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USING A MARKET GAME AS A TOOL FOR TEACHING STRATEGIC BEHAVIOUR IN AN ELECTRICITY INDUSTRY RESTRUCTURING COURSE

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Abstract

Electricity industry restructuring is now being taught in electrical power-engineering curricula around the world. The subject involves a great deal of interdisciplinary concepts, including economic, commercial and other social and environmental aspects of the restructuring process as well as engineering. Among these new concepts, an introduction to market strategic behaviour is essential. This paper describes a teaching tool developed at the University of New South Wales (UNSW) to facilitate students' understanding of strategic behaviour in electricity markets via a set of simple spreadsheet-based games. We also discuss the outcomes from the first trial application of these games in the postgraduate subject Elec9201-Electricity Industry Planning and Economics at UNSW in session 2, 2003.

1. INTRODUCTION

The electricity supply industries around the world have been restructured for more than a decade. To meet the growing demand in providing knowledge for this important economic sector, a subject teaching this restructuring process is now popular in electrical power-engineering curricula. The subject usually involves a great deal of interdisciplinary concepts, including economic, commercial and other social and environmental aspects of the restructuring process as well as engineering. Among these new concepts, an introduction to market strategic behaviour is essential as it helps students understand why the market price is often higher than the marginal cost of producing electricity.

Strategic behaviour is usually defined as trading or bidding actions of electric power generating firms that can profitably influence spot prices. These behaviours include the exercise of *individual market power* of a single firm and the engagement of a group of firms in *tacit collusion* (in this way, collusion can also be seen as an exercise of collective (or joint) market power of a group of firms that act as one). Strategic actions usually involve either withholding generation or setting bidding prices above the marginal cost of producing electricity.

In reality, strategic behaviour is complex and subject to numerous factors such as market organisation, demand and engineering factors. As it is not straightforward for students to understand, a teaching tool to assist students to learn strategic behaviour is thus in high demand.

Several teaching tools for electricity industry restructuring have been developed. Turtiainen et al. [1] at Tampere University of Technology, Finland, built a web-based simulation game to teach students how to operate in electricity market. Their simulation environment allowed participants to make not only trading decisions but also investment decisions. Madrigal and Flores [2] at Morelia Institute of Technology, Mexico, developed a sophisticated software platform to teach various architectures of the electricity spot market. The authors reported that simulations of electricity markets from this platform could also help students understand market power in electricity markets. Both of these teaching tools are comprehensive and successful but required a great deal of programming effort. They might be too complicated for students to learn how to use and to understand strategic behaviour from simulation outcomes.

This paper describes a teaching tool developed at the University of New South Wales (UNSW), Australia, to facilitate students' understanding of strategic behaviour in electricity markets. Simplicity and clarity are our main criteria in developing this teaching tool. A set of spreadsheet-based tools was developed to help create, coordinate and play a set of simple electricity market games. Students can play these games coordinated by an instructor, tutor or even by a student representative.

Playing these games, students can see how the market operates and how market power can be exercised.

The rest of this paper is organised as follows. Sections 2 and 3 describe the design and implementation of the electricity market game. Section 4 reports the outcomes from the first application of these games at UNSW. Section 5 concludes the paper with brief discussions on some possible extensions of the electricity market game.

2. GAME DESIGN

2.1 Assumptions

There are various ways to create games with different degrees of complexity. So as to facilitate the understanding of how the market operates and the strategic behaviour of market participants, a simple model of electricity markets is chosen with following assumptions and features:

- The competition is on the supply side of the market, amongst generating firms.
- There is no demand side participation in the market. That is, the consumers are price takers and are represented by a completely inelastic aggregate demand (i.e. load).
- The transmission network effect is not specifically modelled although the market clearing mechanism uses loss factors to adjust the offer prices for each firm (adjusted offer price = offer price / loss factor). All firms and the aggregate load are connected to a single bus. The loss factors, if included, only increase the offer prices and do not affect the supply demand balance.
- Firms do not have to commit or de-commit their generating units. The unit commitment problem is thus neglected in this simple game.
- Each firm is assumed to have no financial contracts, whereas in practice firms use these as tools for hedging the risk of losing profit.
- A firm has a portfolio of generating units, each of which has a capacity and a constant incremental variable cost (i.e. constant marginal cost). Each firm submits a stepwise offer that includes 10 price/quantity pairs. Offer prices must be in strictly increasing order and within a non-negative range (e.g. $[0, 10000]/MWh). Offer quantities must be non-negative and the sum of all quantities must be equal to the maximum capacity of the firm's generating portfolio.

2.2 Market clearing mechanism

The market clearing mechanism (i.e. the rule of the game) works as follows. Given the submitted offers of all generators and the demand for a spot market, the market coordinator will clear the market so as to minimise the cost of power delivery.

First, all offer prices are adjusted with regard to their loss factors. The generator with the lowest adjusted offer price will be dispatched first, followed by the other generators in order of increasing adjusted offer price (merit order). If the adjusted offer prices are identical, the dispatch order will be as follows: quantity (the higher quantity will get dispatched) and offer band number (the higher band number will get dispatched), otherwise arbitrary.

2.3 Game types

The software supports two types of electricity market game: a single hourly spot market (one-shot game) or a daily set of markets with 24 one-hour trading intervals (day-ahead game). Participants of the game can be organised as follows. Players/students are divided into groups, of which each represents a generating firm (i.e. a game player). The game coordinator (an instructor, tutor or a student representative) will play the role of the market coordinator. The game can be played once or repeatedly with multiple rounds.

2.4 Game process

The process of coordinating and playing game is as follows:

Step 1: the coordinator sets up a game, inputs firms' portfolios and announce the game's set-ups and rules.

Step 2: players submit offers to the coordinator.

Step 3: the coordinator clears the market and announces the market clearing results (dispatch price and quantities) to all players.

Repeat steps 2 and 3 if the game is a repeated one with multiple rounds.

3. GAME IMPLEMENTATION

Microsoft Excel was used to implement the two main tools for the game as Excel workbooks [3]. They include a coordinator's tool and a player's tool. Further details on how to use these tools can be found in [4].

3.1 The coordinator's tool

The coordinator's workbook contains

- A market clearing mechanism worksheet,

- An economic dispatch worksheet to benchmark the market outcome against the perfectly competitive market (with minimum cost), and
- A worksheet to create a game report. Concentration index (HHI) and monopoly index (Learner index) are employed to measure the degree of market power in the game outcomes. For details of these indices, see [5].

3.2 The player's tool

The player's tool is a scenario analysis tool to help determine offer strategies. The tool works as follows.

- Each player conjectures what her competitors will offer in the next round of the game. For example, she might assume that her competitors do not change their offers in the next round of the game. Based on the conjectured offers of all other competitors, she can use the tool to determine a good offer strategy.
- The Excel spreadsheet model constructs the residual demand curve for the player based on the demand and her conjecture on the offers of other competitors. The player can then vary her offer parameters (prices & quantities) to see how her trading profit might change. She can even use Excel solver (and data table) to determine the optimal offer, noting that standard solver in Excel does not necessarily provide a global optimal solution.

This tool is for reference only because it is based on the conjecture on the offers of other participants. Players are encouraged to use this tool for guidance but also consider other information and use their own judgement for decision-making.

4. INITIAL APPLICATION & OUTCOMES

We first applied these games to teach strategic behaviour in electricity market in the postgraduate subject Elec9201-Electricity Industry Planning and Economics at UNSW in session 2, 2003 with the first author playing the role of the teaching assistant and the game coordinator.

4.1 Game set-ups

4.1.1 Market structure

The class with initially more than 30 students was divided into six teams representing 6 generating firms. Each team participated in four separate games of several rounds each, conducted in parallel:

- Game 1 – Hourly spot market game: all six firms had identical portfolios and competed to supply the demand in a one-hour spot market.
- Game 2 – Daily market game: all six firms had identical portfolios and competed to supply a daily demand profile including 24 one-hour trading intervals.
- Game 3: as game 1 but with non-identical generating company portfolios.
- Game 4: as game 2 but with non-identical generating company portfolios.

The generating portfolios were defined as

- Identical generating company portfolios: one generator with a capacity of 1500 MW and incremental variable cost of $12/MWh. The total capacity of the market is thus 9,000 MW.
- Non-identical generating company portfolios:
  - ➢ Firm 1: a base generator with small capacity 500 MW @ $6/MWh.
  - ➢ Firm 2: a base generator with large capacity 2500 MW @ $6/MWh.
  - ➢ Firm 3: a large generator with portfolio with 1500 MW @ $6/MWh, 500 MW @ $20/MWh and 500 MW @ $50/MWh.
  - ➢ Firm 4: a large generator with portfolio with 500 MW @ $6/MWh, 500 MW @ $20/MWh and 500 MW @ $50/MWh.
  - ➢ Firm 5: an intermediate generator with 1000 MW @ $20/MWh.
  - ➢ Firm 6: an open cycle gas turbine generator with 1000 MW @ $ 50/MWh.

  The total capacity of the market remains 9,000 MW.

In these games, all loss factors of all generating firms were set equal to one, i.e. no network effects.

4.1.2 Market demand

The demand is deterministic and inelastic. In the hourly/one shot market games (games 1 and 3), demand is 7000 MW (deterministic or stochastic). In the daily market games (games 2 and 4), the daily demand profile has 2 peaks. The minimum and maximum demands are 1900 and 8000 MW respectively.

4.1.3 Trading information

In the beginning of each round, all teams were provided with information for each game on

- Clearing prices and dispatch quantities (24 intervals for games 2 & 4) in the previous round,
- Offers of all teams in the previous round, and
- The rank of teams in game 1 and 2 in the previous round and the cumulative rank for the rounds to date. Rank is based on individual profit.

4.2 Schedule and assessment for games

4.2.1 Time allocation

The games started from week 4 of the course, which had 16 weeks in total with 3-hour lecture in every Monday class. We allocated one hour (in week 4) to introduce the game structure, rules and demonstration in class. After that, games 1 and 2 were run weekly for 6 and 4 rounds respectively. From week 6, games 3 and 4 were run in parallel with games 1 and 2 for 5 rounds. Offers for each game were submitted on or before 5PM Friday of each week to the coordinator. The market outcomes were then emailed to participants on Monday morning of the following week.

To facilitate game playing, we gave a one-hour lecture on strategic behaviour in electricity market in week 6. In this lecture, we differentiated the exercise of individual market power from tacit collusion (i.e. exercise of joint market power) and introduced a solution concept of game theory, the Nash equilibrium [5]. From week 5, the last half hour of the weekly class was devoted to discussing the outcomes of the four games for the previous round.

4.2.2 Assessment

In the end of the course (week 16), each team was asked to submit a report (about 2000 words) on how they played the game (i.e. strategy on setting offers). In the report each team was asked to discuss for each of the four games:

- The outcomes of each game and the strategies used by the team and the other teams to the extent that the team understood their strategies;
- What the team would have done differently given the observed bidding strategies;
- What strategy the team thought would apply in the longer term in these particular games; and
- Other tools or techniques the team developed or thought would assist to facilitate trading.

Report discussions had to be supported by evidence from the games, technical or academic references or practical experience.

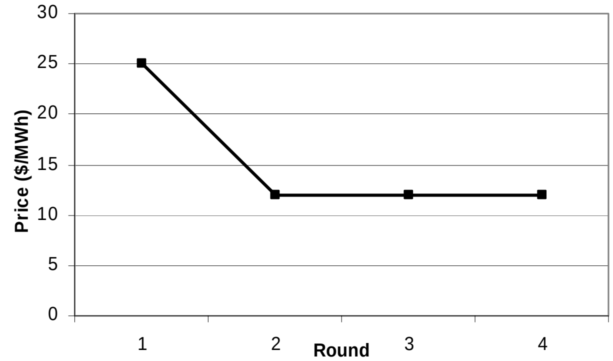

Figure 1 – Spot market price in game 1

The report accounted for 20% of the total course assessment mark. We set the prizes of 2% bonus marks for the teams that have top overall rank in games 1 and 2 and 1% bonus mark for each of the runner-ups.

4.3 Game outcomes

4.3.1 Game 1 and its extensions

Given the demand of 7000 MW, no team has market power in this hourly spot market game. Any team can be excluded from being called for dispatch. The stable equilibrium of the game is that all teams bid on or below their incremental variable cost ($12/MWh), i.e. an equilibrium of the perfectly competitive market. This was reflected from the game outcomes. Figure 1 shows the evolution of the spot market price over the first 4 rounds. Spot price was high in the first round because some teams offered high price. In the forthcoming rounds, all teams competed aggressively by offering all capacity on or below marginal cost. This decreased spot price down to $12/MWh and zero profit to all teams for the next 3 rounds. The game converged quickly to the perfectly competitive equilibrium.

After round 4, we redesigned this game to further stimulate the game playing. In game 1A, the market was divided into two markets. So we had 2 sub-games: game 1Aa (teams 1, 2 and 3) and game 1Ab (teams 4, 5 and 6). The demand for each sub-game was 4000 MW. To gain some bonus mark in game 1A, a team had to compete (in accumulated profit) not only with others within its own sub-game but also with others in the other sub-game. Game 1B had the same market structure as game 1 but the demand was increased to 8500 MW. Both redesigned games were run for 2 rounds. In game 1B, as demand was increased, every team in all games had market power to increase spot price no matter what other teams might do.

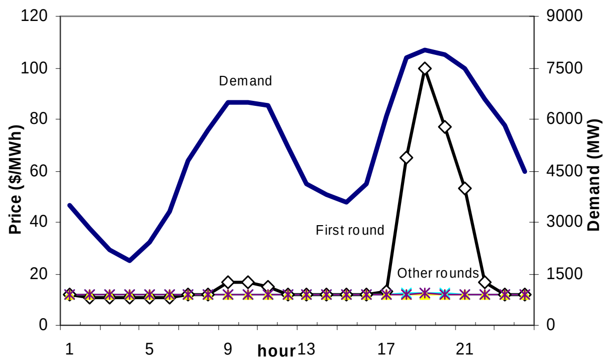

Figure 2- Spot market prices and demand profile in game 2

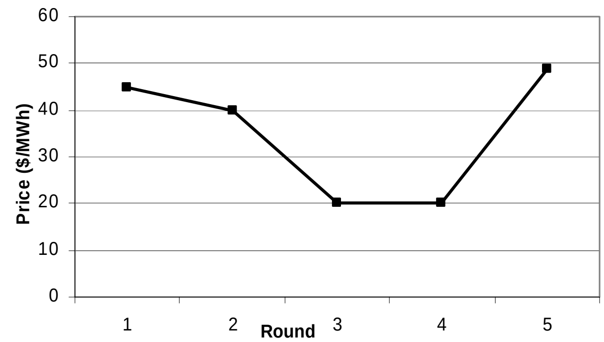

Figure 3-Spot market prices in game 3

The outcomes of the redesigned games were interesting. There was collusion in both markets of game 1A. In the first round, teams in game 1Ab colluded with a spot price of $10,000/MWh, whereas teams in game 1Aa competed but less aggressively with a spot price of $20/MWh. The second round resulted in the reverse outcomes. Teams colluded in game 1Aa with a spot price of $9,991/MWh and competed in game 1Ab with a spot price of $15/MWh. As for game 1B, it resulted in perfectly competitive equilibrium at $12/MWh even though every firm had market power. These outcomes suggested that strategic behaviour might be easier in markets with fewer firms.

4.3.2 Game 2

The market demand is higher than 7500 MW (i.e. total capacity of 5 firms) in trading intervals 18, 19 and 20. In these intervals, every firm has market power on the residual demand to increase spot price whatever other firms might do, whereas in the remaining trading intervals, no generator has market power. It was expected that spot prices were high in trading intervals 18, 19 and 20 and low at marginal cost ($12/MWh) at the others. The game outcomes did not totally meet this expectation. Figure 2 shows the demand and spot prices for the whole day over 4 rounds. As in game 1, spot prices in the first round were high during peak periods. In the subsequent rounds, market is stable at perfectly competitive equilibrium. No generator wanted to exercise market power to set a high spot price but receive a low dispatch quantity.

It might be that the bonus mark scheme in games 1 and 2 discouraged teams to behave strategically. Teams were not concerned about their zero profit but their overall rank in the games to get bonus marks, whereas firms in real markets try to maximise their trading profits.

4.3.3 Games 3 & 4

Games 3 and 4 were created to allow teams to experiment with their ability to exercise market power. Firms 2 and 3 have large capacity and had market power, whereas firms 1, 5, and 6 are small firms that have no market power. These games were played for 5 rounds.

Figure 3 shows the spot prices for the spot market game 3. The moderate spot prices and their competitive offers revealed that firms with market power were too cautious to take advantage of the opportunity to exercise their individual market power. The spot prices even went down to the perfectly competitive price at $20/MWh (i.e. the system short run marginal cost (SRMC) from the economic dispatch calculation) in rounds 3 and 4.

Figure 4 plots the spot market prices and the short run marginal cost for the whole system for the daily market game 4. In this game, even though the demand at some time intervals (e.g. intervals 18, 19 and 20) created even more market power for some firms, this advantage was not pro-actively utilised. Spot prices were not significantly higher than the SRMC and ranged between $6 and $52/MWh. The spot market price was surprisingly below SMRC in round 3 because generator 6, which was not used in the economic dispatch, suddenly got dispatched as they had offered all capacity at $0/MWh, which is much lower than its incremental variable cost ($50/MWh).

4.3.4 Feedback from teams' reports

According to the team reports, students found it rewarding to improve their understanding of strategic behaviour by playing these games. It was a good opportunity for them to share experience in playing games and analysing market behaviour.

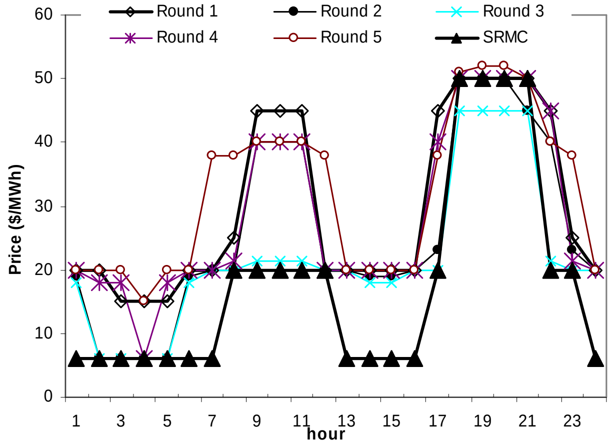

Figure 4 – Spot market prices in game 4

Most teams recognised the market game equilibria in games 1 and 2. They were aware of their market power in some particular trading intervals in games 1A, 1 B and 2 but avoided being the price-setter firm (or marginal firm) since in doing so they had less dispatch and others had advantage in getting bonus marks.

In all games, particularly games 1 and 2, some teams reported that there were times they attempted to initiate tacit collusion by unilaterally withholding generation (put some of their capacities at high prices) but failed to maintain this "nice" strategy because other teams behaved aggressively (put all their capacities at low prices) and captured large market shares. They suggested if the games had been run long enough, they would have been able to set up a successful collusion rather than playing a marginal cost strategy at all times.

Teams paid less attention to games 3 and 4 because there was no bonus marks for these games.

5. CONCLUSION

This paper has described a spreadsheet-based teaching tool developed at UNSW to help students better understand how the market operates and strategic behaviour in a simulated market with a simple market clearing mechanism. The experience from the first application of these games to the electricity industry restructuring course at UNSW has demonstrated that:

- The games are simple but robust;
- They can be used to demonstrate different market outcomes contributed by students' participation;
- Playing these games, students also familiarise themselves with spreadsheet modelling which can be used as a quick and simple tool for decision-making and analysis.

Several options can be further developed upon the current basic design of our electricity market game:

- Games with stochastic demand: random demand for each round of the game can be input in the coordinator's worksheet.
- Day-ahead games with multiple offers: The game coordinator can design a day ahead game with multiple offers, each of which will only apply for a particular period in the trading day, e.g. peak and off-peak periods. To do this in a simple way, the coordinator can use two coordinator's spreadsheet tools for two particular periods of the daily game. The demand profile for each period should be trimmed or modified accordingly.
- A web-based game: the communication in games is currently simple via email. It would be better to allow players to input their offers and get market information via a web site. This would motivate the implementation of web-based market electricity games. This development can still utilise the spreadsheet-based coordinating tool as the main simple calculating kernel.

6. ACKNOWLEDGEMENT

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