

## **Appendix A. Instructions of the Energy Portfolio Management Experiment**

The information in this appendix concerns the original instructions, communicated with subjects participating in the experiments studied in the research paper "Decision Strategies in Sequential Power Markets with Renewable Energy".

While the online experimental market environment was originally designed for this study and the server with the original experimental sessions no longer online, it has been further developed and used by other research groups. The documentation, JAVA code and original instructions are openly accessible via [github.com/eur-rsm/hedging\\_game](https://github.com/eur-rsm/hedging_game).

### **Instructions**

The instructions are simple. If you follow them carefully and make appropriate decisions, you can earn a substantial amount of money. Your earnings will be paid to you in euro at the end of the experiment based upon your final financial position. The average amount of earnings is 25 euro, the maximum is capped at 50 euro.

It is important that you remain silent and do not communicate with other people while the experiment is running. Do not log in before the experimenter tells you to log in. You can register to the game by going to [http://wolf38.ict.eur.nl:8080/hedging\\_game/faces/register](http://wolf38.ict.eur.nl:8080/hedging_game/faces/register). Use your student number as your user name. Passwords can be chosen freely. If for some reason you lose connection to the internet or the game play does not automatically load, do not refresh the page. You can log-in again by using your log in credentials at [http://wolf38.ict.eur.nl:8080/hedging\\_game/faces/login.xhtml](http://wolf38.ict.eur.nl:8080/hedging_game/faces/login.xhtml). If your screen does not update automatically, please go to the address bar and press enter. Do not press F5 to refresh as this might introduce errors.

Please make sure you go through the full documentation. It will help you significantly in understanding the game. The experiment consists of 3 sessions of 30 rounds with each 2 decision periods. The whole experiment will take about 90 minutes.

If you have questions, please indicate this to the experimenter. We appreciate your cooperation.

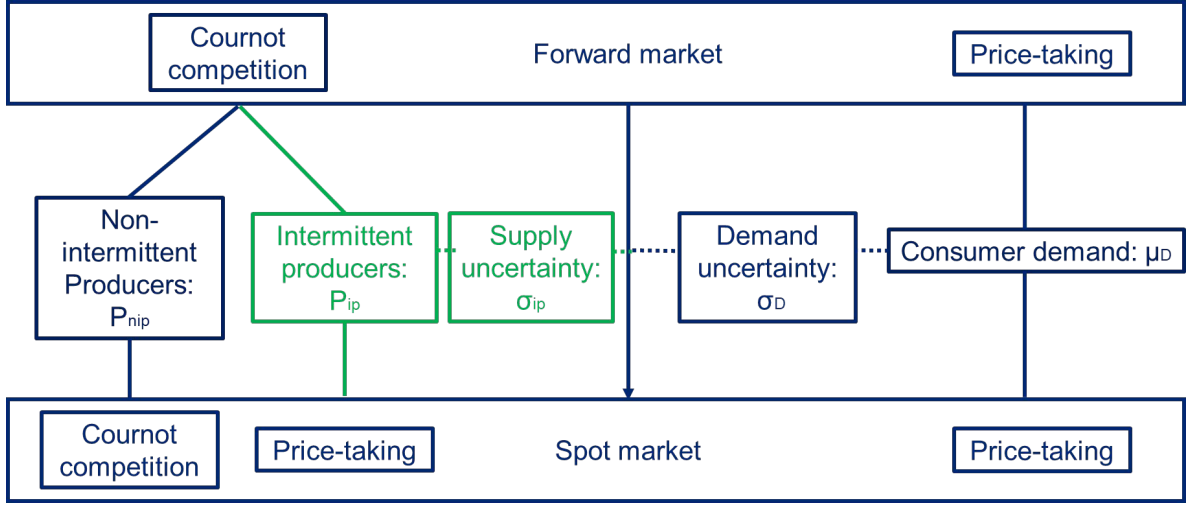


Figure A.1: Schematic model of power forward and spot markets, based Peura and Bunn (2018)\*.

## Background

This is an experiment in the economics of strategic and risk-related decision making in electricity wholesale markets. In the experiment, you will participate in a market as an intermittent (e.g. wind) or non-intermittent (e.g. gas) producer of the fictitious commodity electricity and trade it on a forward and spot market. Between the different sessions, the market share of intermittent and non-intermittent producers varies. The counterbalanced allocation of producers ensures that every player plays an equal amount of rounds with the same production type. The experimenter will announce at the beginning of each round if a new round or session has begun.

Figure A.1 presents a schematic model overview of the forward and spot market under consideration, based on work by Peura and Bunn (2018)\*. The number of all (intermittent and non-intermittent) power producers is set to 15. The consumer agent's demand follows a normalized

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\* Peura, H., Bunn, D. W. (2018). Strategic forward trading and technology. Available at SSRN 2738703.

distribution with  $D \approx N(11500, 1150)$ . We set the maximum capacity of non-intermittent producers to  $P_{nip} = 900$  MW and variable costs of non-intermittent producers to  $\eta_{nip} = 50$  euro/MWh. The production of intermittent producers follows a normalized production of  $P_{ip} \approx N(900, 50)$ . We allow minimum bidding prices of -300 euro/MWh and maximum bidding prices of 3,000 euro/MWh. Note that we will use other numerical examples in the instructions. These are only meant as an illustration to avoid any bias. Please consult the course material of the "Energy Markets and Finance" seminars for further background information on rationales for forward trading in wholesale power markets.

### Game Overview

*An example is used to explain the basic game play, written throughout this document in italic. You can log-in to this example by going to [http://wolf38.ict.eur.nl:8080/hedging\\_game/faces/login.xhtml](http://wolf38.ict.eur.nl:8080/hedging_game/faces/login.xhtml). The example consists out of a market of 6 players with Username: 1 to 6. and respectively the same Password. Thus, for logging in to player 1, submit '1' in the Username and Password field. You will find the game is currently in round 5. Go to the Bids tab to find all the previous bids of the respective player. Unless mentioned otherwise we will use player 1 in the explanation. An overview of this player his game tab is found in Figure A.2.*

**Market Setting** The 'game' tab is the main tab of the game, accessed when logging in to the game. In this tab, you get a portfolio overview under "My Plants" (dark green in A.2). Market information will be presented to you under "Market Info" (light green in A.2). The remaining fields in this tab show the financial overview of your activities in the market. The 'bids' tab gives you an overview of the individual bid history and the cleared market results in all previous rounds. The 'info' tab finally gives general background information on the game. The different tabs are shown in black in Figure A.2.

**Producer Types** There are 2 different producer types:

- **Wind producers** Wind producers supply power from **intermittent** power sources, i.e. wind mills, The supply is therefore uncertain, depending on for instance wind speed. The supply of the wind producer is normally distributed. The expected average and variance can be

found under "Market Info". All wind agents have the same production technology, with the same probability structure, and that their supply is mutually independent.

- **Gas producers** Gas producers supply **non-intermittent** power with a maximum production capacity, which can be found under "Market Info". As this producer converts a storable commodity into electrical energy, you may bear a marginal cost, as you burn more fuel with increasing production. All gas producers have the same production cost function.

*There are 3 wind producers in the game with an expected output of 2500MWh and standard deviation of 125 MWh. As the wind is for free, these producers don't have a marginal cost. There are also 3 gas producers in the game with a maximum output of 2500MWh. They bear a marginal cost of 50 euro/MWh. For simplicity, ramping costs are not considered.*

**Rounds and Periods** Each round of the experiment consists of 2 subsequent periods: the forward market and the spot market. Both markets get cleared via a uniform pricing auction.

- **Forward Market** Trading a forward contract guarantees the supply of 1 entity of power in the unit MWh, at spot in period 2 at a fixed price. All types of producers, can submit a limit offer price and volume; i.e. you can submit the minimum price against which they are willing to sell the submitted number of forward contracts. Wind producers are limited to trade up to 115% of their nominal capacity on the forward market.
- **Spot Market** During period 2, a spot contract is traded. Gas producers may submit both bid limits and offer prices; i.e. a maximum price against which they are willing to purchase power and a minimum price against they are willing to sell power. Wind producers act as price-takers. Once all bids and offers are submitted in period 2, realized consumer demand and actual wind production become transparent to all producers in the market. Next, the automated market operator clears the spot market, thereby setting the market clearing price. At most one bid per producer is cleared, depending on overall market demand.

**Market** The "Market" field shows you the properties of the demand side of the market. Expected demand and standard deviation are given at the beginning of each period to give an indication of expected demand. This is depending on historical data and the current market profile. Once the period is closed, the actual demand and the cleared market price are given here as well.

*Player 1 is currently at the end of round 5. The demand in the forward market is 10.000 MWh and a forward clearing price of 60 euro/MWh is established. In the spot market an actual demand of 1095 was observed. The spot clearing price is 65 euro/MWh.*

**Market Bidding** The 'Market Bidding' field (dark blue in A.2) allows you to place bids for which volume and price you would like to sell or buy electricity. Each period you will have to make decisions on the offer price and the offer volume for the commodity. It may happen that a bid only partially gets cleared.

*Player 1 has made a bid to sell 700 MWh at a price of 60 euro/MWh in the forward market. In the spot market, the player sold an additional 395MWh for a price of 65euro.*

**Financial Position** The financial position can be found at the end of the page of the 'Game' tab (red in A.2) and in the 'Bid' tab for previous rounds. These can be split up into different parts for each period and are shown per power plant and in total. Your earnings in euro's will depend on the total profit you make over the different rounds. Good luck!

*Player 1 sold this round for 42000 euro on the forward market and 25675 euro on the spot market. As the player had to burn fuel to produce this electricity, he bears a cost of 54750 euro. As such, player 1 makes a total profit of 12925. Similar information for the previous rounds can be retrieved under the bids tab. Note that the pay-out depends on the financial position of the other players, so try to outperform your colleagues and the market!*

Game

Bids

Info

Current round : 5

**My Plants**

Gas Plant	Maximum Output (MWh)	2500
	Marginal Cost (€)	50
	Ramping Cost (€)	0

**Market Info**

Wind Plant	#Plants	3
	Expected Output (MWh)	2500
	Output Std.Dev. (MWh)	125
Gas Plant	#Plants	3
	Maximum Output (MWh)	2500
<b>Cost Info</b>		
Wind Plant	Marginal Cost (€)	0
Gas Plant	Marginal Cost (€)	50
	Ramping Cost (€)	0

Market			Future	Spot
Demand	Expected	MWh		0
	StdDev	MWh		500
Demand	Actual	MWh	10,000	1,095
Price		€ / MWh	60	65

**Market Bidding**

			Future	Spot Sell	Spot Buy
Gas Plant	Bid Q	MWh	700	395	0
	Bid P	€ / MWh	60	65	0

**Net Position**

			Future	Spot
Gas Plant		MWh	1,800	1,405

**Financial Position**

			Future	Spot
Gas Plant	Revenue	€	42,000	25,675
	Marginal Cost	€	-35,000	-19,750
	Ramping Cost	€	0	0
	Profit	€	7,000	5,925

Figure A.2: Overview game tab example.