Modeling the Energy Reform in Mexico: Static and Dynamic Government Subvention Models.

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Abstract

In this paper, we conduct numerical experiments based upon the oligopolistic model of electricity in Mexico. In generalized Cournot model, at the Nash equilibrium, electricity firms maximize their profit and enlarge their market shares, taking into account some subvention functions invented by government. The computational game theoretic modeling tool developed in the programming language GAMS, composed as a mixed complementarity problem (MCP) solved by the GAMS algorithm PATH. It turns out that in the extended Cournot models (mutual profit maximization, strategic behavior and price subvention) lead to the reasonable prices and demand for electricity.

1. Introduction

The energy sector in Mexico has certain limitations in terms of private participation, and foreign companies are allowed to operate in the country only through specific service contracts. As required by the Constitution, the electricity sector is federally owned, with the Federal Electricity Commission - *Comisión Federal de Electricidad* (CFE) essentially controlling the whole sector. Attempts to reform the sector have traditionally faced strong political and social resistance in Mexico, where subsidies for residential consumers absorb substantial fiscal resources.

Still, due to the strong participation of the private capital (around of 25% of installed capacities are counted as the private investment), we can separate state-owned capacities as one market player and the aggregated private investor as another in order to apply the methods developed earlier in [1], [15] .)

From 1992 the government allowed private participation under different schemes such as Independent Power Production (IPP), Cogeneration and Self Supply (see Table 1). These legal reforms had been undertaken to comply with the energy chapter of NAFTA, which was constructed to permit continued state control of oil and electricity sectors (as in Articles 27 and 28 of the Mexican Constitution) while at the same time allowing for private participation in the power sector. However, since the Mexican power sector is operated as a vertically integrated publicly owned monopoly, every single IPP project that is operating, or under construction, has sought and received explicit government guarantees, and has no right to sell produced electricity directly to the customer.

Table 1: List of private agents activities.

Activity	*Description*
Self supply	Generation of electricity to meet an industrial facility's own energy needs. Refers to power plants owned and operated by private companies
Cogeneration	Refers to electricity generated simultaneously with steam or other types of secondary thermal energy to be used in an industrial process, or the generation of electricity from the surplus of thermal energy of an industrial process.
Independent Power Production	Refers to power plants with installed capacity larger then 30 MW, built and operated by private companies. All generated power must be sold to CFE under a power purchase agreement
Imports and Exports	Exports refer to electricity produced under cogeneration, IPP or small scale generation categories. Imports refer to electricity exclusively used for self-supply purposes.
Small-scale generation	Refers to power plants with an installed capacity no larger than 30 MW built and operated by private companies. This electricity is to be soldsolely to CFE.

In a liberalized electricity market, firms maximize their profits by producing electricity with different kinds of technologies *i*, and by selling this electricity to customers. The profits are the difference between the revenues from selling electricity and the costs of production. The prices of electricity differ across regions and in addition these prices might depend on the level of total electricity demand in a country. This dependency reflects particular strategic behavior of the electricity producers (CFE and private ones) using the game theoretic model, which can be characterized as a small numerical model, with which market behavior by firms in oligopolistic markets can be investigated (analogous model applied in [3]).

Energy suppliers produce electricity through different technologies. One player can own several power plants, of which total capacity is considered, as well as variable production costs. Investment decisions are not considered here; we limit ourselves to the study of the economic and environmental impact of liberalization with the present capacity structure, making certain adjustments for next periods of time.

The mathematical model of this article presents an advanced version of [6] which specified that the current Germany electricity market supply structure is characterized by natural monopolies, established by increasing returns to scale. Average costs are higher than marginal costs because of high fixed cost shares. Principal market agents are spatially separated in their current regional territories in Germany. Electricity supply and demand by households and industry determine a regional equilibrium price. In order to investigate the effects of a liberalized energy or electricity market in Germany, a computational analysis tool (*LEMI*: Liberalized Energy Market Investigations) was developed It includes strategic behavior of firms and market agents.

LEMI can be characterized as a computational game theoretic modeling tool in order to investigate strategic behavior by firms within the Germany electricity market liberalized completely.

In this paper we examine the case when, at the starting and the finishing stages of the game, electricity suppliers realize a conjectural Cournot-Nash equilibrium with their profits maximized (as in [2]). Profits are calculated upon marginal production costs and price dependent demand, the latter relationship being represented by an inverse demand function, which is twice continuously differentiable.

At the intermediate stage of the game, firms maximize their profits given the strategic behavior of the other agents. Profits are computed on the base of variable production costs, maximum net power, net access costs and transportation costs.

Market shares which may change with merges or cooperation also play an important role. In the oligopolistic market structure, prices can be dependent upon the market shares and market powers. Prices are also influenced by the price elasticity of demand, and it is exactly here that the influence coefficients arise. In a situation of perfect competition, that is not the case.

When solving optimization problems it is often useful to remember that each such a problem can be reduced to a complementarity problem (as in [4]-[5]). Generally speaking, in the complementarity framework, either a nonnegative variable is zero or the corresponding inequality constraint is active, i.e. is in fact equality. Primarily, by solving a mixed complementarity problem (MCP), the Karush-Kuhn-Tucker

(KKT) optimality conditions are determined and solved for a decision variable. The MCP format and the KKT conditions are equivalent. Therefore, each MCP can be transformed to the classical optimality conditions and vice versa. The idea behind the MCP formulation is to develop a program that permits the classical decomposition method to be obsolete, instead ascertaining the MCP conditions directly. The main advantages of MCP are: (1) the simultaneous and parallel determination of decision variables and side constraints, and (2) the solution of complex mathematical programs without an explicit formulation of the objective function. Specially developed solvers detect the MCP format directly and point out, if necessary, if side constraints are defined incorrectly. Present day computer technologies allow an uncomplicated and fast solution of MCPs by mathematical algorithms. At this moment, for instance, GAMS provides MILES and PATH as major solvers, see [7] and [8], respectively.

In addition, applying the MCP method one avoids the intricacy of finding a solution by a standard nonlinear programming (NLP) solver when the starting values are distant from the optimum point.

Transforming an optimization problem into a MCP formulation requires a specification of the first order optimality conditions taking into account all upper and lower bounds of the decision variables.

The MCP format allows a quite simple characterization of simultaneously processed decision variables (as in Games Theory) and a fast solution procedure. GAMS provides this highly efficient formulation mainly to realize reciprocal modeling approaches arising, for example, in game theoretic or applied general equilibrium concepts, *cf.* Ferris and Pang (1995) and [14] .

The paper is organized as follows. After an Introduction in Section 2 we describe the model with exogenously given subvention function. Section 3 presents numerical experiments and in Section 4, we make final conclusions.

2. Mathematical Model.

We model the Mexican electricity industry consisting of two conventional electricity producers indexed *i* which in total form set I. Mexico has been separated in 5 regions, each region *r* is a member of the set R.

Each production level y^i of the firm i correspond to a cost and subvention level according the following marginal cost and subvention functions: $c_y^i(y^i)$ and $e_y^i(y^i)$

The production y^i of each firm is restricted by its installed capacity $\bar{y}^i$ and may be supplied to the home region r or to the neighboring region r* such that

$$y^i = \sum_{r \in R} s^{i,r}$$

Furthermore, the total electricity exports from the region r to the region r*, Ex^{r,r^*} depend on the price for transmission service and is restricted by the transmission restriction

$$\bar{E}^{r,r^*} \geq Ex^{r,r^*}(\tau^{r,r^*})$$

and $\tau^{r,r} = 0$ for transmissions inside of the region. The subvention level σ is determined by the government. The producer price of electricity in each region is denoted by P_S^r.

The consumer price $P^r(Q^r)$ equals the sum of the producer price P_S^r for conventional production plus the average extra cost of the tariff:

$$\varsigma : P^r(Q^r) = P_S^r + (\varsigma - P_S^r)\frac{Z^r}{Q^r} \tag{1}$$

Where Z^r - fraction of Q^r being sold under special contract price (normally applies to heavy industry). This yields after rearranging the producer price:

$$P_S^r = P^r(Q^r)\frac{Q^r}{S^r} - \varsigma\frac{Z^r}{Q^r} \tag{2}$$

The problem of firm i can be stated as the following Lagrangian of the Kuhn-Tucker type:

$$L^i = \sum_{r\in R}\left(P^r(Q^r)\frac{Q^r}{S^r} - \varsigma^r\frac{Z^r}{S^r}\right)s^{i,r} - C^i(y^i) - \sigma E^i(y^i) + k^i(\bar{y}^i - y^i) - \sum \tau^{r,r^*}s^{i,r^*} \tag{3}$$

The first term on the right hand side of equation (3) sums up the revenues from supply in all regions, the second term accounts for the production costs, the third for costs of subvention permits, and the fourth for the shadow price of the production capacity, while the last sum accounts for the transmission costs for the restricted supply in neighboring regions. The optimality conditions to the problem can be summarized in the following way:

$$\frac{\partial L^i}{\partial s^{i,r}} \le 0, s^{i,r} \ge 0, \frac{\partial L^i}{\partial s^{i,r}}s^{i,r} = 0, \tag{4}$$

$$\frac{\partial L^i}{\partial k^{i,r}} \ge 0, k^i \ge 0, \frac{\partial L^i}{\partial k^i}k^i = 0,$$

The main driver of the model is the derivative of the Lagrangian with respect to the supply of the firm in a certain region:

$\frac{\partial L}{\partial s^{i,r}}$ which is dependent on the assumed market behavior.

The derivative of the price taking firm's profit with respect to supply can be written as:

$$\frac{\partial L^i}{\partial s^{i,r}} P^r(Q^r) + \left(P^r(Q^r) - \varsigma^r\right)\frac{Z^r}{Q^r} - C^i(y^i) - \sigma E^i(y^i) - k^i - \tau^{r,r*} \tag{5}$$

Under Cournot behavior of the firms, the effect on the revenue caused by the choice of output is taken into account by the firms. If we write the demand elasticity as

$$\varepsilon^r = \left| \frac{dQ^r}{dP^r} \frac{P_0^r}{Q_0^r} \right| \tag{6}$$

And with the regional share of the firm i: $\vartheta^{i,r}$, the derivative of the problem (3) w.r.t. the supply in Nash equilibrium can be expressed as:

$$\frac{\partial L^i}{\partial s^{i,r}} = P^r(Q^r) + (P^r(Q^r) - \varsigma^r)\frac{Z^r}{Q^r} - C^i(y^i) - \sigma E^i(y^i) - k^i - \tau^{r,r^*} -$$
$$-\vartheta^{i,r}\left((P^{r^*}(Q^{r^*}) - \varsigma^{r^*})\frac{Z^r}{Q^r} + \frac{P^r(Q^r)}{\varepsilon^r} \right)$$

(6)

If we compare the optimality conditions under the Cournot-Nash assumption with those of the price taking case, it is apparent that only a term which depends on the market share is added in equation (6). This last term includes the mark-up

$$\vartheta^{i,r}\frac{P^r(Q^r)}{\varepsilon^r} \tag{7}$$

Known from conventional oligopoly models, and a term induced by the feed-in tariff ς which reduces the mark-up if the feed-in tariff is greater then the market price

$$P^r : \vartheta^{i,r}(P^r(Q^r) - \varsigma^r)\frac{Z^r}{Q^r} \tag{8}$$

The latter term results from the firms conjecture about a constant output of the rivals in the Nash-equilibrium with regard to a marginal change in own output.

Consequently the firm´s burden on production induced by the feed-in tariff is diminished by an output increase.

We can now represent the complete model with price taking behavior of minor actors and strategic behavior of dominant firms (see: [11-13]). Thus, we introduce the binary variable l^i which is zero in the case of price taking firms and one in case of strategic firms. The combined optimality condition for price takers and strategic firms can be expressed as:

$$\begin{aligned}\frac{\partial L^i}{\partial s^{i,r}} &= p^r(Q^r) + (P^r(Q^r) - \varsigma^r)\frac{Z^r}{Q^r} - C^i(y^i) - \sigma E^i(y^i) - k^i - \tau^{r,r^*} - \\ &- l^i \vartheta^{i,r}\left((P^{r^*}(Q^{r^*}) - \varsigma^{r^*}\right)\frac{Z^r}{Q^r} + \frac{P^r(Q^r)}{\varepsilon^r})\end{aligned} \tag{9}$$

Also, we assume the marginal cost function of firm i is

$$C^i(y^i) = a^i \exp\left(b^i \frac{y^i}{\bar{y}^i} \right) \tag{10}$$

and its subvention function, respectively

$$E^i(y^i) = f^i \exp\left(g^i \frac{y^i}{\bar{y}^i} \right) \tag{11}$$

3. **Numerical results and Discussions.**

TABLE 2. Consumer tariffs for Mexican households (Centavos / kWh)

Year	Below 75kWh	Between 75kWh and 140kWh	Consume exceeding 140kWh
2002	\$46.9	\$65.0	\$162.3
2004	\$52.9	\$88.7	\$186.2
2006	\$59.7	\$98.6	\$208.0
2008	\$63.9	\$104.9	\$222.7
2010	\$68.7	\$113.7	\$240.9

As we see from Table 2, low energy consumers are still hardly subsidized by the government. But taking an average consumption by a household as 300kWh we see that an average price for one kWh is better reflected by the mixed oligopoly model, which includes the subsidies as the CFE's objective function.

Tables 3, 4 and 5 represent the results of our experiments for different σ selected by the government.. We have divided Mexico into 5 regions: North (Region 1), Baja California (Region 2), Central (Region 3), Distrito Federal (Region 4), and South (Region 5).

TABLE 3. Prices per region in Mexico for σ =9% (Centavos/kWh).

Regions	Perfect Competition	Classic Oligopoly	Oligopoly with subvention
Zone 1	$124.88	$192.34	$155.56
Zone 2	$155.45	$257.78	$222.32
Zone 3	$126.11	$196, 80	$161.56
Zone 4	$191.55	$302,43	$252,77
Zone 5	$145.11	$243,78	$165.88

Table 3 presents the results for σ =9%. If we compare Table 3 with upcoming Table 4 we will see that there is certain increase in prices but it is compensated by social effect of subsidies. If we compare price increase for σ =24,5% (as in Table 5) we can note that social effect of highly subsidized energy has a very negative effect on the unsubsidized industries/customers. It is reasonable to accept σ =15,5% as an optimal.

TABLE 4. Prices per region in Mexico for σ =15,5% (Centavos/kWh).

Regions	Perfect Competition	Classic Oligopoly	Oligopoly with subvention
Zone 1	$134.29	$193.44	$158.01
Zone 2	$157.44	$267.23	$234.01
Zone 3	$128.18	$201,71	$164.92
Zone 4	$193.35	$305,17	$256,62
Zone 5	$151.12	$247,34	$183.44

Table 4 presents the results for σ =13,5%. The calculations for the perfect competition are far below the actual domestic rates (compare with Table 1). The best approximation of real prices is achieved by the Oligopoly with subvention model. The Central and North regions have the highest demand and, consequently, the price. In reality, CFE is maintaining the same price over regions, which means certain extra subsidies to the North and Central regions.

As our calculation showed, σ =13,5% gives us the best possible consumer price.

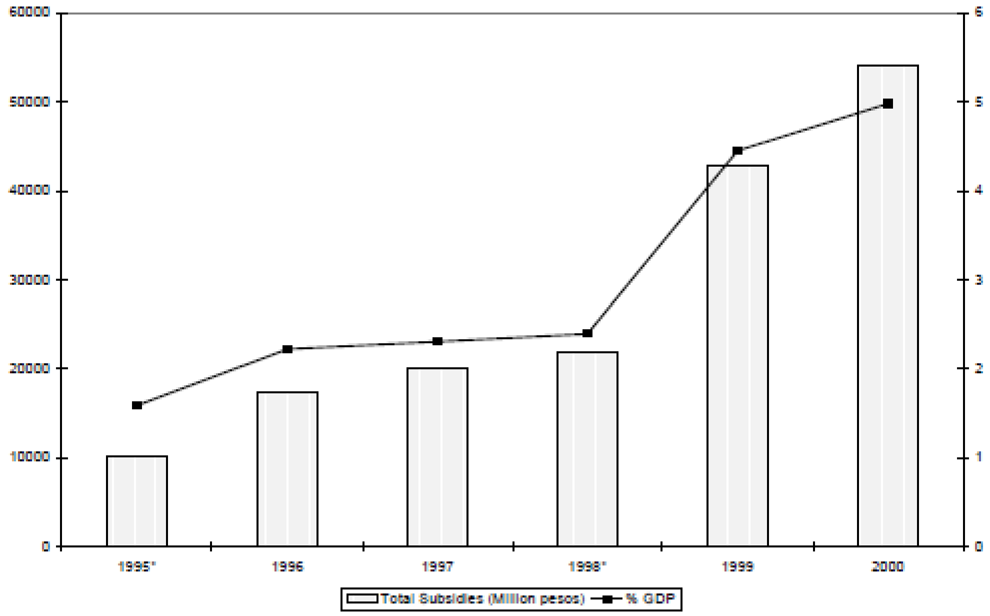
TABLE 5. Prices per region in Mexico for σ =24,5% (Centavos/kWh).

Regions	Perfect Competition	Classic Oligopoly	Oligopoly with subvention
Zone 1	$511.38	$880.16	$790.28
Zone 2	$670.27	$1084.44	$890.28
Zone 3	$520.12	$847.34	$693.14
Zone 4	$807.14	$1311.07	$1078.34
Zone 5	$612.27	$994.31	$816.24

Table 5 shows expected electricity prices for σ =27,5%. It is clear, that too heavy support of the poor customer has to be equalized by the higher market price for non-subsidized industries/customers.

Official sources estimate a net subsidy of USD $5 billion a year (see Figure 1):

FIGURE 1. Net subsidies in the electricity sector in Mexico.



It is so high principally because of residential and agricultural tariffs are set way below cost— residential tariffs alone could be as high as 3% of GDP. (The distributional effects of this subsidy are enormous; total tax collection, outside the oil sector, is only 10% of GDP.) In 2000, residential consumers received 64.1% of the total subsidy; the industrial sector, 17.9%; the agriculture sector, 11%; and the commercial sector, 5.3%.

As a consequence of this policy, residential consumers face a tariff that is among the lowest in the world; but, it relies on a regressive scheme as shown by [10] . A new 31- category tariff scheme adopted at the end of 2000 marks a further step at rationalization; still, the residential tariffs remain below cost—implying a subsidy for 98% of users.

Politically it has proved extremely difficult, if not impossible, to raise residential and agricultural tariffs. Thus, most analysts conclude that the only practical way to make the sector financially sound is to reduce costs—yet that, too, is politically challenging as it requires confronting the powerful unions that are embedded in CFE and are to block any attempt to allow private investment into the sector or to modify significantly the market architecture (e.g., tariff reform) in ways that could hurt their interests.

The strategy was to make the true costs of generating power more transparent—through market competition—and to empower independent regulators who would be able to scrutinize costs.

In addition to promising the delivery of electric service at lower cost, a shift to competitive electricity markets would make it possible to remove key operational decisions in the sector from the grip of the unions. Markets built around transparent rules as well as tariffs set at levels that ensured recovery of costs would attract private investment into new generating capacity and would also allow CFE to direct their scarce resources towards dire needs such as repair and maintenance of their existing assets.

Indeed, the experience in telecommunications, highways, the pension system, and the banking system, seemed to confirm, at the time, that privatization and the introduction of market forces would lead to an influx of private capital that could constrain the government’s ability to torque tariffs to its macroeconomic and political agendas. Today, the political case for privatization and market reforms is thus extremely difficult to make. Truly, policy makers often engage in verbal and legal contortions to argue that the proposed reforms do not involve privatization and unfettered markets.

4. Conclusions

In this paper, we assumed certain subvention function which depends on exogenous goal set by the government and firm´s level of production. Computationally, this oligopolistic market structure can be realized as a Cournot-Nash equilibrium game in which the firms maximize their profits. This model is composed in GAMS as a mixed complementarity problem (MCP) solved by a nonlinear complementarity and equation system solvers. The test calculations show that a switch from monopoly to generalized Cournot-Nash equilibrium may lead to lower consumer prices combined with a higher demand .Consequently, there are several improvements, which should be included in the model. Cost data needs to be more reliable, and a usage of a cost function instead of point cost data should be considered. Additionally, temporal distortions which might enter the model by using data for a single base year (2010) could be removed.

Also, capacity and transport cost data needs improvement since some data points rely on our own assumptions. The same holds for the demand elasticity.

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