+1)$$
$$- \left(\mathrm{b_i} + \mathrm{c_i}x_i(t+1)\right)\Bigg]_{x_i(t+1)=x_i(t)}$$

Due to the equality of supply and demand at any given time the result is as following equation:

$$\mathrm{x_i(t+1) - x_i(t+1) =} \tag{9}$$
$$\mathrm{k_i(t+1)}\Bigg[\mathrm{e(t+1) - f(t+1)}\sum_{j=1}^{n} x_j\mathrm{(t+1)}$$
$$- \mathrm{f(t+1)}\sum_{j=1}^{n}\frac{\mathrm{d}x_j\mathrm{(t+1)}}{\mathrm{dx_i(t+1)}}x_i(t+1)$$
$$- \left(\mathrm{b_i} + \mathrm{c_i}x_i(t+1)\right)\Bigg]_{x_i(t+1)=x_i(t)}$$

Realistic assumption for each generator is the next bid for each similar company according to the previous round.

A realistic assumption is that each production company believes that the quantity produced by

its competitors will approximately be the same as in the previous period

Therefore, assuming $x_j(t+1) = x_j(t)\ , j \neq i$lead to the following:

$$\frac{dx_j(t+1)}{dx_i(t+1)} = 0 \quad \text{‘} \forall j \neq i \qquad (10)$$

Which it is the Cournot assumption that according to the assumption we will reach the equation (9) to the following equation.

$$\mathrm{x_i}(\mathrm{t}+1) - \mathrm{x_i}(\mathrm{t}+1) = \qquad (11)$$

$$\mathrm{k_i}(\mathrm{t}+1)\left[\mathrm{e}(\mathrm{t}+1) - \mathrm{f}(\mathrm{t}+1)\sum_{j=1}^{n} x_j(\mathrm{t}) - \mathrm{f}(\mathrm{t}+1)x_i(t) - \left(\mathrm{b_i} + \mathrm{c_i}x_i(t)\right)\right] =$$

$$\mathrm{k_i}(\mathrm{t}+1)\left[(-2f(t+1) - c_i)x_i(t) - f(t+1)\textstyle\sum_{j=1}^{n} x_j(\mathrm{t}) + \mathrm{e}(\mathrm{t}+1) - \mathrm{b_i}\right]3.4$$

4.2-Estimating the Cost Function of Production Method

Power plants studied in this research are from thermal type. In short run for a thermal power plant for producing electricity - variable costs include fuel costs and maintenance costs which are variable. Since a power plant built and operating, its capacity and technology may not change in short run and it is fixed. Fuel costs constitute more than 80% of the total variable cost of production in addition in the short run correction cost function the variable maintenance costs come to the model in a linear kind (Bernstein et al, 2000).

So the main challenge in cost correction is about the costs of the fuel.

The production amount is a function of fixed and variable inputs.

$$\mathrm{X}_t = f(Y_t, \overline{Y_t}) \qquad (12)$$

In this regard $\overline{Y_t}$ shows the fixed vector and $Y_t$variable inputs in the production. Thus the short run function due to the fixed amount of Y_t in short run is as follow:

$$C_t(X_t, W_t) = W_t f^{-1}(X_t) \tag{13}$$

In this equation $C_t(X_t, W_t)$is the function of cost in short-term and W_t is the price vector at time t for a specified unit. So the relationship between the amount of fuel and produced amount can identify the variable cost function in short term in the power industry. For defining the relationship between the fuel and the production, a thermodynamic relationship is used based on thermal unit properties. The relationship which is called input-output curve of thermal unit, is based on a second or third order nonlinear equation, specifies the input energy rate change into the output (Wood et al, 1996). The most important element which creates the nonlinear curve is the startup cost or fuel consumption without production. These costs will cause an increase in the efficiency units as well as production and cost function becomes non-linear form. The form of the cost function in nonlinear model clarifies into the second or third grade. And may be estimated as following equation:

$$C_{it}^{G}(X_{it}, W_{it})\left({}^{Rial}/_{h}\right) = W_{it}\left({}^{Rial}/_{kcal}\right) * \left(a_i X_{it}^2 + b_i X_{it} + c_i\right) \tag{14}$$

In this regard, a_i, b_i, c_i are inverse coefficients for production function for $f^{-1}(Y(t))$and $W_{it}$is the fuel price for i unit .

Thus, to estimate the cost of power plants, the least consumption of the power station is considered on the production amount as a quadratic function. In this definition produced amount is based on megawatt and fuel consumption is based on cubic meters and the data used in this study, the plants use only natural gas as fuel. To obtain input thermal rate, gas heating value was used which is equivalent to8/700Mcal/m 3 (mega calories per cubic meter).

4.3-Estimation Method of the Demand Function

The electricity market in Iran is activated only in wholesale, demand sides are the electricity distribution companies and final consumers have no effects on the level of demand. Price is considered as the only explanatory variable for hourly electricity demand which is considered to represent a linear relationship between the price of electricity and the consumption amount corresponding to it which is defined for each hour in the linear form.

4.4-Adjustment Coefficients

To determine the coefficientk_i, at any time for a power station first the station product change rate and the total demand rate for the same hours in the day before are calculated and then multiplied in each other.

5. Empirical Results and Data Sources

The presented model above is to determine the manufacturer optimal bidding based on dynamic cournot strategy. According to this in order to compare the model results with the actual behavior of actors, the model runs at a local market. It is important that the implementation of this model in electricity market is not possible due to the high density of needed information and disability to reach that in a research. So the study is restricted to Isfahan electricity market. The suggested model can be used every time so in the study the research was done in three specific time which expressed peak, mid and low time of consumption. Concentration of calculating methods and repetition provide overgeneralization. Here the players are: Montazeri and Isfahan and the south combined cycle with the capacity of 1600, 835 and 945 respectively. Their share is more than 88 percent of the studied market and the calculations are done by Eviews 7 software and Matlab software \has been used for solving the model.

5.1-Result of the Cost and Demand functions Estimation

Table 1 variable cost functions are tested and the results obtained based on stationary variables.

Table1. Augmented Dickey-Fuller Test for Plant Cost Function Variable

		Critical Value		
variables	Test Statistics	Level 1%	Level 5%	Level 10%
Montazeri Fuel	-3.680126	-3.497727	-2.890926	-2.582514
jonub Fuel	-3.989433	-3.498439	-2.891234	-2.582678
Isfahan Fuel	-8.854843	-3.517847	-2.899619	-2.587134
Montazeri producton	-3.605334	-3.497727	-2.890926	-2.582514
Jonub producton	-3.898313	-3.498439	-2.891234	-2.582678
Isfahan production	-6.326043	-3.517847	-2.899619	-2.587134

The results of cost estimating of power stations in the form of a quadratic function of the producers listed in Table 2. In this table the parameters of $a_{i,} b_i$and c_i are constant factor, the production coefficient and the coefficient square for each power station. The Values in parenthesis are t-statistics in correspond to the numbers of coefficients and all significant coefficients which are meaningful.

$$C_i(x_i(t)) = a_i(t) + b_i(t)x_i(t) + \frac{1}{2}c_i(t)x_i^2(t) \quad , i = 1,2,\dots,n$$

Table2. The Results of Estimating the Plant Cost Function

	a_i		b_i		c_i	
Power plant	Coefficient	Std-Error	Coefficient	Std-Error	Coefficient	Std-Error
Isfahan	0.68 (8.34)	0.08	1407 (14.4)	97.5	299862 (10.8)	27619
Jonub	0.945 (2.9)	0.39	1830 (4.7)	387	200865 (2.2)	88531
Montazeri	0.14 (1.89)	0.07	2085 (13.9)	149	163750 (2.3)	70827

In the first column of Table 3 test probabilities are specified in a functional form. Functional form expresses the null hypothesis to be true, where all the possibilities are higher than 0/05 and suggests that the functional form is chosen correctly. In the second column of Table 3 the probability of no autocorrelation between error terms is one of the basic assumptions of OLS method that has been stated, the null hypothesis of this test is the probability of rejecting the null hypothesis for all three plants which is more than 0.05 is not denied. According to the obtained results, the problem of autocorrelation is not found. In the third column of Table 3 test for normality of the error probability is expressed. Given the null hypothesis that the probability values are greater than 0.05 is not rejected normally of the error term is expressed .In the fourth column of Table 3 heteroscedasticity test are expressed. In this test the null hypothesis is equal to homoscedasticity. The possibilities more than 0.05 more likely to indicate that the null hypothesis is true, there is no heteroscedasticity problem.

Table 3. Tests for Power Plants Cost Functions

	Reset Ramsey Test	LM Test	Jarque-Bera	White Test
Isfahan	0.16	0.82	0.38	0.44
Jonub	0.27	0.91	0.55	0.3
Montazeri	0.64	0.27	0.18	0.64

In table 4 the stability of different demand functions were tested and the results obtained based on stationary variables.

Table4. Augmented Dickey-Fuller Test Results for the Variables Hourly Demand Functions

		Critical Value		
variables	Test Statistics	Level 1%	Level 5%	Level 10%
Demand at 1	-5.070882	-3.522887	-2.901779	-2.588280
Demand at 14	-6.571258	-3.522887	-2.901779	-2.588280
Demand at 22	-4.982066	-3.524233	-2.902358	-2.588587
Price at 1	-2.927065	-3.522887	-2.901779	-2.588280
price at 14	-2.966160	-3.522887	-2.901779	-2.588280
price at 22	-3.677304	-3.522887	-2.901779	-2.588280

In Table 5 the electrical hourly estimation are changed into a linear function of the price. In this table the parameters of $a\ (t)$, $b\ (t)$ and $d\ (t)$ are constant, the coefficient of price the dummy variable for per hours.

The Values in parenthesis are t-statistics in correspond to the numbers of coefficients and all significant coefficients which are meaningful.

$D(t) = a(t) - b(t)p(t) + d(t)$

Table 5. The Estimation Results of Demand Function

	$a(t)$		$b(t)$		$d(t)$		
Power plant	Coefficient	Std-Error	Coefficient	Std-Error	Coefficient	Std-Error	R^2
Demand at 1	3003 (9.36)	320.5	0.0003 (-2.5)	0.001	-479 (-15.9)	29.9	0.77
Demand at 14	3269 (7.17)	459	3.5 (-2.19)	1.6	-293.9 (-9.7)	30.2	0.57
Demand at 22	3966 (10.5)	374	۵/۴ (-4.3)	1.25	-176 (-9.5)	18.5	0.60

Field tests of functional form, autocorrelation and heteroscedasticity were performed based on demand functions. Corresponding probability values are shown in Table 6, which is more than 0.05, so the functional form is correct and there is no problem of autocorrelation and heteroscedasticity.

Table 6.Results of Estimating the Demand Function

	Reset Ramsey Test	LM Test	White Test
Demand at 1	0.56	0.09	0.45
Demand at 14	0.124	0.535	0.8
Demand at 22	0.41	0.13	0.42

5.2- The Results of Cournot Solution

Matlab program was used for conducting Cournot and related calculations and code writing program is given in the Appendix. Here the results are given as a satisfactory element.

The obtained values obtained from cournot solutions for each power station is less than the maximum capacity of the plant. Maximum capacity of Isfahan power stations, South combined cycle and martyr Montazeri are 835 945 and 1600 MW respectively, so there is no problem in this respect. It is noteworthy that the obtained values considered regardless of the share of manufacturing industry, it is assumed that the power consumption by the industrial sector is provided by other stations as Folad Mubarakeh and Zobahan so obtained production values are not far from mind.The obtained values by cournot solving on the table is for a base day and for other days adjustment factor is used- the calculations are done for weekdays. Production values in this table are based on Megawatt.

Table 7. The Results of Cournot Solution for a Base Day

Hours / Power plants	At 1	At 14	At 22
Isfahan	359	555	632
Jonub	507	742	903
Montazeri	829	535	635

In Table 8 production values at each plant are separately achieved by using baseline values in the previous section and the adjustment coefficients. Dynamic in Cournot solutions means adjustment coefficient. The model runs for 6 days in the first week of fall. Here the possibility of comparing Cournot values with dynamic approach and actual values exist and the model can be generalized. The values in the table are based on Megawatt.

Table 8. Actual Power production Values and the Values of the Dynamic Approach Cournot

	hours	At 1		At 14		At 22	
Power plants		Cournot	Real	Cournot	Real	Cournot	Real
Isfahan	First Day	359	430	558	564	627	574
	Second Day	344	425	835	579	835	578
	Third Day	835	560	300	570	300	597
	Forth Day	835	595	835	422	429	578
	Fifh Day	500	445	835	595	535	590
	Sixth Day	121	292	835	449	419	455
Jonub	First Day	510	557	696	570	888	585
	Second Day	517	502	945	570	945	591
	Third Day	164	605	370	574	446	594
	Forth Day	0	612	945	578	508	600
	Fifh Day	945	617	945	574	945	407
	Sixth Day	0	422	945	578	945	602
Montazeri	First Day	829	968	792	1268	669	1338
	Second Day	715	1269	657	1288	770	1381
	Third Day	1119	1051	1600	1126	1600	1155
	Forth Day	1369	997	345	1125	1414	1173
	Fifh Day	780	1163	375	1132	676	1159
	Sixth Day	1600	1007	547	1128	558	1159

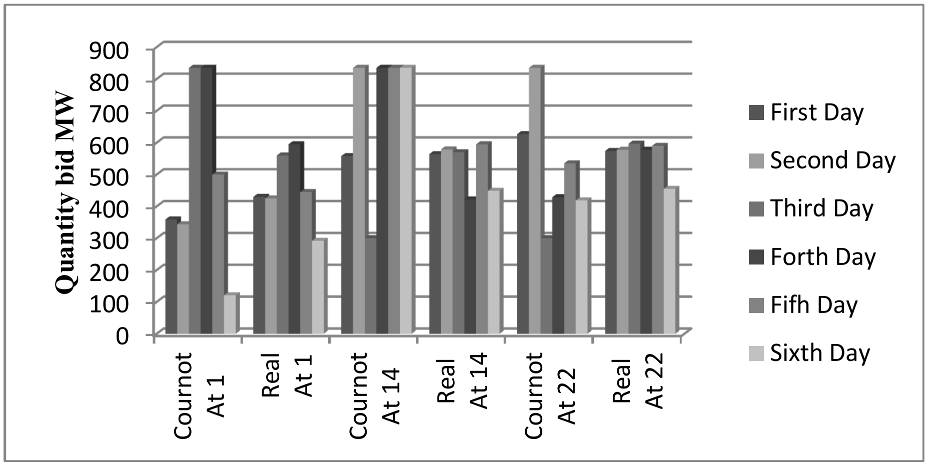

Figure 2. Graph Comparing the Actual Output Values and the Values Obtained from the Cournot Solution of Isfahan Plant

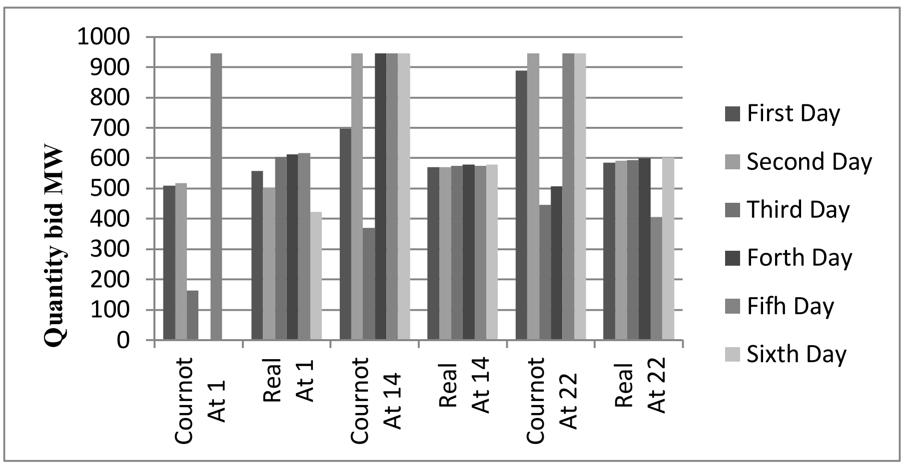

Figure 3. Graph Comparing the Actual Output Values and the Values Obtained from the Cournot Solution of Jonub Plant

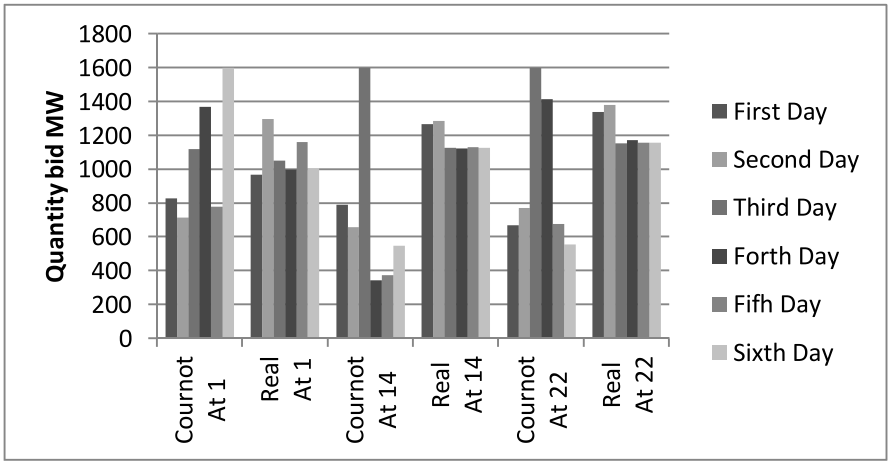

Figure 2. Graph Comparing the Actual Output Values and the Values Obtained from the Cournot Solution of Montazeri Plant

6. Concluding Remarks

With the spread of restructuring process in power industry and electricity markets in different parts of the world in 1382- Important steps in this direction were made in Iran. From 1382 – 1385 the plants acted in an unreal form only for practicing in the domain but after that the plant benefit had a connection to their behaviors in the market. Producers (plants) should offer their suggestions to the Office of the electricity market. Obviously, each plant needs a strategy for maximizing their profits. This strategy is highlighted in this paper. The model was implemented in Isfahan regional electricity market and Montazery, Isfahan and Isfahan South combined cycle power plants have been studied, the cost functions of mentioned plants are calculated in a quadric functions and for Isfahan electricity demand functions as a linear way.

Consuming industries are not considered in this study assumes that meet their needs on other plants such as Folad Mubarakeh, Zobahan and etc. The demand function was estimated by using the data on production amount and prices in 3 months in the fall of 1391 (on weekdays), which includes 75 data and cost functions are estimated based on fuel consumption at different levels of Montazeri, Isfahan and South combined cycle and the number of used data reveal 100 ones.

Then benefit function was defined based on calculations in hourly form and it was estimated that the plants are considering their benefit by Cournot strategy. This means that they define their outputs in a way which maximizes their benefit by fixed considering of the amount of their rivals' production amount. In this case we achieve a production amount for each plant based on the data which is considered as the base amount. Since the consumption pattern is similar for similar hours in the same days the production amount is achieved by the amount of yesterday production and adjustment coefficient in profit function derivation and this is the dynamic approach is Cournot model. The model was studied respectively in 1, 14 and 22 as representatives of low-medium and high peak of consumption.

In this study we have investigated whether the three mentioned plants mentioned in suggesting to the markets use Cournot strategy with dynamic approach. According to the data and obtained graphs from model using and comparing the model with the realistic data we can conclude no meaningful relationship between them. Studied plants won't use dynamic Cournot strategy for their amount suggesting.

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Appendix

Coding program is used in this paper to determine the amount of base load

```
%q1=x q2=y q3=z f=samtechape q1+q2+q3
clc
clearall
symsxpyz
f=input('f:')
h1=input('h1:')
h2=input('h2:')
h3=input('h3:')
yy=finverse(f,p)
yyy=subs(yy,p,x+y+z)
h1=subs(h1,p,yyy)
h2=subs(h2,p,yyy)
h3=subs(h3,p,yyy)
eq1=diff(h1,x)
eq2=diff(h2,y)
eq3=diff(h3,z)
s=solve(eq1,eq2,eq3)
q1=s.x;
q2=s.y;
q3=s.z;
q1=vpa(q1)
q2=vpa(q2)
q3=vpa(q3)
```

Coding program is used for the dynamic cournot

Isfahan power plant

```
clc
clearall
symsq1q2q3
q_prim1=input('q_prim1:')
q_prim2=input('q_prim2:')
q_prim3=input('q_prim3:')
dd1= input('dd1:')
dd2= input('dd2:')
dd3= input('dd3:')
Q=input('Q:')
h=input('h:')
Q_prim= q_prim1+ q_prim2+ q_prim3;
x=(Q-Q_prim)/(Q_prim);
y1=(dd1- q_prim1)/ (q_prim1);
k1=x*y1;
```

```
out1= q_prim1+(k1*(subs(diff(h,q1),{q1,q2,q3},{ q_prim1, q_prim2, q_prim3})))
```

South combined cycle power plant

```
clc
clearall
symsq1q2q3
q_prim1=input('q_prim1:')
q_prim2=input('q_prim2:')
q_prim3=input('q_prim3:')
dd1= input('dd1:')
dd2= input('dd2:')
dd3= input('dd3:')
Q=input('Q:')
h=input('h:')
Q_prim= q_prim1+ q_prim2+ q_prim3;
x=(Q-Q_prim)/(Q_prim);
y2=(dd2- q_prim2)/ (q_prim2);
k2=x*y2;
out2= q_prim2+(k2*(subs(diff(h,q2),{q1,q2,q3},{ q_prim1, q_prim2, q_prim3})))
```

Montazery power plant

```
clc
clearall
symsq1q2q3
q_prim1=input('q_prim1:')
q_prim2=input('q_prim2:')
q_prim3=input('q_prim3:')
dd1= input('dd1:')
dd2= input('dd2:')
dd3= input('dd3:')
Q=input('Q:')
h=input('h:')
Q_prim= q_prim1+ q_prim2+ q_prim3;
x=(Q-Q_prim)/(Q_prim);
y3=(dd3- q_prim3)/ (q_prim3);
k3=x*y3;
out3= q_prim3+(k3*(subs(diff(h,q3),{q1,q2,q3},{ q_prim1, q_prim2, q_prim3})))
```