2008 IEEE Electrical Power & Energy Conference

Estimation of marginal cost function using bid price and quantity to power market

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Abstract— **A major challenge for designers of competitive electricity markets is to devise market rules that limit the capability of electricity producers to exercise market power. Market power is the ability of a firm owning generation assets to raise the market price by its bidding behavior and to profit from this price increase. In addition, an important plan of market monitoring units in long term and competition policy framework is to persuade the participants to bid prices near to their marginal costs. Therefore, estimation of marginal cost function is important in way that Regulatory use it to increase competition in electricity markets. Bid price of the power plant to the power market contains some important information that can lead to more exact estimation of their marginal cost.**

In this paper the marginal cost of a typical power plant is estimated using optimal bidding behavior model in a competitive electricity market and Iran power market data.

Index Terms— **Marginal cost function, Model of optimal bidding behavior, Bertrand oligopoly model.**

I. Introduction

IN following restructuring in electricity market in the world and successfully of those in some countries, at present time all believe that existing of competition market in electricity supply, induce efficient, because power generator companies compete for product of power with high quality and prepare better and different service [1].

In Iran, from 2003 power industry restructured in order to increase of competition and interest of private investment in wholesale market. In present condition of power industry, a major aim of competitive market designer specified regulator body, is to devise market rules that limit the capability of electricity producers to exercise market power. In order to measuring of market power of generator units using Lerner Index, generator units marginal cost is required that in this paper using "Optimal bidding behavior model" for estimation of marginal cost function of electricity production, used in the competitive electricity market. Then using introduced model and Iran power market data, estimated gas and steam units marginal cost of neka generator.

II. Theory of Model

Although in real world only one perfect competition and pure monopoly exists, different models of oligopoly based on non-cooperative behavior exist where a few firms independently work. A firm in a perfect competitive and pure monopoly operates in an active manner, In contrast, the firm in an oligopolistic model can not indifferent to behavior of others competitor.

In oligopoly markets there exist a few firms, so each firm knows that he/she can affect the market price and hence affecting the competitor profits. So, oligopoly market different with competitive market and pure monopoly market, so that, each firm must consider the behavior of competitors' firms to determine their best policies. We can different model for oligopoly depend on that the firm choice price or quantity as strategy variable.

A. Bertrand Model

In the Bertrand model, firm choice price as strategy variable. In the simple state, Bertrand model based on following assumption:

1. Consumers are price taker.
2. Firms produce identical products.
3. No entry to the industry.
4. Firms set price rather than quantities.
5. Each firm is willing to sell as much quantity as is demanded at the price it sets.
6. Firms have market power cooperatively, so that individuals can set price above marginal cost.

If consumers have complete information and realize that firms produce identical products, they buy the one with the lowest price. In other hand, in a simple condition, in the Bertrand model each firm believes that its rival price is fixed, so by a slight price cut, the firm is able to capture all its rival business. So in the Bertrand equilibrium, firms make zero profits and no firm can increase its profits by raising or lowering its price. If any of assumption in above ignore, can considered Bertrand model in the real state, and then price not equal to marginal cost. For example, if all firms produce homogenous product, Bertrand price is above marginal cost. Or market last for many periods, then partial or total collusion becomes more likely. And finally, if firms have limited production capacity, then the Bertrand equilibrium condition not valid (P=MC), this assumption as limited production capacity used in the power industry [2].

Bertrand model can be investigated as a competitive bidding model framework, so that each firm participate in the auction and bidding price that who would like sale its good or service to buyers and customers.

Make decision method of firm in oligopoly market condition shown in Figure (1). With attention to this figure, if vertical axis be price and horizontal axis be quantity, and assume Total demand of market is given, then firm A face with demand residual, that obtain from market demand subtract aggregate bidding function all participant beside firm A . firm A choice best point of the product level with attention to residual demand that he face with it.

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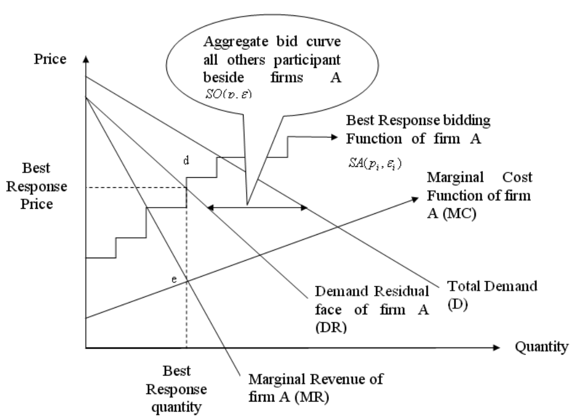

Figure1. Make decision of firm in oligopoly condition.

If assumed all firms produce humongous product. Or by perfect information, this firm know functional form of its' marginal cost, so in the oligopoly market by use of equilibrium condition (MR=MC), this firm following price and quantity that maximize its' profit. This show by point, D, on the figure (1). Given marginal cost is strong assumption, that in practice a external vision not any inform from those, and any private firm not willing and force to reveal this information to anthers. Whatever this researcher to face is sets of price and quantity that firms offer to market. The question arise is, whether can used this information and estimate marginal cost function.

This paper consider the optimization problem of firm (profit maximization) from researcher vision, that means by imperfect information assumption, researcher ask this question that by attention to given offer price and quantity (that arise from profit maximization problem of firm) of generator to market, what functional form for marginal cost that maximize its' profit?

B. Review of literature

Up to now, variety study estimate marginal cost function in oligopoly model condition. Rosse (1970), devised estimation procedures to recover cost functions from data on market-clearing prices and quantities. He used a sample of monopoly local newspapers and the assumption of profit maximization, in united state for 1964- 1958, to estimate the underlying marginal cost function of the monopolists [3].

Porter (1983), employed a related approach in his study of price wars in the U.S. railroad industry during the 1886-1880. He assumes a firm-level, homogeneous product, quantity-setting conjectural variation oligopoly equilibrium. He aggregates the firm-level first-order conditions to produce an industry-wide supply function which he jointly estimates along with an industry-level demand function [4].

Bresnahan (1981 and 1987) quantifies the extent of market power possessed by each vehicle model in the U.S. automobile industry using a discrete choice differentiated products model of individual demand with vertical product differentiation in the unobserved product quality dimension. Aggregating these discrete purchase decisions across U.S. households, yields an aggregate demand system for all automobile models. Bresnahan assumes Nash/Bertrand competition among the automobile makers facing this aggregate demand system to estimate the implied marginal cost of producing automobiles of each quality level [5].

Berry, Levinsohn and Pakes (1995) allow for a multinomial logit discrete choice demand structure at the consumer level and assume unobservable (to the researcher) stochastic consumer-level marginal utilities of product attributes. These marginal utilities are assumed to be independent non-identically normally distributed across of product attributes and independent identically distributed across consumers. Integrating individual-level purchase decisions with respect to these normal distributions yields a product-level the aggregate demand system for automobiles. The authors assume that the conditional indirect utility functions for each consumer contain the same vector of unobservable (to the researcher) product characteristics, and that these product characteristics are uncorrelated with all observable product characteristics. This stochastic structure induces correlation between equilibrium prices and the vector of unobserved random product characteristics in the aggregate demand system. These authors propose and implement an instrumental variables estimation technique which exploits this lack of correlation between observed and unobserved product characteristics to estimate the demand system jointly with the marginal cost function under the assumption of Nash/Bertrand competition among automobile producers [6].

Goldberg (1995), uses individual household-level data to estimate a general discrete-choice model for automobile purchases at the household-level. She then uses weights giving the representativeness of each these household in the population of U.S. households to produce a system of aggregate demand functions for automobiles based on the choice probabilities implied by her model of household-level automobile demand. Using the assumption of the Nash/Bertrand competition among automobile producers, she then computes implied marginal cost [7].

III. Model and Estimation Method

In order to measure of market power of Neka generator in the electricity market, needs to marginal cost estimation all units of this generator. By attention to only offering price and quantity of this generator to power market of Iran is available, appropriate method for this work is method of wolak (2002), that applied for estimating marginal cost of generator units in the electricity market of Australian.

A. Model

Assumed that neka power plant operator maximize its' profit following:

$$\Pi_{id}(\Theta,\varepsilon)=\sum_{i=1}^{24}\left[\begin{array}{l} DR_i(P_i(\varepsilon_i,\Theta),\varepsilon i)P_i(\varepsilon_i,\Theta) \\ -\sum_{j=1}^{6}C_j(SA_{ij}(P_i(\varepsilon_i,\Theta),\Theta),\beta_j) \end{array}\right]$$

(1)

That:

π_{id} : Variable profits to Firm A at price p, in load period i of day d.

Q_{id} : Total market demand in load period i of day d.

$\mathrm{SO}_{\mathrm{id}}(\mathrm{p})$: Amount of capacity bid by all other firms besides Firm A into the market in load period i of day d at price p.

$DR_{id} = Q_{id} - SO_{id}(P)$: Residual demand faced by Firm A in load period i of day d, specifying the demand faced by Firm A at price p.

MC: Marginal cost of producing a MWH by Firm A

$\mathrm{SA}_{\mathrm{id}}(\mathrm{p})$: Bid function of Firm A for load period i of day d giving the amount it is willing to supply as a function of the price p.

β_j : Vector of parameter of cost function for genset j.

ε , is the vector of residual demand shock realization for i=1… 24. $P_i(\varepsilon_i, \Theta)$, the market clearing price for load period i given the residual demand shock realization, ε_i , and vector of daily offer Θ , is the solution in P to the equation $DR_i(P, \varepsilon_i) = SA_i(P, \Theta)$.

Wolak (2000), implement same work for Australian electricity market, with different in Australian electricity market:

1. Daily period is i=1,…,48.
2. The offering price can not variety during day.
3. Beside energy market, also financial contract exist.
4. Type of auction in Australian electricity market is uniform.
5. Range of price offering in Australian electricity market between -9,999.99 $ AU – 5,000.00 $ AU per MWh is allow.

Generalize method of moment; define Moment Restrictions for unit, j, and steps, K, using first order condition as following:

$$E_{\varepsilon}\left(\frac{\partial \Pi_d(\Theta_d, \varepsilon}{\partial P_{ijk}}\right) = 0 \tag{2}$$

Θ , index by d , as there are different values of Θ for each day during the sample period. Equation (2) defines the JxKx1 moment restrictions that will use to estimate the parameters of the genset-level cost functions. The Sample analogue of this moment restriction is:

$$\frac{\partial \Pi_d(\Theta_d, \varepsilon)}{\partial P_{km}} = \sum_{i=1}^{24} \left[\begin{array}{l} \left(DR'_i(p_i(\varepsilon_i, \Theta), \varepsilon_i) P_i(\varepsilon_i, \Theta) + (DR_i(P_i(\varepsilon_i, \Theta), \varepsilon_i)\right) \\ -\sum_{j=1}^{6} C' j(SA_{ij}(P_i(\varepsilon_i, \Theta)), \beta_j)(\frac{\partial SA_{ij}}{\partial P_i})) \frac{\partial P_i}{\partial P_{km}} \\ -\sum_{j=1}^{6} C'_j(SA_{ij}(P_i(\varepsilon_i, \Theta)), \beta_j) \frac{\partial SA_{ij}}{\partial P_{km}} \end{array} \right] \tag{3}$$

Where pi is shorthand for the market-clearing price in load period i. Let $l_d(\beta)$ denote the JxK dimensional vector of partial derivatives given in (2), where β is the vector composed of β_j for j=1,...,J. Assuming that the functional form for Cj(q, β_j) is correct, the first-order conditions for expected profit-maximization with respect to daily bid prices imply that E($l_d(\beta)$) = 0 where β^0 is the true value of β. Consequently, solving for the value of b which minimizes:

$$\left[\frac{1}{D}\sum_{d=1}^{D} l_d(b)\right]' \left[\frac{1}{D}\sum_{d=1}^{D} l_d(b)\right] \tag{4}$$

will yield a consistent estimate of β . In the equation (4), D, is number of days that equal 366. Let b (I) denote this consistent estimate of β , where "I" denotes the fact that the identity matrix is used as the GMM weighting matrix. So, can construct a consistent estimate of the optimal GMM weighting matrix using this consistent estimate of β as follows:

$$V_D(b(I)) = \frac{1}{D}\sum_{d=1}^{D} l_d(b(I))\, l_d(b(I))' \tag{5}$$

The optimal GMM estimator finds the value of b that minimizes:

$$[\frac{1}{D}\sum l_d(b)]' V_D(b(I)^{-1} [\frac{1}{D}\sum_{d=1}^{D} l_d(b)]$$

(6
)

Let b (.) denote this estimator, where "." denotes the fact this estimator is based on a consistent estimate of the optimal weighting matrix.

Operationalizing this estimation procedure requires computing values for the partial derivative of SAij(p, Θ) with respect to p and pkj and the partial derivative of pi(,i, Θ) with respect to pkj. Define SAij(p, Θ) as:

$$SA_{ij}^{h}(P, \Theta) = \sum_{k=1}^{10} q_{ikj} \Phi((P - P_{lj})/h)$$

Which implies?

$$SA_i^{h}(P, \Theta) = \sum_{j=1}^{J}\sum_{k=1}^{10} q_{ikj}\ \Phi((P - P_{kj})/h) \tag{7}$$

This definition of SAij(p, Θ) yields the following two partial derivatives:

$$\frac{\partial SA_{ij}}{\partial P_i} = \frac{1}{h}\sum_{k=1}^{10} q_{ikj}\ \varphi((P - P_{lj})\ /\ h) \tag{8}$$

$$\frac{\partial SA_{ij}}{\partial Pkj} = -\frac{1}{h} q_{ikj}\ \varphi((P - P_{kj})\ /\ h) \tag{9}$$

The final partial derivative required to compute the sample analogue of (2) can be computed by applying the implicit function theorem to the equation DRi(p, ε_i) = SAi(p, Θ). This yields the expression:

$$\frac{\partial P_i}{\partial P_{kj}} = \frac{\dfrac{\partial SA_i(P_i(\varepsilon_i,\Theta),\Theta)}{\partial P_{kj}}}{DR'_i(P_i(\varepsilon_i,\Theta),\varepsilon_i) - SA'_i(P_i(\varepsilon_i,\Theta),\Theta)} \quad (10)$$

There are several methods to calculate $DR'(p^E,\varepsilon)$, the results from these methods are the same. Wolak (2002) , calculated $DR'(p^E,\varepsilon)$ from $(DR(p^E+\delta,\varepsilon)-DR(p^E,\varepsilon))/\delta$, δ is between ten sent and one A.U \$, Wolak (2002) in another estimate method residual demand from following relation:

$$DR(p,\varepsilon) = Q_d(\varepsilon) - SO_h(p,\varepsilon) \quad (11)$$

That all other participants aggregate supply beside firm A is:

$$So_h(P,\varepsilon) = \sum_{n=1}^{N}\sum_{k=1}^{10} qo_{nk}\ \Phi((P-Po_{nk})/h) \quad (12)$$

That qo_{nk} is the kth bid increment of genset n and Po_{nk} is bid price for increment k of genset n, where N is the total number of gensets in the market excluding those owned by Firm A. The function $\Phi(t)$ is the standard normal cumulative distribution function and h is a user-selected smoothing parameter. This parameter smooth the corners on the aggregate supply bid function of all other market participants besides Firm A. Smaller values of h introduce less smoothing value of $DR'(p^E,\varepsilon)$. This second technique by used wolak (2002) was adopted because it is very easy to adjust the degree of smoothing in the resulting residual demand function. Using this technique in this paper results in:

$$DR'_h(P,\varepsilon) = -\frac{1}{h}\sum_{n=1}^{N}\sum_{k=1}^{10} qo_{nk}\,\varphi((P-Po_{nk})/h) \quad (13)$$

Where $\varphi(t)$ is the standard normal density function. With calculate $DR'(p^E,\varepsilon)$, can compute $C'(DR(p^E,\varepsilon))$, by using (4) equation for any market clearing price. As derivative of residual demand curve with respect to price used in (10) is given in equation (13) and the other partial derivatives are given in (8) and (9). Given data on market-clearing prices and the bids for all market participants, can compute all of the inputs into equation (3). Only need to choose a value for h, the smoothing parameter that enters the smoothed residual demand function and the smoothed bid functions of Firm A.

The final step necessary to implement this estimation technique is choosing the functional form for the marginal cost function for each genset. Neka generator owns two power plants, gas and steam. Steam power plant has four identical gensets that the firm operates during the sample period. The gensets at steam power plant have a maximum capacity of 440 MW and a lower operating limit of 220 MW. The gas power plant has two identical gensets that the firm operates during the sample period. This gensets at gas power plant have a maximum capacity of 140 MW and a lower operating limit of 60 MW. Because it is physically impossible for a genset to supply energy safely at a rate below its lowest operating limit, specified a functional form for marginal cost to take this into account. Consequently, assume following parametric functional forms for the two unit-level marginal cost functions:

$$C'_1(q,\beta_1) = \beta_{10} + \beta_{11}(q-60) + \beta_{12}(q-60)^2$$
$$C'_2(q,\beta_2) = \beta_{20} + \beta_{21}(q-220) + \beta_{22}(q-220)^2$$

These functional forms are substituted into (3) to construct the sample moment restrictions necessary to construct the objective function. And for minimize stated term in above must be estimate following parameters vector:

$$\beta = (\beta_{10}, \beta_{11}.\beta_{12}, \beta_{20}, \beta_{21}, \beta_{22})'$$

IV. Generalized Method of Moments

In fact, this method is generalized of moments method that have long past in estimation of statistics models parameters. Generalized method of moments chooses the parameters which minimize the following term:

$$J_T = m(\theta)' W m(\theta)$$

Where θ is a $k\times 1$ vector of parameters, $m(\theta)$ is a $L\times 1$ vector of orthogonality condition, and W is a $L\times L$ positive definite weighting matrix.

If there are as many moment conditions as parameters, the moments will all be perfectly matched and the parameters estimated will coincide with theoretical relation. This is referred to as the "just identified" case. In the situation where there are more moment conditions than parameters ("over-identified") not all of the moment restriction will be satisfied so a weighting matrix W determines the relative importance of the various moment conditions. Hansen (1982) is to point out that setting $W = S^{-1}$, the inverse of an asymptotic covariance matrix, is optimal in the sense that it yields $\hat{\theta}$ with the smallest asymptotic variance.

In general, an "optimal" weighting matrix requires an estimate of the parameter vector, yet at the same time, estimating the parameters requires a weighting matrix. To solve this dependency, common practice is to set the initial weighting matrix to the identity then calculate the parameter estimates. A new weighting matrix is calculated with the last parameter estimates, and then new parameter estimates with the updated weighting matrix.

$$W_0 = I \quad (14)$$

$$\hat{\theta}_1 = \arg\min \quad m(\theta)' W_0 m(\theta) \quad (15)$$

$$W_1 = f(\hat{\theta}_1) \quad (16)$$

$$\hat{\theta}_2 = \arg\min \quad m(\theta)' W_1 m(\theta) \quad (17)$$

The process can then be iterated further by calculating

W_2 then minimizing to find $\hat{\theta}_3$ and so on. In general, iterating to end with $\hat{\theta}_n$ is called n-stage GMM. This iteration can fare until the change in objective function is sufficiently small. The program of this section is written with MATLAB software so that the user can easily control this process [9].

V. Estimation results

Like already debated, this firm that in fact is Neka generator, has two same gas genset and four same steam genset, So in this paper by using GMM method estimate coefficient of marginal cost of this six genset. The coefficient of these generator units by using both unit and weighted matrix is optimal. In estimation of this coefficient assume h=1400, although estimation result with change from 100 to 2000 not changed.

Table (1) in the annex 1, show estimation result of marginal cost function of gas genset by used unity and optimal weighted matrix.

Table (2) in the annex 1, show estimation result of marginal cost function of steam genset by used unity and optimal weighted matrix.

The optimized value of the objective function from the GMM estimation with the consistent estimate of the optimal weighting matrix can be used to test the overidentifying restrictions implied by best-response bidding or validation of restriction. In fact, these tests represent good fitness. For implement this test constitute null hypothesis it following:

$$\begin{cases} H_0 : L \succ K \\ H_1 : L \leq K \end{cases}$$

That in this test, L, number of equation and K, is number of parameters. And null hypothesis denote to validate of parameters estimated.

From the results of Hansen (1982), the optimized value of the objective function is asymptotically distributed as a chi-quare random variable with 12 degrees of freedom–the number of moment restrictions less the number of parameters estimated, $\chi^2(q-p)$, under the null hypothesis that all of the moment restrictions imposed to estimate the parameters are valid. The optimized value of the objective function using a consistent estimate of the optimal weighting matrix is 0.000124, which is less than the 0.05 critical value from a chi-squared random variable, $\chi^2(18-6=12)=21.03$, with 12 degrees of freedom. Also, statistics value, $J = n \times M = 1.092$, is less than the 0.05 critical value from a chi-squared random variable, $\chi^2(18-6=12)=21.03$, with 12 degrees of freedom. This implies that the null hypothesis of the validity of the moment restrictions it following:

$$E_{\varepsilon}\left(\frac{\partial \Pi_d(\Theta_d, \varepsilon}{\partial P_{ijk}}\right) = 0$$

Cannot be rejected by the actual bid data, this hypothesis test implies that given the parametric genset-unit cost functions, the over-identifying moment restrictions implied by assumption of expected profit-maximizing behavior by Neka Firm cannot be rejected.

Figures (1) and (2) in annex 2, show estimated genset level marginal cost functions for gas and steam along with point-wise 98% confidence intervals for the case of the consistent estimate of the optimal weighting matrix estimation results. Using the identity matrix as the GMM weighting matrix did not yield significantly different results. The confidence intervals indicate that the marginal cost curves are fairly precisely estimated.

VI. Conclusion

By attention to marginal cost curves of gas and steam genset, important result of this research is, if Neka operator has rational behavior, for gas genset probably offer this form, that or not accept in auction and then not produce, or if

Accept then produce in maximum capacity level. Inversely, for steam genset offering so that, always wins in the auction and then produce in the minimum level of capacity. in addition, gas genset used more intensively by Neka powerplant operator than steam genset.

The other result of this research to emerge from this analysis is the increasing, convex marginal cost curves for all cases. One potential explanation for this result comes from discussions with market participants in wholesale electricity markets around the world. They argue that genset owners behave as if their marginal cost curves look like those in Figures 1 and 2, because they are hedging against the risk of unit outages when they have sold a significant amount of forward contracts (in the electricity market of Iran this risk same capacity unsuccessful test penalty, if this sample unit with proving dispatch center, can not produce as level of said capacity, 20 times of offering price penalize). Because of the enormous financial risk associated with losing a genset in real-time combined with the inability to quickly bring up another unit in time to meet this contingency, generation unit owners apply a large and increasing opportunity cost to the last one-third to one-quarter of the capacity of each genset. That way they will leave sufficient unloaded capacity on all of their units in the hours leading up to the daily peak so that they can be assured of meeting their forward financial commitments for the day even if one of their units is forced out.

This desire to use other units as physical hedges against the likelihood of a forced outage seems to be a very plausible explanation for the form of the marginal cost functions that estimate in this paper.

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APPENDIX

(A)

Table 1. Coefficient estimation of marginal cost function of Gas unit

	Gas Units					
	Unity Matrix			Optimal Weighting Matrix		
Var. Name	Coef.	St.dev.	t-std	Coef.	St.dev.	t-std
Intercept	0.00004	0.00296	0.014	0.00001	0.00000068	14.78
$(q-60)$	0.00134	0.00002	47.2	0.00032	0.00013204	2.45
$(q-60)^2$	0.15878	0.0000009	163870	0.03831	0.0009856	38.87

Note: All coefficients are given for optimal weighting matrix at 98% confident interval.

Table 2. Coefficient estimation of marginal cost function of Steam unit

	Steam Units					
	Unity Matrix			Optimal Weighting Matrix		
Var. Name	Coef.	St.dev.	t-std	Coef.	St.dev.	t-std
Intercept	0.00004	0.002968	0.014	0.00001	0.00000067	15.01
$(q-220)$	0.0068	0.0000093	728.11	0.00163	0.0002036	8.05
$(q-220)^2$	1.45279	0.0000001	11447543.23	0.35048	0.00058684	597.23

Note: All coefficients are given for optimal weighting matrix at 98% confident interval

(B)

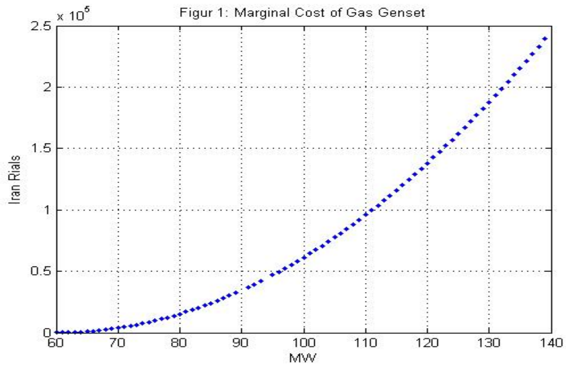

Figure1. Gas Units Marginal Cost Curve

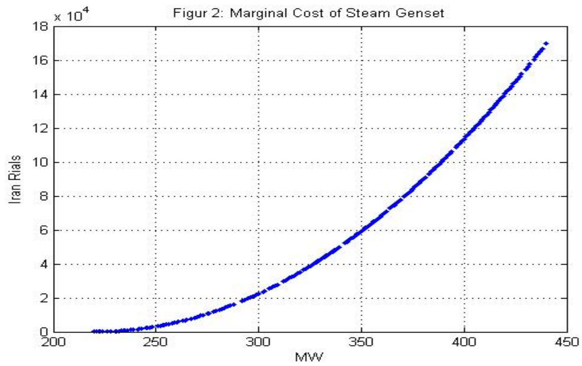

Figure2. Steam Units Marginal Cost Curve