ABSTRACT

As public utilities continue to evolve from regulated monopoly structures to open markets that promote free and fair competition, new players, new rules and new behaviors will continue to emerge, and given the uncertainties associated with this process, the need for suitable and a well-representative model increases. In this paper we present an Agent-Based Model (ABM) developed to capture some of the salient features of a deregulated electricity retail. We use the model to explore how different modes of deregulation affect the price of electricity. It also incorporates the effect of spatial distribution of retailers and the area of service covered by each retailer.

Keywords: Electricity, Agent-based models, complex adaptive system, deregulation, retailing.

1. INTRODUCTION

The pressure towards deregulation of the electricity supply industry – as being a public service utility – continues around the world but it proceeds at varying paces, despite the uncertainties related to the potential market design. This opens the way for competition to take place in that industry, resulting in breaking down large public monopolies into a number of enterprises that compete for supplying electricity to both industrial and consumer markets.

As a result of this movement, new players, new rules and new behaviors will continue to emerge. On the supply side, utilities cannot continue to make investment and pricing decisions using the same approaches that worked well in the past. They have to consider the new possibilities available to customers. On the demand side, customers will be more astute in carefully considering a deal or strategy which will best satisfy their electricity needs at minimal cost; this includes selecting the best supplier and finding the optimal use of electricity with respect to change in electricity price.

Rather than trying to predict the outcomes of the electricity market after deregulation, the analysis would be more useful if it concentrated on understanding the system behavior that emerges from the interactions of the market entities under different aspects, and to determine if a proposed market structure would be able to function efficiently and effectively under some conditions such as physical limitations of the electricity system (e.g. transmission constraints) [1]. Being classified as a complex adaptive system, because of complex interactions among participants in the market, deregulated electricity market calls for a model that simulates the interactions of a large number of players so as to study the macro-scale consequences of these interactions. ABM is differentiated from other simulation techniques by its focus on finding the set of basic decision rules that can generate the complex results examined in the real world. In practice, each agent makes its own decisions based partly on its knowledge about other agents in the system. Several tools for ABM implementation exist. General-purpose tools include spreadsheets, mathematics packages, and traditional programming languages. However, special-purpose tools such as Swarm, Repast, Ascape, and NetLogo are among the most widely used. Such tools provide the necessary infrastructure for rapid model construction and data analysis.

A great deal of agent-based computational economic modeling research efforts oriented at electricity markets have focused on the market connecting generators with aggregators or distribution utilities [2]; i.e. at the wholesale level. Our focus in this paper will be on modeling electricity market at the retail level. For that, a Generic Electricity Retailing Agent-based Model (GERAM) is proposed and developed. In GERAM, two kinds of agents, electricity retailers and consumers, were defined. Electricity retailers compete for customers within localized, but overlapping, areas and the decisions of agents in the model are affected by their location; hence the model is spatially-influenced.

In Section 2, a summary of electricity markets, their underlying structure and the idea of deregulation is presented. Section 3 summarizes theories in the literature about modeling deregulated electricity markets with the use of Agent-based Models. GERAM is explained in section 4 and the results obtained are presented in section 5. Finally, section 6 discusses the future work.

2. ELECTRICITY MARKET DEREGULATION

Regulated markets are often found when natural monopolies in an essential goods or services – such as water services, electricity, natural gas distribution, telecommunication and public transport – need to somehow controlled to realize the greatest social benefit. The regulation may cover the conditions of supplying the goods and services and specifically the price allowed to be charged.

The electrical power industry involves four main phases from the production process until the delivery of electricity to areas that need electricity: electricity generation (electricity production stations), transmission (the high voltage network which is known as the national grid), distribution (local lines companies), and retailing (electricity retail companies which compete to buy wholesale electricity and compete to retail it to consumers).

During the 1990s, a deep transformation in the electricity industry took place in many countries. This sector is moving from a monopoly structure to a more competitive one, as the transportation and telecommunications sectors. This process in which the government removes restriction to encourage greater competition among private players, and less regulation to protect the public interest is called deregulation.
Competition has been introduced in the wholesale generation and retailing of electricity. Wholesale electricity market involves several generation companies that compete to sell their electricity in a centralized pool (or spot market) and/or through bilateral contracts with buyers. Retail competition describes a market where consumers have the ability to choose among different suppliers or buy directly from the wholesale market. In some countries, such as Norway, this was done instantly for all customers. Other countries progressively implement it under a multiyear program, according to different customer sizes (as in England and Wales, Australia, and Argentina) [3].

Woo et al. [4] had listed critical questions to be addressed prior to electricity deregulation. Among these: Will many price-taking sellers compete for sales to many buyers? Will electricity consumers respond to wholesale price changes, as consumers prefer rate stability? Will consumers benefit when deregulation takes place before the current status, or we just have faith in the success of competition? Can the projected benefits of deregulation be obtained through other alternatives such as performance-based regulation which may be less risky? And if deregulation fails, can it be reversed? These questions were a result of deregulation problems observed in the past and a checklist for how to help avoid such problems in the future. The reason why some countries failed in the electricity deregulation process is that they didn’t fully address these questions before implementing deregulation.

When deregulating an electricity market, it is important to consider the impact of the deregulation process on both the wholesale and retail market, to prevent a market failure similar to the case of California electricity crisis between 2000 and 2001, where some electricity wholesalers were purchasing from a spot market at very high prices but were unable to increase retail rates because the state capped retail prices, causing the bankruptcy of two wholesalers.

As mentioned, when end-use customers can choose their supplier from competing electricity retailers, a retail electricity market appears; one term used in the United States for this type of consumer choice is energy choice or retail choice. Competitive retail suppliers give consumers flexibility in their energy purchases by providing them with a variety of service plans. The deregulation process had moved electricity retailing from administrative function within an integrated utility to risk management function within a competitive electricity market. Therefore, electricity retailers can now offer fixed prices of electricity for their consumers and manage the risk involved in purchasing electricity from electricity pools or sport market.

The role of the regulator in retail competition is crucial to ensure fair competition. It should set clear rules to prevent discriminatory actions, while actively promoting the entrance of new participants [3].

Legislative changes in New Zealand in 1999, allow for any consumer to switch their electricity retailer. Since 1 July 2007, all consumers in both the gas and electricity markets of the EU are given the right to take part in the free market, by switching between suppliers or renegotiating terms and conditions with their existing supplier. Many countries, such as Australia, United Kingdom, New Zealand, some US states (e.g Texas) …etc, provide consumers with the ability to choose their electricity and/or gas supplier in retail market mostly through an interactive well-designed websites that give them the ability to exchange information and compare prices and get the best deal according to different preferences and status. Detailed information and examples of electricity deregulation in several countries can be found in [3], [5] and [6] and for explanations of the status of the electricity industry around the world view [7].

The predictive accuracy of top-down approaches – when modeling the future of deregulated electricity sector performance – depends entirely on the actual occurrence of the scenario(s) hypothesized. In such cases, a simulation model that uses a bottom-up representation of the whole system without any hypothetical scenarios would be much effective. Agent systems are one of these approaches [8].

### 3. AGENT-BASED MODELS FOR ELECTRICITY MARKET

Bower and Bunn [9] presented an ABM of the wholesale market for electricity market in England & Wales which allows for comparing market prices, and the bidding strategies of individual generators under the different trading arrangements. The market is represented where each generating company is a separate computer generated autonomous adaptive agent that participate in a repetitive daily market and search for strategies that maximize their profit based on the results obtained in the previous iteration. Each company expresses its strategic decisions by means of the prices at which it offers the output of its plants. Every day, companies try to achieve two main objectives: a minimum rate of utilization for their generation portfolio and a higher profit than that of the previous day. The only information available to each generation company consists of its own profits and the hourly output of its generating units. As usual in these models, the demand side is simply represented by a linear demand curve. They compared the market outcome that results under the pay-as-bid rule to that obtained when uniform pricing is assumed. Additionally, they evaluated the impact of allowing companies to submit different offers for each hour, instead of keeping them unchanged for the whole day. The conclusion is that daily bidding together with uniform pricing yields the lowest prices, whereas hourly bidding under the pay-as-bid rule leads to the highest prices.

Bagnall and Smith [10] examined the feasibility of using autonomous, adaptive agent models to simulate generators in the UK electricity generation market to gain insights into the effects of certain market mechanisms on the bidding strategies. The learning process of the agents is based not only in their past profit performance but also on variables external to the behavior of the agents such as demand. The model consists of generating companies, each owning one generating unit differentiated by its type; specifications of each type are determined by parameters such as fixed cost, startup cost, unit generating cost, and capability. Market information and mechanisms are also modeled; market demand, capacity premium (estimate for the probability that availability cannot meet demand), constraints, scheduling algorithm and settlement. Agents have two objectives; the first to ensure that it is not losing money, and the other is to maximize profit. Learning Classifier Systems (LCS) was the learning method used by agents. Results of the model showed that agents learn to group similar environments together through the use of classifier system rules; it was also shown that the agents bid higher under the pay-at-bid price system (No

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1 Electric Power Supply Association (EPSA) (http://www.epsa.org/industry/primer/?fa=sold)
2 Electricity spot markets are where generators compete to supply energy through their supply prices or bids. An electricity spot market or pool is unlike virtually any other market since it must match demand and supply continuously to maintain network “electric equilibrium”. In some pools consumers also compete to purchase energy by submitting demand-side bids (von der Fehr and Harbord 1998).
SMP) opposed to SMP (System Marginal Price), however the SMP system results in slightly higher total cost of generation.

Researchers at Argonne National Laboratory in Chicago developed Electricity Market Complex Adaptive System (EMCAS): an electronic laboratory that probes the possible effects of market rules by simulating the strategic behavior of participants. Market participants are represented as “agents” with their own set of objectives and decision-making rules. Similar to how organizations and individuals operate in the real world, agents are modeled as independent elements that make decisions and take actions using limited and/or uncertain information available to them. They learn from their previous experiences and alter their behavior based on the success or failure of their previous strategies. Electricity prices are driven by demand for electricity, cost of electricity production, transmission congestion, external events, and company strategies [11]. In [1] the U.S. Midwest Power Market has been analyzed using EMCAS.

SEPIA (Simulator for Electric Power Industry Agents) is an example of adaptive agent model; it is a comprehensive and scenario-free modeling and optimization tool. Some scenarios conducted from the simulation in SEPIA were illustrated in [8]. The environment is classified into zones each with certain boundaries where generation company and consumer company agents are interacting through bilateral contracts. One of important issues that should be considered is the limits of the transmission network. When contracts require power to be transmitted across zone boundaries, they must be checked against an available transmission capability table; the table’s data are maintained by the transmission network operator agent. In the examples tested:

1. Each consumer company agent independently operates and tries to purchase power for the lowest possible price.
2. Each generation company controls one or more generators and try to maximize its profit by selling its power for the highest possible price.
3. The transmission network operator calculates available transmission capability (ATC) and posts it to all generation and consumer companies to access. It does not allow transactions if they violate transmission limits.

It was found that the generation companies are influenced by each other and by the other agents when setting their prices; this is obvious when examining the results of prices set by generation companies.

In [2] an ABM was developed to model changes in contracts at the retail level, where the distribution utility offers alternative contracts to its entire residential customers — that are the least price-responsive sector compared to commercial and industrial — to encourage more price-responsiveness than would be the case where fixed-rate contracts rule. They suggested a mechanism for contract selection. The focus was only on the adoption of TOU (Time Of Use) rates, not RTP (Real-Time Price) contracts. The advantages to the utility come from sharing the risk of wholesale price fluctuations that affect the utility’s costs; households have the advantage of being able to manage their utility bills better and, with that better management, reduce utility costs in its budget. Results showed that when spot prices are above fixed-rate prices, households will usually prefer TOU rate structure, which allows for load shifting and hence reduced utility bills.

Brazier et al. [12] developed a multi-agent model for load balancing, to smoothen the total peak load, through negotiation between utilities and customers. Focus was on residential consumers; one utility agent and a number of customer agents are used. In the negotiation process, both utility and customers need to succeed to make a good deal; utility companies are willing to decrease the price of electricity if consumers are willing to decrease peak usage; consumers are willing reduce their usage in return for lower electricity bill. The announce reward tables method of negotiation described in [12] is used. A case tested where the normal capacity for electricity is 100 whereas the usage is 135. The utility agent designed a reward table contains 10 possible choices for cut-down levels, each with its corresponding reward. The negotiation took three rounds. Results showed that as negotiation proceeds between utility and customers, customers were ready to choose higher cut-down levels in response to extra reward offered by utility.

An extensive though slighted dated literature review about ABMs for electricity market can be found in [13]. Models presented earlier have focused on the wholesale part of electricity market – except [2]. Yet none has dealt with the retail aspect within the context of the competition between retailers and the customers’ right to choose between those retailers. GERAM’s focus is on that theme.

4. A GENERIC ELECTRICITY RETAILING AGENT-BASED MODEL (GERAM)

With any given retail market there are two sets of behaviors that may be modeled to drive prices: retailers and customers. In an agent-based system for modeling retail petrol market, one kind of agents (retailers) is defined [14]. In our proposed GERAM, two kinds of agents, electricity retailers and consumers, are modeled. Electricity retailers compete for customers within localized, but overlapping, areas. Decisions of agents in the model are affected by their location, and hence expressed as spatially-influenced.

The aim is to model the interactions between the electricity retailers and the customers at an individual level by the use of agents, to come out with some emergent behaviors that appear based on some simple rules adopted by both retailers and customers. Initial findings are presented and performance of agents is tested under different conditions. GERAM is built based on ideas derived from different studies; agent rules [14] and zonal divisions [8].

4.1 Electricity Retailer (ER) Agents

ER agents possess several parameters shown in table 1. Each ER has to make a decision regarding the selling price which will maximize its profit; i.e. the price setting strategy depends on the status of the company’s profit, and indirectly influenced by other companies’ prices because customers are influenced by price offered by their ER, so if they found better prices with other ERs they will accordingly switch to other ER, and consequently ER profit will be affected by its customers.

Profit maximization strategy similar to the one implemented in [15] is used. However, as suggested in [15], other strategies such as attaining market share could be used.

4.2 Customer Agents

Customer may decide on which company to buy from based on distance and attractiveness (closeness and price), as mentioned in [14] when they modeled retail petrol market. Distance is an important factor when considering petrol market because customers usually try to find the closest station to fill from along with finding best price. In GERAM, customers decide which ER to buy from based on price only. Table 2 shows customers’ parameters.
Table 1: Definition of variables used by ER agents

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>My-customers</td>
<td>Number of customers who buy electricity from me</td>
</tr>
<tr>
<td>List-of-customers</td>
<td>Names of customers who buy electricity from me</td>
</tr>
<tr>
<td>Field</td>
<td>The area of service, determined by a radius around the company.</td>
</tr>
<tr>
<td>Cost-of-production</td>
<td>The amount (per KWH) that it costs ER to buy electricity (from generation companies) and sell it (to customer), (fixed with time)</td>
</tr>
<tr>
<td>Transmission-cost</td>
<td>The cost of transmission of electricity from ER to customers belong to this ER. It is function of distance from consumer and equals to: ( \exp(\beta \times \text{distance}) ), where ( \beta ) is a coefficient controlling the impact of distance</td>
</tr>
<tr>
<td>Amount-sold</td>
<td>Total amount of electricity sold to my customers.</td>
</tr>
<tr>
<td>Strategy</td>
<td>Price-setting strategy of the company. There are 3 strategies to choose from.</td>
</tr>
<tr>
<td>Price</td>
<td>The selling price of electricity to customers (fixed for all ER’s customers but can change by time)</td>
</tr>
<tr>
<td>Total-cost</td>
<td>((\text{cost of production} \times \text{amount sold}) + \text{(transmission cost)})</td>
</tr>
<tr>
<td>Profit</td>
<td>((\text{price} \times \text{amount sold}) - \text{(total cost)})</td>
</tr>
</tbody>
</table>

4.3 Model Framework

NetLogo 4.0 was used to create GERAM, where Electricity retailers and customers agents are located in a two-dimensional grid. Their rules are shown in boxes 1 and 2.

The model interface is divided into 3 parts: the 2D platform area where agents are located, the user control keys in which the user can choose different model settings, and the results area which are represented in graphs (figure 1). The model starts by agents taking place in the 2D platform; each customer agent takes the color of the ER it belongs to, so red customers belong to red ER and so on. The number written on ER agent is the number of customers belong to this ER, and is changing as number of customers changes through the model running.

The profit maximization algorithm that ER agents follow is composed of simple rules:

- **if** current_profit \(> \) last_profit by x_percent
  - **Use the same pricing strategy**
- **else**
- **if** current_profit \(>\) last_profit by less than x_percent
  - **Keep the price constant**
- **else**
  - **Change to other pricing strategy**

Customer agents use choice algorithm to decide on their company using simple rules:

- **if** current_bill \(>\) last_bill
  - **Change my company**
- **else**
  - **Stay with my current company**

Table 2: Definition of variables used by Customers agents

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>My-company</td>
<td>The company that customer belongs to or take electricity from</td>
</tr>
<tr>
<td>number-of-neighbours</td>
<td>The number of customers in the neighbourhood</td>
</tr>
<tr>
<td>distance-from-my-company</td>
<td>The distance between the customer and its company</td>
</tr>
<tr>
<td>required-amount</td>
<td>The amount of electricity needed by the customer.</td>
</tr>
<tr>
<td>purchasing-price</td>
<td>The price of the company that the customer belongs to.</td>
</tr>
</tbody>
</table>

4.4 Experimenting with GERAM

In GERAM experiments, we explore the model’s "space" of possible behaviors and determine which combinations of settings cause certain behaviors, through running the model many times, by varying the model’s settings and recording the results of each model run. Primarily, the effect of changing four parameters on the behavior of the model is tested:

1) Number of ER agents offering the service
2) The area of service of ER agents
3) Initial prices of ER agents
4) The level of profit under which ER agent will not change its strategy

The behavior that may be tested can be: prices offered by ER agents, profit of ER agents and the number of customers possessed by each ER. Mainly the focus will be on the effect of these parameters on the prices. In all experiments, the model was run several runs with 500 steps and it shows stability from earlier steps, so 300 steps were enough to reach the steady state of the model results.

**BOX 1: Companies Rules**
- Each company has a field representing its area of service. It is determined by a radius around the company. The user of the model can alter the field of each company using sliders located on model interface.
- There are 3 price strategies that company may choose among in each iteration:
  1. Increase price (by 1)
  2. Decrease price (by 1)
  3. Keep the price constant
- Initially, each company is given random strategy to use, and then it may change this strategy throughout the model.

**BOX 2: Customers Rules**
- There are 2 types of customers:
  1. "Free Customers" who can choose the company to take electricity from.
  2. "Restricted Customers" who cannot choose among companies.
- A certain customer is "free" when it existed in a field of more than one company. Otherwise it is "restricted" to take electricity from the company that covers its location. If any customer not existed in a field of any company, then it is assigned to the company that is nearest to its location.
- Only free customers use Choice algorithm
5. RESULTS AND CONCLUSION

The average prices don’t change much as the number of companies in the system changes (figure 2). This is because, once a company decreases its price by one unit, the customers switch to it, which leads all companies in the system to change their current pricing strategy to compensate their loss due to customers’ escape, and because the speed of customers’ escaping is high – as customers are very sensitive to any change in price – the prices offered by all companies in the system are close. However, the actual purchased price by customers is lower when the number of companies increases, i.e. the gap between average price offered by companies and average price purchased by customers increases as the number of companies increases. Yet it becomes similar at some point (4-companies and 5-companies model). In this context, we suggest that 4-companies model would be the best choice under the circumstances that all 4 companies offer their services to all customers (full overlap).

As the percent of free customers in the system becomes larger and when the overlap between service areas of companies increases, the average prices decrease (figure 3). So companies who offer the service should serve in areas where other companies also serve, so that to allow for competition; otherwise, the system would lack competition especially if there is an area served only by one company which will turn the situation into monopoly. If such a situation appeared (for e.g. a region that is newly constructed and still not served by existing companies), then the role of the regulator should be to ensure that the offered price by this company matches the prices of companies in other regions to protect the customers of that region from price spikes.

It has also shown that average prices are oscillating around the initial price (figure 4). For that, the regulator must ensure that companies will start their prices with prices near the minimum limit, yet not actually the minimum price itself as we saw that the minimum price will eventually increases to reach the same level of prices obtained with initial prices that are higher than the minimum (in our model those initial prices are 67, 68, 69 and 70 which lead to the same level of average price), so starting with 69 or 70 would be the best choices in this case, as customers won’t witness high increase percents in prices.

Finally, the level of profit (x%) in which the company considered as profitable company and stay applying the same current pricing strategy is tested. If the company’s profit increases above x%, it will keep its current strategy; if increasing below x%, it will keep its current price constant; otherwise, it will change its strategy. Results with different values of x% (figure 5) show that as this percentage increases, average prices decrease in a remarkable way. This is because this level affects the speed of changing strategy. So, it is suggested that companies use a profit level that allows for a proper delay before fixing its profitable strategy (in our case, it is 50% or 75%).
6. FUTURE WORK

Work to be done in the future should move towards modifying GERAM in a way that makes it more representative of electricity market. This can be achieved by allowing for the connection between the wholesale and retail market, as retailers would then use data resulted from the wholesale market, mainly the amount it costs the retailers to buy electricity from the wholesale market and the amount that can be offered by retailers to their customers.

Another important limitation of GERAM that should be tackled in future work is customers demand from electricity. In GERAM, customers’ demands are fixed. However, customers should have the ability to adjust their demand according to price changes. This then would drive suppliers to reduce their prices in order to compensate the reduction in profit that resulted from reduced demand. One should examine how will customers’ demand adjustment affects the prices offered by companies and vice versa.

A maximum limit for prices offered by companies – of what is called price-cap which is considered as a limited price control – should be well-defined. In GERAM, this maximum is defined by an assumed value that allows for a change of about 13% above the production cost. However, price cap, when calculated, takes into account several criteria, which must be considered when setting this maximum value. However, in future researches, this maximum could be removed as prices will be indirectly controlled by the competition.

Further researches can be made on the model by adding new features to agents to examine more dynamics of the market. Features include: defining different types of contracts between retailers and customer in which customers can choose how they want to pay for their electricity. Another feature is classifying customers into different categories (industrial, commercial and residential) each with its own demand levels, and prices are set different for each category.

Finally, for GERAM to be more representative of reality, real data about the spatial distribution of companies should be incorporated along with the service areas they cover and the available capacity each company can supply. Companies may also adopt more complex price-setting strategies. Data regarding customers’ consumption from electricity should also be used.

REFERENCES


