Abstract

Efficiency is an integral objective of liberalizing electricity markets, yet it is a crucial aspect as well. Experience of other countries in restructuring electricity markets shows that restructuring a market does not necessarily result in efficiency in it. Also, there is no universally agreed-upon set of rules. For these very reasons, evaluating an electricity market is vital to policy makers. Calculating welfare loss in a market measures production inefficiencies in it, and reducing welfare loss enhances production efficiencies in that market. Therefore, in this paper, we have measured welfare loss in peak hours of 2006, as the first year of the restructured market’s performance, and 2012 and have found causative factors in welfare loss in order to find possible solutions to production inefficiencies in the market. We have used an econometric approach to test the significance of these factors to welfare loss in Iran’s restructured, pay-as-bid electricity market. We have found out that there is welfare loss in the market due to exercising market power by strategic firms. In addition, welfare loss in peak hours is minimum. In other words, strategic firms exercised more non-competitive behavior in hours with lower demand compared to the peak hours in 2006 and 2012. Also, we have found that structural indices, HHI and the market share ratio, display invalid results about competition in Iran’s electricity market.

1. Introduction

Efficiency has always been the clear goal of electricity markets. Even before liberalizing electricity markets, in cost-of-service systems, market operators tried to produce power as efficiently as possible. The Iranian electricity market is no exception. Iran’s wholesale electricity market was inaugurated in 2003, and Iran Grid Management Corporation (IGMC) was inaugurated in 2004 in order to build a competitive environment on the supply side and the distribution side of the electric industry. Although the Iranian electricity market has had positive consequences, such as clarification and separation of costs of different sectors, provision of incentives for attracting private sectors’ investments and paving the way for privatization and liberalization of the industry (IGMC Website), the economic discussions about proper market design and architecture are in their infancy. Regardless of technical challenges in terms of infrastructure, transmission network constraints, generation shortage and market power problems, the current discussion focuses on the market’s performance, degree of competition in it.
and the market’s production efficiencies. The major challenge for the new problem arises from differences between the Iranian market design and other well-known market designs in the world. Given these differences, the Iranian electricity market needs much more efforts and research studies to fulfil competition and achieve production efficiencies in the market in the new restructured circumstances.

In general, competitive prices instead of regulated rates raises the potential for some firms to drive up market prices by exercising market power in the electricity market (for example, see Wolfram, 1999; Joskow and Kahn, 2002; Mansur, 2007b and Borenstein & et al. 2002). The main goal of this paper is modelling the actual welfare loss in the Iranian electricity market based on the economic and technical market conditions in 2006, as an initial year of restructuring, and 2012\(^1\), so we can find possible solutions to welfare loss in the market, thereby enhancing production efficiencies in the market.

Before describing economic efficiency in the production of power, it is necessary to differ short-run (static) efficiency from long-run (dynamic) one. Short-run efficiency stems from an economic dispatch schedule. In an economic dispatch schedule, electricity is produced by the least-costly producers and is sold to the highest offers considering constraints. For example, distribution constraints could make generation of some power plants indispensable, such as islands in which only local power plants can meet the demand. Albeit every firm produces power in a way to minimize its costs, the total generation is not necessarily minimum in that way. Every system operator tries to minimize the aggregate cost of production with available information. This information could make a dispatch schedule either efficient or inefficient. If the information reflects the actual costs of production of each power plant, the system operator meets the demand with the least-costly suppliers, and if this information is not based on firms’ actual costs of production, the dispatch schedule is deformed, and the production is distorted. This is the reason why the design of a market is important for its efficient production because the information available for system operators differs in different market designs. At the end of section 2, we will discuss this matter more.

A market should have other characteristics as well as having economic dispatch schedules. A market should be able to attract investors in all parts of the market, such as generation and distribution. For example, technology of power plants should enhance, so more economic technologies come to the market and expensive ones leave it. Positions of power plants and distribution facilities are important because they could force the system operator to dispatch expensive producers before relatively cheaper ones due to distribution constraints. All of these traits in a market improves long-run efficiency in the market.

We have measured welfare loss in the Iranian electricity market to evaluate production inefficiencies in it. Nonetheless, the purpose of this paper is not measuring welfare loss in the market. This paper tries to distinguish causative factors in welfare loss in order to find possible solutions to production inefficiencies in the market because welfare effects in electricity markets result from inefficient production (Mansur, 2007a). Strategic firms in the electricity market with asymmetric costs

\(^1\) The Iranian year starts in March and ends in March. Therefore, by 2006, we mean the period which started on 21 March 2006 and ended on 20 March 2007, and by 2012, we mean the period that started on 20 March 2012 and ended on 20 March 2013.
and strategies are the reasons for production distortion from competitive equilibrium (Borenstein & Farrell, 2000). Therefore, welfare loss in an electricity market is due to exercising market power by strategic firms.

There are three different approaches for estimating market power in a market (Paul & et al., 2005). The first one is evaluating the potential for exercising market power using structural indices. These indices survey only the structure of a market and does not concern with the performance of the market’s players. Hence, these indices show potentialities of concentration in a market and do not display the actual behavior of the producers. Nonetheless, these indices are easy to calculate and they can be used for testing other approaches of analyzing a market (behavioral indices and simulation models). Asgari and Monsef addressed market power problem in the Iranian electricity market using structural indices (Asgari & Monsef, 2010). They found out that some suppliers in the electricity market of Iran can exercise market power despite the fact that these suppliers have relatively small market shares.

The second technique for calculating market power in an electricity market is using behavioral indices. Unlike structural indices, behavioral indices assess the actual behavior of suppliers in the market. Assessing the actual behavior could be comparing marginal costs to bids, searching for firms with high revenues and searching for firms that could produce more and profit from this excessive production, but they did not use this opportunity. Wolak and Patrick surveyed revenues of firms in England and Wales and found out that the market’s regulations and structure gave two firms opportunities to earn more than their production costs (Wolak & Patrick, 2001). Short and swan analyzed competition in the Australian national electricity market using Lerner index (Short & Swan, 2002). They assessed the performance of the wholesale electricity market in two different periods and found a substantial distance between the actual outcomes and the competitive outcomes of the market.

The last technique is using simulation models, which is more complex than the previous methods and will be explained more in appendix A. We have used a simulation model to estimate welfare loss in the electricity market of Iran. This counterfactual benchmark whose name is competitive benchmark analysis has been used by wolfram to measure price-cost markups in the British electricity industry (Wolfarm, 1999). Her estimates showed that prices were higher than marginal costs. Borenstein and et al. measured inefficiencies in California’s wholesale electricity market (Borenstein & et al., 2002). They found out that 59% of increase in production costs from 1999 to 2000 was due to increase in exercising market power. Furthermore, Mansur stated that competitive benchmark analysis overstates welfare loss in a market due to disregarding intertemporal constraints (Mansur, 2007a).

In section 2, Iran’s electricity market and its unique characteristics will be explained. Econometric model, its paradigm and data will be discussed in section 3. Section 4 will present the results of estimates. Finally, section 5 is the conclusions and bullet points of this papers’ findings.

2. Iran’s Electricity Market

Deregulation in the electricity industry of Iran was first taken into consideration by TAVANIR (Iran Power Generation and Transmission Company) more than two decades ago in 90s. In 2001, TAVANIR started making a plan for restructuring Iran’s electricity market. Finally, TAVANIR’s board members voted for the plan in 2002. Iran’s Ministry of Energy (MOE) announce the first edition of
electricity trades’ regulations to TAVAMIR in 25 August 2003, and Iran’s electricity market officially started working on October 2003. Iran’s Grid Management Corporation, under which the System Operator (SO) and Market Operator (MO) operate, was established on August 2004 (Energy, 2004). Table 1 denotes the main characteristics of the Iranian electricity market in 2012. More accurately, these numbers show the market’s characteristics in the span between March 2012 and March 2013.

<table>
<thead>
<tr>
<th>Table 1, the Iranian Electricity Market Profile in 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Nominal</strong></td>
</tr>
<tr>
<td>Capacity</td>
</tr>
<tr>
<td>68940 MW</td>
</tr>
<tr>
<td><strong>Total Actual Capacity</strong></td>
</tr>
<tr>
<td>60723 MW</td>
</tr>
<tr>
<td><strong>Maximum Demand</strong></td>
</tr>
<tr>
<td>42367 MW</td>
</tr>
<tr>
<td><strong>Generation</strong></td>
</tr>
<tr>
<td>Steam Turbine</td>
</tr>
<tr>
<td>36.10%</td>
</tr>
<tr>
<td>Gas Turbine</td>
</tr>
<tr>
<td>26.49%</td>
</tr>
<tr>
<td>Combined Cycle</td>
</tr>
<tr>
<td>31.67%</td>
</tr>
<tr>
<td>Diesel</td>
</tr>
<tr>
<td>0.03%</td>
</tr>
<tr>
<td>Hydroelectric</td>
</tr>
<tr>
<td>4.90%</td>
</tr>
<tr>
<td>Nuclear and Renewable</td>
</tr>
<tr>
<td>0.81%</td>
</tr>
<tr>
<td><strong>Generation Capitation</strong></td>
</tr>
<tr>
<td>135 KWh¹</td>
</tr>
</tbody>
</table>

*Source:* (TAVANIR, 2013)

1. Kilowatt hour

MOE is responsible for producing power in Iran. Nonetheless, they vested all their powers for producing electricity in TAVANIR. TAVANIR is divided into Regional Electricity Companies and Regional Water Companies (RWC), which are responsible for meeting the electricity demand in their regions. The Iranian electricity market is an hourly, day-ahead, unilateral, pay-as-bid, wholesale electricity market. Auctions in the market are held 24 times for a typical day. Suppliers, Regional Electricity Companies (REC) as representatives of their regions’ power plants and private companies, send their sealed bids of their units three days before the day in which they intend to produce electricity. Each bid comprise at most ten amount of generation and the unit’s offered price for each amount. MO arranges the dispatch schedule one day before the day for which suppliers bided. MO arranges bids from the cheapest to the most expensive, like figure 2. As it is shown in figure 2, the demand functions are inelastic in the market’s auctions, and distribution companies forecast the aggregate demand for every hour and report it to MO. Interception of the aggregate demand and the arrangement of bids from the cheapest to the most expensive determines the winners of an auction. The most expensive bid, that wins the auction, is called Market-Clearing Price (MCP). The bids below MCP are the winners of that auction. MO informs each firm confidentially with the results of their bids one day before the day they bided for.

Payments to suppliers consist of two parts in Iran’s electricity market. One part is because of suppliers’ capacity, which they bid, and the rate of this payment is fixed. The other part is because of firms’ production and is exactly firms’ bids. Not until suppliers got the opportunity to sell their production in Tehran’s stock exchange in 2013, did they sell their production in any other market but the wholesale electricity market.
In the Iranian electricity market, all thermal power plants use natural gas, crude oil and gas oil. Fuel prices are heavily subsidized and set by MOE annually. Iran’s electricity market has a tight price cap on suppliers’ bids in order to inhibit exercising market power. MOE sets this price cap annually as well.

The most significant features of Iran’s electricity market are as follows:

- Unilateral auction, distribution companies and Regional Electric Companies (RECs) are just entitled to forecast their hourly demand, namely, the demand curve in a certain hour is a vertical line whose value is equal to the aggregated demand in that hour and the price elasticity of demand is zero (figure 2).
- A day-ahead market
- The discriminatory pricing on the supply side, the method of payment to producers is pay as bid.
- The uniform pricing on demand side, the price of energy for distribution companies and RECs is equal to a weighted average bided price and capacity payments.
- Tight price cap.
- Availability of based payments for transmission services (IGMC Website).

It is worthy of note that in a pay-as-bid auction, firms have more incentives to exercise market power in comparison with firms in a uniform-price auction (Tierney & Schatzki, 2008). They explained the rationales for this potential difference this way: For example, in figure 1, plant A eventually earns more than its bid, all plants earn MCP. Therefore, this is unreasonable for plant A to bid more than its actual cost since nobody can compete with it. However, in a pay-as-bid auction, plants are exactly paid their bids for their production, so all plants bid above their actual cost because the more they bid, the more they are paid if they win the auction. In order to win the auction and maximize their benefit, plants bid based on their best guess of the MCP. Since bids are not based on marginal costs and are random in a pay-as-bid auction, it is difficult to forecast MCP, and plants might bid above the actual MCP. Therefore, plants with higher variable production costs are dispatched before plants with relatively lower variable production costs, and this increases the market’s short-run inefficiency more in a pay-as-bid auction in comparison with a uniform-price auction. For example, in figure 2, despite the fact that plant D is more costly than plant C, plant D is dispatched sooner because its bid was fewer than C’s. Also, plant A lost the auction because its guess of the MCP was not correct.
3. Econometric Model

In this paper, we have used an econometric model for analyzing welfare loss and finding its causative factors, so we can find possible solutions to welfare loss in the electricity market. The econometric equation of welfare loss is as follows:

\[
\log(\text{deadweight loss}_i) = \alpha + \beta_1 \log(\text{largest producer}_i) + \beta_2 \log(\text{capacity}_i) + \beta_3 \log(\text{demand}_i) + \beta_4 \log(\text{HHI}_i) + u_i
\]

**Equation 1**

Where deadweight loss

\( i \) is the welfare loss in the \( i \) th period, peak hours of 2006 and 2012. Largest producer

\( i \) is the market share of the biggest producer of the market, Tehran, in the \( i \) th period. Capacity

\( i \) shows the capacity for generation of the market in the \( i \) th period. Demand

\( i \) is the aggregate demand of electricity in the \( i \) th period. HHI

\( i \) shows Herfindahl Hirschmann Index of the market in the \( i \) th period. \( \beta_i \) \((i = 1, 2, 3, 4)\) are elasticities of welfare loss. For instance, \( \beta_1 \) is Tehran’s market share elasticity of welfare loss. Finally, \( u_i \) shows the disturbances in the model. In this section, we will explain each variable, rationales for choosing explanatory ones and the way we have compiled and calculated them.

3.1. Welfare Loss

The only short-run welfare effects in electricity markets stem from inefficient production (Mansur, 2007a). Hence, reduction in welfare loss in a market equals to enhancement in production efficiencies in that market. For this very reason, we have modeled welfare loss in order to find tactics which could mitigate welfare loss in the market. In appendix A, we will discuss the counter factual benchmark used for measuring welfare loss in peak hours of 2006 and 2012 in Iran’s electricity market.
3.2. Market Share

The market-share concentration ratio shows the ratio of capacity of the largest producers in a market to the aggregate capacity of that market. The number of producers depends on the structure of that market. In Iran’s electricity market, we have considered only the market share of the largest company, Tehran, because most of the suppliers are governmental. For example, Tehran’s market share was above 25% in peak hours of 2006. Also, Tehran and khoozestan combined owned more than 40% of the generation capacity of the market in peak hours of 2006.

In the USA, Federal Energy Regulatory Commission (FERC) set 20 percent as the benchmark for market share ratio in 1992, and the commission stated this benchmark is still warranted in 2011 (FERC, 2011). In other words, firms with market share above 20% are likely to exercise market power.

The market share ratio evaluates the potential concentration in the market. The bigger this ratio is in a market, the less concentrated that market is, so producers exercise less market power. Therefore, we have assumed that the market-share elasticity of welfare loss (β₁ in equation 1) will be positive.

3.3. Herfindahl-Hirschman Index (HHI)

The market-share ratio only considers a small number of producers, only one of them in our case, in a market. Therefore, the market-share ratio does not give a clear image about the concentration in the market. Unlike market share ratio, HHI takes account of all producers in a market. This way it is more apt to discuss concentration in the market. HHI’s formula is as follows:

\[ HHI = \sum_{i=1}^{n} S_i^2 \]  

Equation 2

\( S_i \) is the market share of the ith producer. The commission of FERC stated that a market with HHI below 1000 is unconcentrated, and a market with HHI between 1000 and 1800 is moderately concentrated, and if HHI exceeds 1800, the market is highly concentrated (FERC, 2011).

The more HHI in a market is, the more concentrated that market is, so it is more likely that producers in the market exercise market power and increase welfare loss in the market. Therefore, we have presumed that HHI elasticity of welfare loss (β₄ in equation 1) will be positive.

3.4. Capacity and Demand

As mentioned before, in a pay-as-bid auction, more firms have incentives to exercise market power (at the end of section 2). Also, welfare loss is due to production distortion. For example, in figure 2, plant A distorted the production from the cheapest producer, which is itself, to plants E and F, which are the most-costly producers. This production distortion and welfare loss in this period decreases if the aggregate demand gets bigger enough that plant A becomes mandatory for meeting the demand. Therefore, we have presumed that the demand elasticity of welfare loss (β₃ in equation 1) will be negative. Also, if there is less capacity for plant A in the market to distort the production to, the
production distortion and welfare loss in this period diminishes. Hence, we have assumed that the capacity elasticity of welfare loss ($\beta_2$ in equation 1) will be positive.

### 3.5 Estimation of the Econometric Model

We have used Ordinary Least Squares (OLS) method to estimate equation 1. This method minimizes the sum of residuals of a regression model. To describe rudiments of OLS, we assume that there is only one independent variable ($Y_i = \alpha + \beta X_i + e_i$, i= 1, 2..., n. Where i is the number of observations). Therefore, residuals are taken from the following equation:

$$e_i = Y_i - \hat{\alpha} - \hat{\beta} X_i$$

Equation 3

$\hat{\alpha}$ and $\hat{\beta}$ are guesses of regression parameters $\alpha$ and $\beta$. Minimizing Residual Sum of Squares (RSS) results in an adequately accurate regression line (best linear unbiased estimate). Minimizing $RSS = \sum_{i=1}^{n} e_i^2$ using first-condition order results in estimates of the regression parameters which are

$$\hat{\beta} = \frac{\sum_{i=1}^{n} x_i y_i}{\sum_{i=1}^{n} x_i^2} \text{ and } \hat{\alpha} = \bar{Y} - \hat{\beta} \bar{X}.$$ 

$\bar{Y}$ and $\bar{X}$ are mean of observed quantities of dependent and independent variables respectively. For regressions with more than one explanatory variable, estimation basics are the same.

For estimating a regression model, there are some hypotheses and qualities that should be tested. We will describe tests for the model for making its results reliable. These tests are explained more in appendix B.

### 3.6 Data

Taken from IGMC website, dispatching reports of Iran’s electricity market in peak hours of 2006 and 2012 comprise the amount of generation and constraints, distribution and technical constraints, of each power plant (IGMC, 2006-2013). The aggregate generation and capacity of each peak hour gives the demand and generation capacity of the market in that hour. HHI and the market share ratio are calculated using these data. For measuring welfare loss, we needed data for calculating marginal costs of each generation unit. For estimating marginal costs of each generation unit, we needed its heat rate, fuel prices and variable operation and maintenance costs of that unit. Heat rates and fuel prices are taken from TAVANIR annual report of Iran’s electricity generation (Tavanir, 2013). Variable operation and maintenance costs are taken from Office of Production Planning of TAVANIR.

### 4. Results

In order to model welfare loss in the Iranian electricity market, we have surveyed the market’s performance in peak hours of 2006 and 2012. 2012 was a leap year, and data files for two days of 2006 were corrupted. Therefore, we have analyzed 366 days in 2012 and 363 days in 2006. 419 generation units generated electricity in the wholesale electricity market in 2006 while 543 ones produced in 2012. HHI in the market decreased from 1066 on average in peak hours of 2006 to 694 on average in the peak hours of 2012. The largest producer’s share has decreased from 24% on average in peak hours of 2006 to
18% on average in peak hours of 2012. The total variable cost of strategic production of the market exceeded the one in the competitive production of the market by 1.17% in 2006 while this number changed to 5.19% in 2012. After calculating and obtaining series for each year, we have estimated and modelled welfare loss using OLS. The results are indicated in table 2.

**Table 2, Estimation Results of Welfare Loss**

<table>
<thead>
<tr>
<th>Estimation Results</th>
<th>2006</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Std. Error</td>
</tr>
<tr>
<td>Intercept(α)</td>
<td>252.4993</td>
<td>25.87584</td>
</tr>
<tr>
<td>Log(hhi)</td>
<td>-25.91582</td>
<td>2.75547</td>
</tr>
<tr>
<td>Log(largestproducer)</td>
<td>13.58622</td>
<td>2.318887</td>
</tr>
<tr>
<td>Log(capacity)</td>
<td>11.58684</td>
<td>1.020435</td>
</tr>
<tr>
<td>Log(demand)</td>
<td>-15.40582</td>
<td>1.46141</td>
</tr>
<tr>
<td>AR(1)</td>
<td>0.52391</td>
<td>0.047659</td>
</tr>
</tbody>
</table>

**Source:** Calculations

In this table, estimation results of both 2006 and 2012 are presented. For each year, coefficients of each variable in equation 1, which are elasticities of welfare loss, standard errors of these coefficients, the probabilities for testing the significance of independent variables and explanatory power of the model are presented in table 2. All elasticities are significant because all probabilities are small. HHI elasticities of welfare loss is negative in both models despite the fact that we expected them to be positive. Demand elasticities of welfare loss are negative in both years. Market-share elasticities and capacity elasticities of welfare loss are positive in both years. The explanatory power of models are 0.55 and 0.8 in 2006 and 2012 respectively. The estimations of equation 1 in 2006 and 2012 are as follows:

**Equation 4, Estimation of the Model in 2006**

\[
\text{LOG(DWL)} = 252.499344389 - 25.9158205293 \times \text{LOG(HHI)} + 13.586217925 \times \text{LOG(LARGEST PRODUCER)} + 11.5868387203 \times \text{LOG(CAPACITY)} - 15.4058154525 \times \text{LOG(DEMAND)} + [\text{AR(1)}=0.523909925188]
\]

**Equation 5, Estimation of the Model in 2012**

\[
\text{LOG(DWL)} = 1.02690337429 - 3.02433700273 \times \text{LOG(HHI)} + 1.13167617248 \times \text{LOG(LARGEST PRODUCER)} + 4.78105573072 \times \text{LOG(CAPACITY)} - 0.949645383571 \times \text{LOG(DEMAND)} + [\text{AR(1)}=0.536785187478]
\]

5. Conclusion

One of the most important reasons that the Iranian electricity market has been restructured is increasing production efficiencies in it. Welfare loss in an electricity market in short run is due to production inefficiencies; therefore, we have tried to model welfare loss in the market in order to find possible solutions to welfare loss in the market. In other words, we have modelled welfare loss in the market to find possible tactics to increase production efficiencies in the market. To do so, we have
calculated welfare loss in the market in peak hours of 2006 and 2012 and have used its possible causative factors to estimate it. Our calculations show that there were welfare loss in the Iranian electricity market in both years. As it was described in section 2, the Iranian electricity market has some important characteristics. Based on the results, as demand increases and available supply decreases, strategic behavior of players decreases. Basically, the shortage of a supply threshold and the tight price cap in this market guarantee high prices on peak hours while in hours with relatively lower demand, there would be high incentives to behave strategically and exercise market power. Therefore, the most important results of the model are as follows:

- The simulation model exhibits the market power exertion by the players. Had strategic producers bided their marginal costs, there would not have been production distortion and welfare loss in the market.
- The inefficiency of the production sector in the Iranian power market annually imposes, at least, a cost of 1,164,852 billion Rials on the Iranian economy. This number is minimum because our calculations are subjected to only peak hours, in which welfare loss is minimum compared to other hours of days since the demand elasticity of welfare have been negative in the models in both 2006 and 2012.
- In spite of the fact that based on the structural indices the Iranian power market does not have a high potential for non-competitive behavior, the simulation model shows that the generators in the Iranian market show strategic behavior.
- The most important reason for welfare loss in the market is the urgent shortage of supply threshold in this market rather than the extent of concentration in the industry.
- Changing to a uniform-price auction could mitigate welfare loss in the market. As it was explained at the end of section 2, firms with incentives to exercise market power in a pay-as-bid action are more than firms with incentives in a uniform-price auction.
- Removing the price cap on bids could alleviate welfare loss in the market. The price cap gives firms with marginal costs near the price cap incentives to bid it, thereby making prices higher.
- Most firms are governmental in Iran’s electricity market, thereby having large market shares and incentives to exercise market power. Private companies of the market combined produced 13.9% of the whole electricity generation of the market in peak hours of 2012 while Tehran produced 18.3% of it. Speeding up the process of privatization in the market could decrease welfare loss in the market.
Appendix A: Counterfactual Benchmark for Measuring Welfare Loss in Iran’s Electricity Market

We have used competitive benchmark analysis to measure welfare loss in the Iranian electricity market. The basic idea of competitive benchmark analysis is developing an estimate of the market prices that would result if all companies behaved as price-takers (i.e. if no company attempted to exercise market power) and to compare that price to the observed market price (Paul & et al., 2005).

In our case, we have calculated optimal generation of each generation unit and have compared it to the real generation level. Therefore, this comparison has enabled us to measure welfare loss in the Iranian electricity market. The optimal dispatch schedule for each peak hour of 2006 and 2012 has been obtained by meeting demand with the least-costly producers. To do so, we have calculated marginal costs generation units using their heat rates.

Heat rate\(^1\) is an accepted estimation of thermal power plants’ marginal costs (Borenstein, et al. 2002; Mansur, 2007a). In addition, using heat rates for calculating short-run marginal costs disregards producers’ intertemporal constraints, like start-up costs, ramp rates and minimum run times. However, intertemporal constraints’ influence is insignificant in the Iranian electricity market. The reason for this matter is that producers need permission to be off and cannot follow the on-off strategy. Although it is an assumption to use marginal costs as constant variables, and the technical efficiency of power plants increases as they run more, the incorrect measuring gets small, and the variation of heat rate gets negligible (Mansur, 2007a). Moreover, in order to heighten calculations’ accuracy, all calculations in this paper have been limited to peak hours. The assumption is based on the constant rates of return for electricity producer power plants. Therefore, the typical well-known engineering formula based on years of regulation used to estimate marginal costs is as follows:

\[
MC_{it} = MO_i + HR_i \times \left( w_{it}^{fuel} / NG \right) + \sum_j w_{it}^{j} r_j^i
\]

Equation A1

Where \(MO_i\) is the variable operating and maintenance costs, and \(HR_i\) is the average heat rate, which measures technical efficiency of \(i\)th generator. \(w_{it}^{fuel}\) is the fuel price for generator \(i\), and \(w_{it}^{j}\) and \(r_j^i\) are emission prices\(^2\) and emission rate of particular pollutant for producer \(i\). \(NG\) is the caloric value of natural gas used by the \(i\)th generator. In order to estimate the fuel costs, we assumed all firms use natural gas as their fuel. In the next subsection, we will discuss why intertemporal constraints, such as start-up costs, minimum run times and down times, are insignificant and do not make heat rate inaccurate. Therefore, heat rate shows the performance of the firms in Iran’s electricity market almost perfectly. It is essential to remember that all these discussions about heat rate are only about the fuel part of equation A1, and the variable operating and maintenance costs have also been used for each firm in this paper’s estimation of short-run marginal costs.

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\(^1\) One of unique features of a generation unit is its heat rate. Heat rate for a generation unit shows that how much energy that unit consumes to generate one kilowatt hour electricity in average (kilocalorie/kilowatt hour).

\(^2\) In the electricity market of Iran, the firms do not pay for the amount of their emission according to the market’s regulations. Therefore, our estimate does not comprise the emission costs either.
In theory, welfare loss in an electricity market is the result of misallocation of resources and production inefficiencies. Allocative efficiency is achieved when the consumer’s value is equal to the cost of resources used in production. However, in an electricity market due to the regulatory structure of retail markets and priority of electricity provision in any cost, demand is perfectly inelastic (Mansur, 2007a). Therefore, measuring welfare losses in the electricity markets is limited to production-inefficiency assessment, which is achieved when the total output is produced in the minimum cost.

In Iran’s electricity market, we have calculated welfare loss by comparing the actual behavior to the competitive benchmark, so the calculation is as follows:

\[
\Delta W = \sum_{t=1}^{N} \int_{0}^{RD_t} (\beta_t(q) - \beta^*_t(q)) \, dq
\]  

Equation A2

Where \( \Delta W \) measures welfare effects in a particular period, for instance 2006 or 2012, and \( RD_t \) is the residual demand in peak hours. \( \beta_t(q) \), and \( \beta^*_t(q) \) are aggregate marginal cost function under strategic behavior and market supply function under competitive behavior in each hour respectively. Total output in each hour is determined by \( q \) and \( N \) is the number of hours in the studied periods. Namely, \( N \) is the number of peak hours in 2006 and 2012. The residual demand in each peak hour of 2006 and 2012 is obtained through equation (A3).

\[
RD_t = \overline{D}_t - \sum_{i=1}^{M} q^\text{Rev}_{it} - \sum_{i=1}^{M} q^\text{DW}_{it} - \sum_{i=1}^{N} q^\text{Min}_{it} - \sum_{i=1}^{M} q^\text{Kish}_{it}
\]  

Equation A3

While \( \overline{D}_t \) is total market demand in each peak hour, which is the aggregate generation of that peak hour and is perfectly inelastic. \( q^\text{Rev}_{it} \), \( q^\text{DW}_{it} \), \( q^\text{Kish}_{it} \) show the amount of energy produced by hydroelectric, diesel, wind and Kish REC power plants respectively. According to the Iran’s electricity market’s regulations, hydroelectric, wind and diesel power plants can produce electricity even without participating or winning an auction to support these types of production. Kish REC produces electricity for Kish island, which is not connected to the national electricity network. For this very reason, Kish REC’s production in each peak hour has been considered as its optimal production in that peak hour in the competitive benchmark. Another fact worthy of note is that plants with stream-turbine technology incur a relatively large amount of money or time for starting and getting on line. According to the Iranian electricity market’s regulations, this type of plants can produce their minimum capacity if they lose the auctions, so they can avert start-up costs. Hence, \( q^\text{Min}_{it} \) represents the minimum generation level of stream-turbine power plants at hour \( t \), which has been taken into account in this model as a must-take generation.
Appendix B: Test for Improving the Regression Model

B.1. Stationarity and Cointegration

Before even running a model, variables or time series should be analyzed. Time series could be divided into stationary and non-stationary types. Non-stationary time series does lack either constant mean or variance, sometimes both. If a series has constant mean and variance, it is a weak stationary. All series, dependent and explanatory variables, should be stationary in a regression model. For example, some time series might have infinite mean by the passage of time, so these non-stationary series are not reliable.

However, if a linear combination of non-stationary series has some conditions, this linear model is cointegrated and reliable. For cointegration, all series should be stationary at the same difference (for example I(1), which means $x_t - x_{t-1}$ is I(0) or trend stationary), and the residuals of the linear model should be trend stationary. All series in our model are I(1) and residuals of equation 1 are I(0), so our model is cointegrated. We have used unit root test in Eviews software to recognize stationarity of series. The results are as follows:

<table>
<thead>
<tr>
<th>Table B1, Unit Root Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability$^1$</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Level</td>
</tr>
<tr>
<td>Welfare Loss 0.7024</td>
</tr>
<tr>
<td>Share 0.2046</td>
</tr>
<tr>
<td>HHI 0.3234</td>
</tr>
<tr>
<td>Demand 0.4201</td>
</tr>
<tr>
<td>Capacity 0.3144</td>
</tr>
<tr>
<td>U 0</td>
</tr>
</tbody>
</table>

$^1$ Probability fewer than 0.05 means that the series is a weak stationary.

B.2. Correlation

In using OLS, we assumed that disturbances are not correlated. In other words, disturbances from previous periods do not affect the disturbances of the next periods ($E[u_i, u_j] = 0$ i, j = 1, 2, 3..., n). To check this assumption we have used Durbin Watson (DW) static. We have run one model for each year (2006 and 2012), and statistic values are $DW_{2006} = 1.01$ and $DW_{2012} = 0.89$. These statistics are not near 2, so both models have correlations. To remove correlation from disturbances of both models, we have added Auto Regressive (AR) apiece, which is dependent variable (welfare loss) with one lag. Then, we have tested the model using Breusch-Godfrey test in Eviews software. The probabilities for 2006 and 2012 are 0.057 and 0.94. Since these statistics are greater than 0.05, disturbances in the models do not have correlations.
References


