Experimental economics for market design

Klaus Vogstad[1*], Santiago Arango[1] and Hans Ivar Skjelbred[2]
Tel: +47 928 510 67 : klausv@stud.ntnu.no
[*]Corresponding author
[1]Dept of Energy and Process Engineering, Norwegian Univ. of Science and Technology
[2]Skjelbred Consulting

1 Abstract

This study reports of an experimental economics analysis of the new proposed Swedish-Norwegian tradable green certificate market (TGC). The green certificate market is a financial instrument to stimulate renewables within the context of liberalized, transnational electricity markets (a kind of market-oriented subsidy scheme). Green certificates are financial assets issued to green producers that can be traded freely. Previous system dynamics studies showed that trading- and investment behaviour were critical factors in analyzing the market dynamics. As a follow-up, this experimental economics study conducted 14 laboratory experiments with about 10 to 20 students per session. A particular feature is that participants handle both short-term trading and long-term investments, which allow us to analyse the interplay between these types of decisions without imposing behavioural assumptions on the two types of decisions. The laboratory experiment shows that the market is likely to crash, due to the long time delays of supply side adjustment. The study provided new insights concerning agents trading and investment strategies, and the performance of various market designs. The mix of trading strategies employed in response to the experiments, are difficult to capture in an SD model.

2 Introduction

Substantial economic interests are at stake when introducing new market reforms. The Californian electricity market reform provides such an example. The enormous costs of market failures and inefficiencies can be avoided if it was possible to test market designs prior to implementation in the same manner as we test medicals or new technologies before market introduction. This paper reports of a series of *experimental economics* laboratory tests of the proposed joint *Swedish-Norwegian green certificate market* recently conducted for the *Norwegian Water Resources and Energy Directorate*. Both the Norwegian and Swedish authorities are revising their plans for this market.

Results from a system dynamics study caught the attention of the authorities, and decided to support the more detailed experimental economics study reported here. The results from the experimental economics study reaffirmed some of our previous concerns about the TGC market, and lead to conclusions and recommendations that contradicts the recommendations of other experts using standard economic approaches.

3 What is a Tradable green certificate?

The green certificates market is a financial instrument to promote renewables within the context of transnational liberalised markets. A tradable green certificate (TGC) is a financial asset issued to certified green producers. For each MWh of wind power generated, the producer receives a corresponding number of TGCs. These assets can be traded freely among producers, and consumers who have a TGC obligation. The TGC obligation is determined by the authorities as an increasing share of TGCs over a future time horizon of

10-20 years[1]. In practice, retailers deal with the obligations for end-users, while larger consumer may choose to handle their obligations themselves.

The price of TGCs depends on the cost of production and demand, but also the *market institution* (that is the arrangement of rules and regulations for the TGC market). Designing market rules are important for creating well-working, efficient markets. Designing and monitoring such markets is the responsibility of the authorities.
Possibility of storing TGCs, expectation formation and time delays in the acquisition of new capacity makes this market dynamically complex and provides interesting case for system dynamics and experimental economics.

Pigouvian taxes has traditionally been the way of handling externalities. Coase (1960), however, pointed out the inconsistencies in the theoretical foundations of Pigouvian taxes. Under standard economic assumptions (zero transaction costs, perfect rationality and perfect information), agents would make arrangements between themselves in such a way that welfare is maximised, taking social costs of externalities into account.
Coase (1960) proposed an alternative to Pigouvian taxes by assigning property rights to the externalities. Later on, Dales (1968) proposed using property rights to address pollution problems. Examples of such arrangements are the tradable emission permits of NOx and SOx in California, and the CO2 emission permits in from the Kyoto agreement. TGCs are somewhat similar to tradable emission permits, but where the objective here is to increase renewable generation (to achieve sustainability) rather than a direct emission reduction target.

TGC markets are currently in place in Australia, England and Sweden. As part of their deregulation process, EU aims at introducing TGC's to reach their renewables target. Renewable portfolio standards are in place in 14 states in the US, some with green certificates.

Equilibrium approaches dominate studies of the TGC market among academics and consultants. These studies can tell us a lot about the consequences of a perfect, well-working market in terms of distribution effects, prices and interactions with other markets. However, the equilibrium approach tells nothing about under which conditions a market behaves as a near-perfect market. The choice of market design, its regulation and rules are critical factors for an efficient, well-working market.

Schaeffer and Sonnemans (2001) reports of an experimental laboratory study of green certificates trading. Vogstad et al (2003, 2005a,b) performed a system dynamics analysis of the Swedish TGC market, supplemented by laboratory experiments.

Analyses based on equilibrium approaches of the TGC market can be found in Amundsen and Mortensen (2001), Bye et al (2002), Jensen and Skytte (2002;2003) and Hindsberger (2003), where the main concern is the interaction between the TGC market and other markets when in equilibrium.

4 Experimental economics and system dynamics

Experimental economics is a newer branch of economics that employ laboratory experiments to study motivated human trading behaviour in a controlled environment. Economics has traditionally been considered an empirical science, relying on field observations rather than controlled laboratory experiments. The development of experimental economics made it possible to test basic economic assumptions and hypotheses under

1. Such a long-term renewables target is also called Renewable Portfolio Standard (RPS).

controlled conditions. Vernon Smith received the Nobel price in Economics in 2002 for his contribution to the field experimental economics, in particular creating computerised experimental laboratories. His work also includes the studies of power market designs (Rassenti et al. 2002, 2003).

Through laboratory studies, we can better understand phenomena that would otherwise be too complex to understand in a complex, real market. With controlled experiments, it is possible to detect potential design flaws at an early stage, in the same way a technology or a medicine needs to pass laboratory tests before market introduction.

Unlike neoclassical economists and system dynamicists, experimental economists are not comfortable with imposing behavioural assumptions on economic agents. Instead, individuals represent the behaviour of agents in a market environment defined by the rules of the market institution.

System dynamics has since the Beer game made use of experiments or flight simulators to study how system behaviour arises from decision policies (Sterman, 2000). Typical studies have addressed management problems (Sterman, 1989; Diehl and Sterman, 1995; Paich and Sterman, 1993) and management of renewable resources (Moxnes, 2000).

Kampmann (1992) combined experimental economics, system dynamics and psychology in this thesis where subjects' performance are tested under various market institutions and degrees of complexity. System dynamicists try to capture the decision rules governing the decisions by direct observation, and then study how system behaviour arise from the structure within which these decision rules operate. Experimental economists on the other hand, make use of individuals to represent decision makers, and to study the price formation in simple and controlled experiments.

While the critical assumption in economics models and system dynamics are the behavioural assumptions, experimental economics assume that the individuals within the experiment are representative for decision makers in the real world.

Incentives are used to induce representative behaviour of subjects. A subjects' utility can be expressed as $V(m,z)$, where m is the *reward*, and z are all other factors affecting the perceived utility of a decision. The subject receives a reward Δm from desirable outcomes of its decisions, defined by the rules of the experiment which the subjects fully understands (salience). Three conditions from *induced-value theory* must be fulfilled (Friedman and Sunder, 1994):

- *Monotonicity :* $\frac{\partial V}{\partial m} > 0$ - The subjects prefer more of the same reward without being satiated.
- *Salience :* The subject must understand the rules of the game, and how he or she may increase his/her reward Δm.
- *Dominance :* $\Delta m \gg \Delta z$ - the reward must dominate other factors that might influence the subjects' perceived change in *utility* ΔV.

These requirements have implications for the choice of subjects and the experimental design. First, money is a more convenient reward than, say milk shake (*Monotonicity*). Second, cognitive limitations of subjects put constraints on the complexity of the experiment. An experimental game that replicates detailed aspects of reality will usually conflict with the salience requirement. Last, the reward must be large enough to dominate other factors. Typically, graduate students are better subjects than professors and PhD's, who tend to become more interested in the outcome of the experiments rather than their reward.

5 The laboratory model

The short time duration of our project required us to develop and test the computer model in parallel with experiments. During a one-month period, we developed the model from scratch in Matlab v7, which had the necessary modelling flexibility for our purpose. *Figure 1* illustrates the model representing a stock of renewables generation capacity, TGC holdings for *n* producers and *m* traders with quota obligations. Each producer *n* consists of a *trader* in charge of TGC trading and an *investor* in charge of capacity investments. We chose a computerised double-auction market (CDA) to represent bilateral trade that takes place in the Swedish TGC market[1]. Market participants (consumers with quota obligations and producers) can continuously post bids/asks and accept existing ones in the marketplace, where market statistics, transactions and other information is displayed.

Consumers start with initial obligations of 200 MWh/yr in 2005, increasing each year by 30 MWh/yr to reach 650 MWh/yr in 2020. If 5consumers participate, the total yearly demand (quota obligation) is 1000 MWh/yr. Numbers are simplified in order to ease back-of-the-envelope calculations for participants. Quota obligations must be met by the end of each year, and are automatically subtracted from the subjects' holdings by the end of each year. Missing TGC's result in penalty costs of 250 NOK/MWh per TGC short of obligation.

Producers start initially with 215 MWh TGC's. The producer's initial production capacity is 215 MWh/yr. Capacity lifetime is 10 years, initially uniformly distributed on the vintages (21.5 MWh/yr on each vintage). Additionally, there are 2 years of 21.5 MWh/yr capacity in the pipeline. Certificates can be traded continuously (the program updates in real time every second)

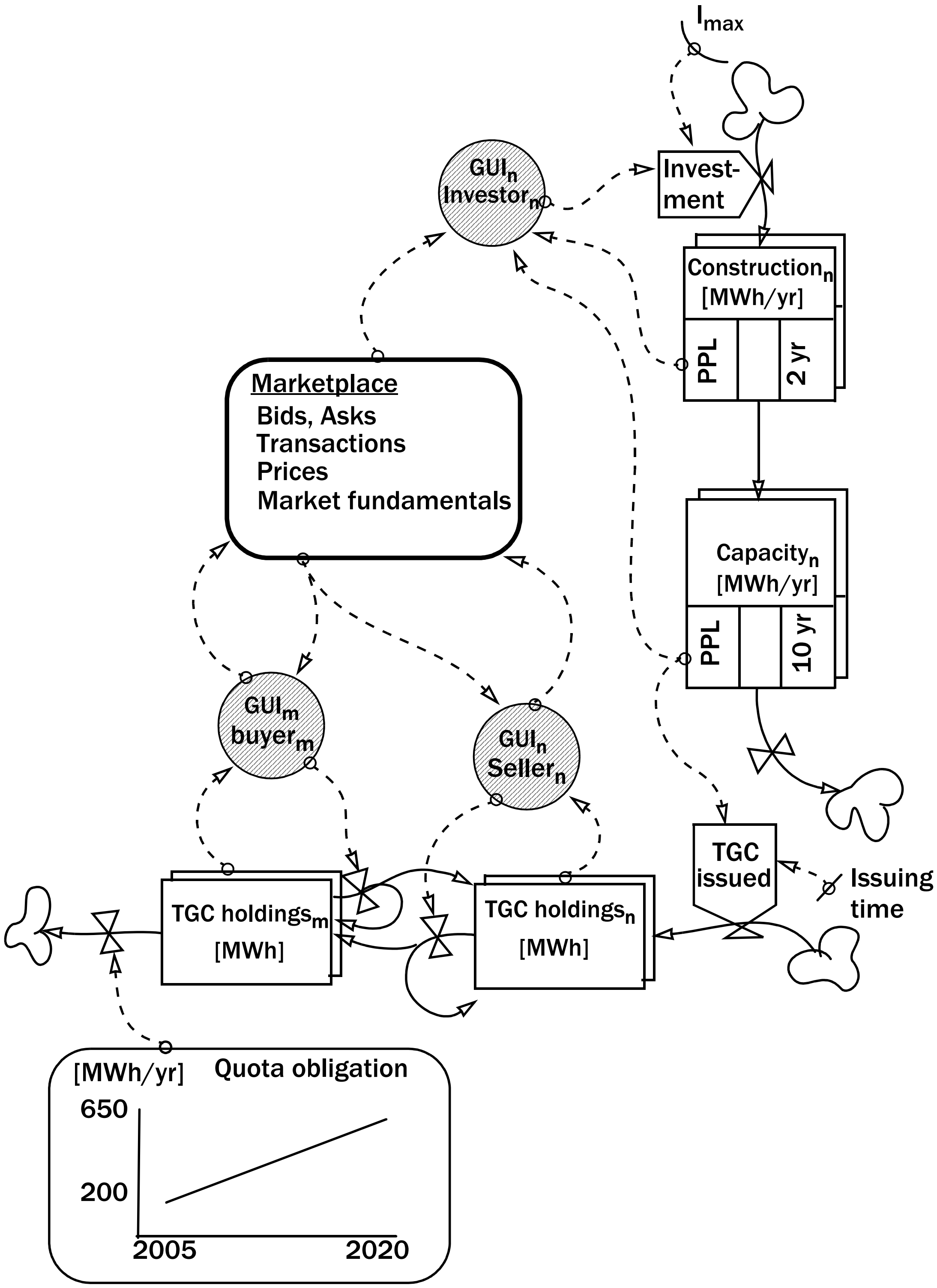
Investor collaborates with the producer, and together they represent one company. The producer and investor of a company sit next to each other in the laboratory. They collaborate on strategies and decisions, and share profits at the end of the simulation. While the trader can make trades continuously, investment orders are initiated at the start of each year.

Incentives: Subjects are paid on average 120 NOK for a session, ranging for 60 to 200 NOK depending on their relative performance measured in accumulated profits at the end of the experiment (1 € = 8 NOK). Excess TGCs have no value when the simulation finishes.

Subjects in the experiment were recruited from technology/management studies at NTNU, mainly undergraduates from the energy- and environment programme. We made use of the same subjects, who became quite experienced in the trading. There might be problems related to using the same subjects in subsequent experiments. Our main concern was however, 1) to avoid mixing inexperienced with experienced subjects in the same ses-

1. See https://elcertifikat.svk.se for more information on the Swedish TGC market (in Swedish)

Figure 1 Model of the Green certificates (TGC) market.



sion and 2) Use experienced players that have a good understanding of their task.

Figure 2 Graphical user interface for one of the traders with TGC quota obligations.

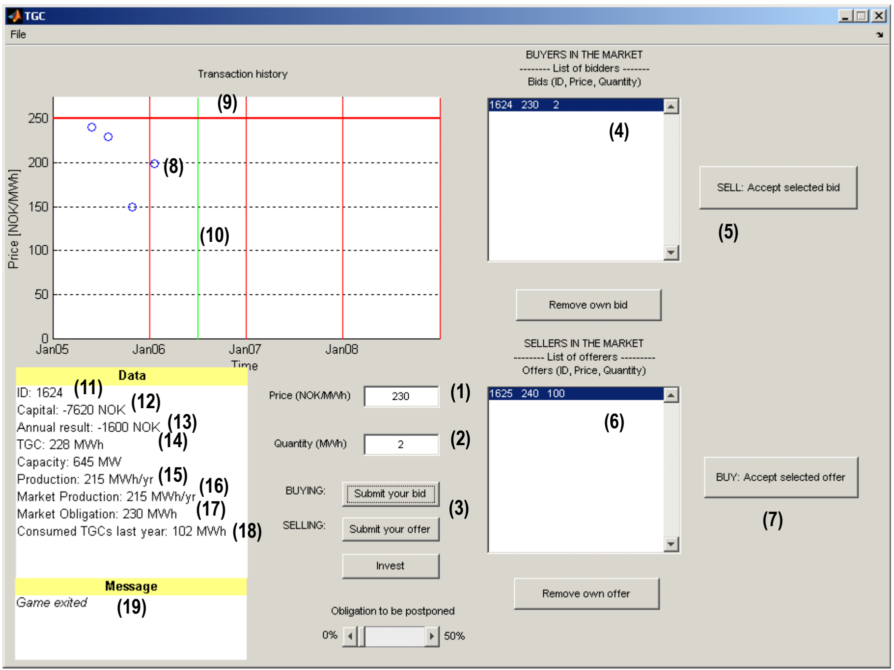


Figure 3 Left: Irregularities during experiments are annotated. Right: Investor and trader monitoring the price development.

6 Model assumptions of the TGC market

Our task was to test various market designs as input to the planning of a joint Swedish-Norwegian TGC market. The current Swedish TGC market design was therefore the basis for our analysis.

Information on TGC trading, capital (accumulated profits), yearly profits and TGC holdings updates continuously with transactions and price graphs. Information on the Graphical user interface updates every second, which gives the model a time resolution of 1 second. It takes 3 minutes to complete one year, and 45 minutes to complete the simulation period 2005-2020. Capacity additions, hand-in of obligations and issuing of new TGC's occur once a year, Players can only make trades for the current year. In reality, contracts on future delivery are possible.

Issuing of TGC's are made on a monthly basis in reality, and the generation of bio, wind and hydropower can vary by up to +/-20%, and exhibit seasonal patterns. The results from Schaeffer and Sonnemans (2001), showed that seasonality and stochasticity of generation had insignificant impact on the TGC price, as unlimited banking tends to filter out these short-term fluctuations. In a long-term market that facilitates banking, short-term variations in supply are of less concern. Our model is therefore simplified to issuing certificates on a yearly basis without stochasticity.

Lifetime of installed capacity is 10 years, and construction delay is 2 years. In addition, orders for new capacity are registered by the end of each year.

Hydro, wind and CHP bio cannot easily adjust its production capacity. The long run marginal costs (LRMC) of new capacity are 300 NOK/MWh. The electricity is sold in the spot market for 200 NOK/MWh, and the TGC price needed to make investments profitable is then 100 NOK/MWh. To simplify, the cost of generation is therefore 100 NOK/MWh for new capacity.

We do not consider interactions with other markets, such as the spot market, CO2 quota market etc. Other studies address these concerns (Amundsen and Mortensen, 1999, 2000; Nielsen and Skytte, 2002, 2003; Hindsberger 2003; Bye et al. 2003). Vogstad et al. (2003) shows that many of the dynamic interrelationships within the TGC market are more important for its price development than its interactions with other markets. Hence, the TGC market can justifiably be analysed independent of these.

7 Experiments

Table 1 summarise the experiments. Several of the experiments were repeated and yielded the same results, however we choose to report all of the experiments in order not to be "selective" in the interpretation of results. The experiments can be organised into seven groups

Group I - No investments. We eliminate investments and focus on trading in the double auction, bilateral market.

Group II - Players trade certificates, and make investments. Pair of players form teams (companies) where one player make investment decisions, and the other trade certificates. They collaborate during the simulation, and share profits at the end of the simulation. Investors also participate in the subsequent groups III-V.

Group III - Experiments where up to 50% of the quota obligations can be transferred to the next year.

Group IV - Penalty price is 150% times the previous year's average price as in the current Swedish market design.

Group V - Introduction of 5% interest rate. The interest rate should have been implemented in earlier experiments, but was first introduced in the two last experiments.

Table 1 Summary of experiments

	Description	Experiment	Result
I	No investments	s1a, s1b,s2	High prices
II	Investments by agents, banking and yearly quota obligations.	s4,s5,s6,s7,s8	Boom/bust
III	Quota obligations can partly be transferred to next year	s9,s10	High prices
IV	Adaptive penalty price	s11,s12	Boom/bust amplified
V	Interest on capital	s13,s14	Unstable equilibrium?

8 Group I experimental results (s1a,s1b,s2)

Producer's profit π at price p and sales volume V are $\pi = (p-100)V$, and buyers profit's (avoided costs) are $\pi = (250-p)V$. In a perfect market, prices should converge towards long-run marginal costs, which in this case is 100 NOK/MWh. What we observed, is that market prices are well above marginal costs. We believe this has to do with the market design: Buyers must acquire their quota within one year, or else pay penalty price of 250 NOK/MWh for each certificate short. Producers on the other hand, can still gain profits from their certificates if their certificates are not sold within the year. There is no expiration time on certificates, and producers can try selling their certificates next year.

We haven't found similar results in the experimental economics literature yet, but some more general studies seem to be of relevance. Smith (1962, pp119-120) showed that with a perfectly elastic supply curve (i.e.horisontal), prices converge above the equilibrium price. Another of Smith's experiments (Smith, 1990 pp167-168) where both the demand and supply curves were perfectly elastic (horizontal), showed that prices settled above equilibrium when subjects had complete information. With incomplete information, the market price converged towards equilibrium (!). When producers know the penalty price of 250 NOK/MWh, the marginal costs of all competitors (100 NOK/MWh), and the demand and supply, this kind of complete information increase possibilities for tacit collusions.

Our experiment differs by the possibility of banking among traders, which makes the situation even more favourable for the producers. Smith's results suggest that even if banking was not permitted, prices will still converge above marginal costs.

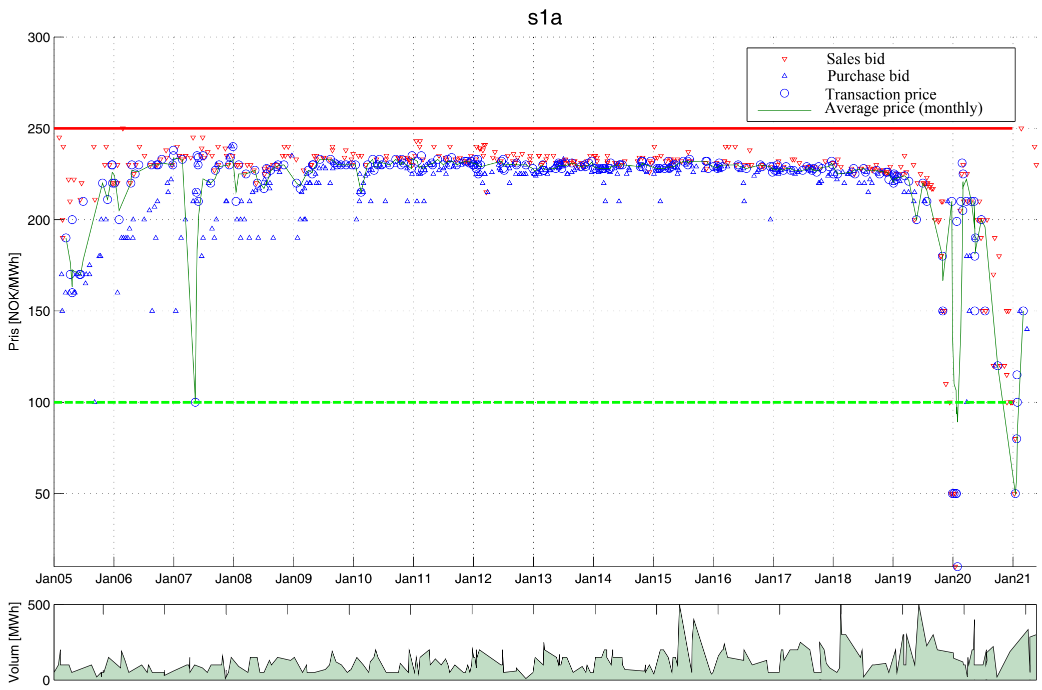
From these results, it is clear that the market equilibrium may depend not only upon the demand and supply curve, but also the market institution, its rules and regulations. We observed initially some learning effects in the first period of our s1a and s1b, where the first transactions vary from 150 to 230 NOK/MWh in price. In subsequent experiments s2-s14 however, there is almost no variance in transaction prices. Even though only a few participants had previous experience, the market bids revealed the preferences of buyers and sellers quite rapidly.

The following pages display the experimental results organised as follows. A section with some description of the results accompanied by the price graph containing bids, asks and transaction prices and total volume over time.

Below the price graph, a table summarises main parameters in the experiment, and a smaller graph displays development of supply, quota obligation and TGC holdings.

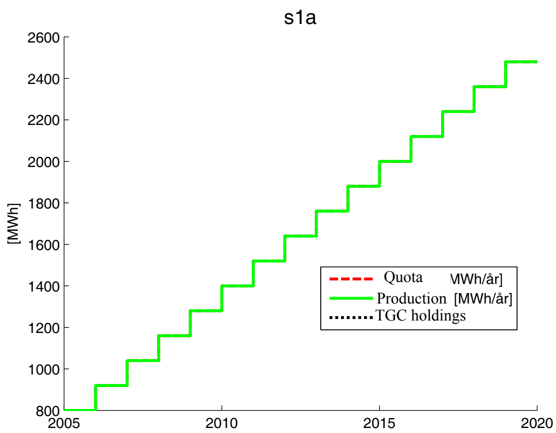
Experiment s1a

With production in balance with quota obligations each year, an equal distribution of profits suggest prices around at $100 + \frac{(250 - 100)}{2} = 175$ NOK/MWh, and asks started at this price. Offers were significantly higher, and at the end of the first year, transactions took place at prices closer to the penalty price. In fact, prices stabilised around 225 throughout the simulation period. Price drops are due to “end effect”, where excess TGC is of no value. We believe the reason for this is the fact that sellers can bank certificates, providing them with the options of realising their profits in subsequent years. The buyers on the other hand, must pay the penalty price of 250 NOK/MWh for each certificate in short of their quota by the end of each year. Certificates not consumed creates in this case a surplus of certificates for the next year, but this does not seem to impinge on prices before the end of the simulation. The current market design of allowing banking for producers while buyers face yearly obligations create possibilities supramarginal profits.



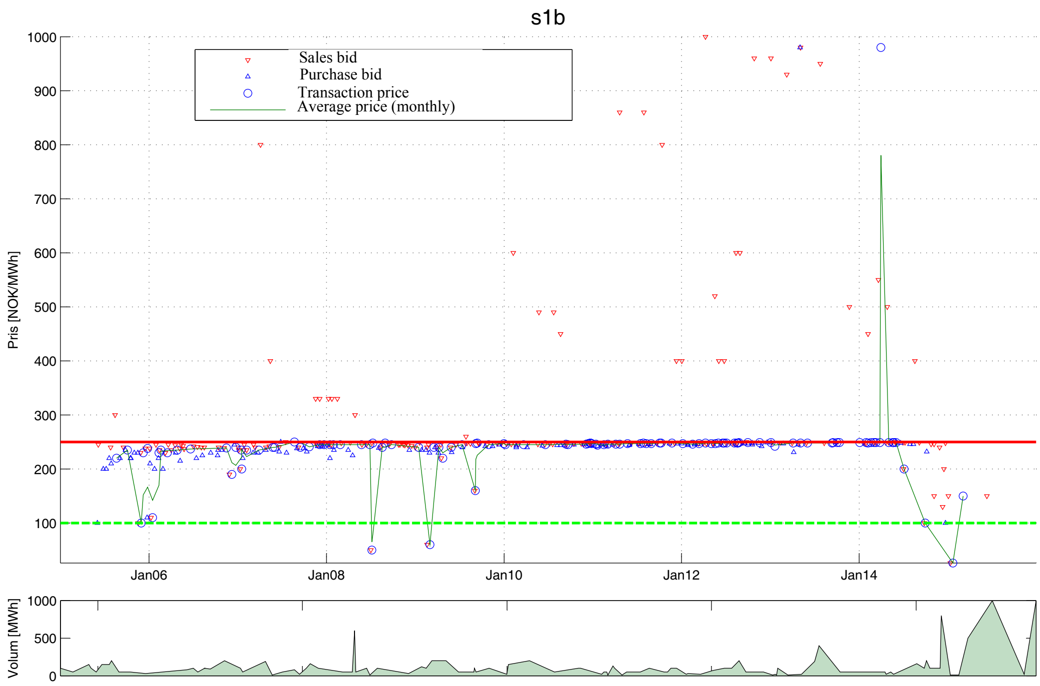
Parameter

	B	S	I	T
Buyer, **S**eller, **I**nvestor, **T**otal	4	4	0	8
Penalty price	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/a			
Interest rate	0%/a			
Market information	Total quota obligation			
Other: Yearly production = demand				

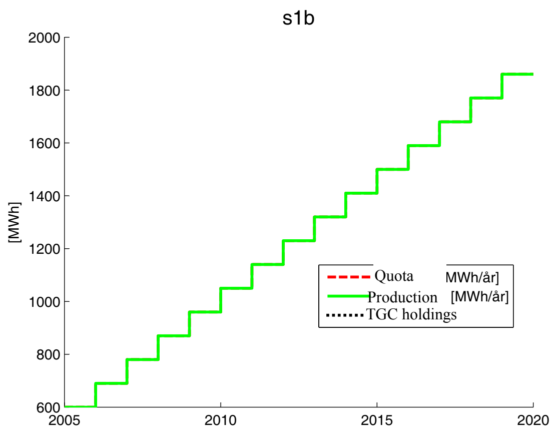


Experiment s1b

Prices settled even closer to the penalty price level than in the previous experiment. However, some irrational bidding occurred throughout the session, as some of the players in this expeirment did not quite understand the workings of the market. Incidentally, a player accepted an offer far above market penalty price by mistake. Apart from these exceptions, market prices stay close to penalty prices throughout the session.

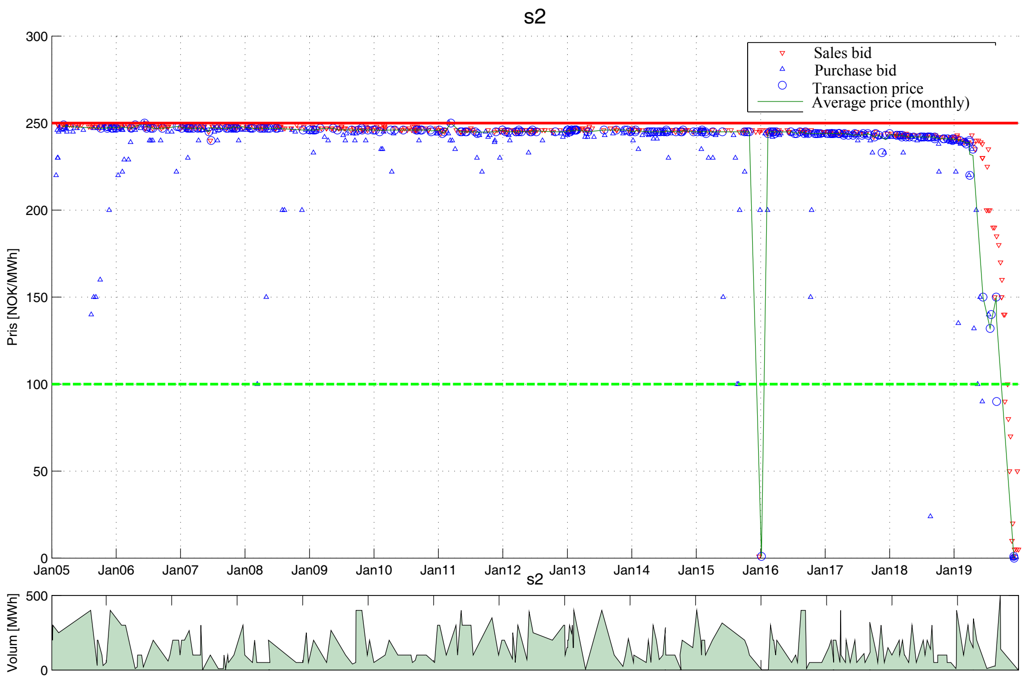


Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	5	5	0	10
Penalty price	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation			
Other: Yearly production = demand				



Experiment s2

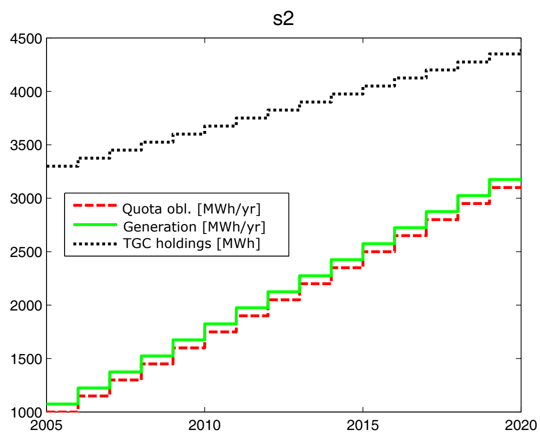
One might think that the high prices are due to the tight demand/supply balance, and that excess supply will lead to downward price shifts. In this experiment, each producer started with an excess supply equivalent of three times the first year's quota obligation. In addition, there is a 10% overcapacity in production. The results below shows that the excess demand had little or no influence on the price formation. Rather, prices are even closer to the penalty price level, than in the first experiment. Participants from session s1a also participated in this experiment, and they have learned that they can sell certificates at prices close to penalty price. At the end of the simulation, the stock of TGC's have accumulated to almost 4500 MWh, which means there should be some potential of producers increasing their profits by underbidding their competitors, which is what happens at the end period.



Parameter

Buyer, Seller, Investor, Total	B	S	I	T
	5	5	0	10
Penalty price	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation			

Other: Yearly production = demand TGC holding 2005 = 3 x Quota obligation 2005



9 Group II experimental results (s3-s8)

The main purpose of the TGC market is to provide price signals for long-term investments. This series of experiments aim at understanding the dynamics of price expectations and investments. In the first experiment s3, we model investments as a function of expected profitability (based on previous market prices), anchored to the equilibrium capacity (K) replacement rate $\frac{K_t}{L}$ [MWh/yr^2] with lifetime L. Previous experimental economic studies (Schaeffer and Sonnemans, 2001) as well as system dynamics analyses (Vogstad et al. 2003), used this type of formulation.

In the first three years of these simulations, there is no change in production capacity due to time delays in capacity construction. Orders for new capacity placed during the first year, will be registered by the turn of that year, and from there and two more years passes before the ordered capacity comes on line. There are however, surplus of certificates in the beginning.

In experiment s3, the investment function overinvests without paying attention to total demand, which is known to the end of the simulation period. The function may work well when prices are close to equilibrium, but in this case, prices do not reflect market fundamentals. Price collapse is inevitable.

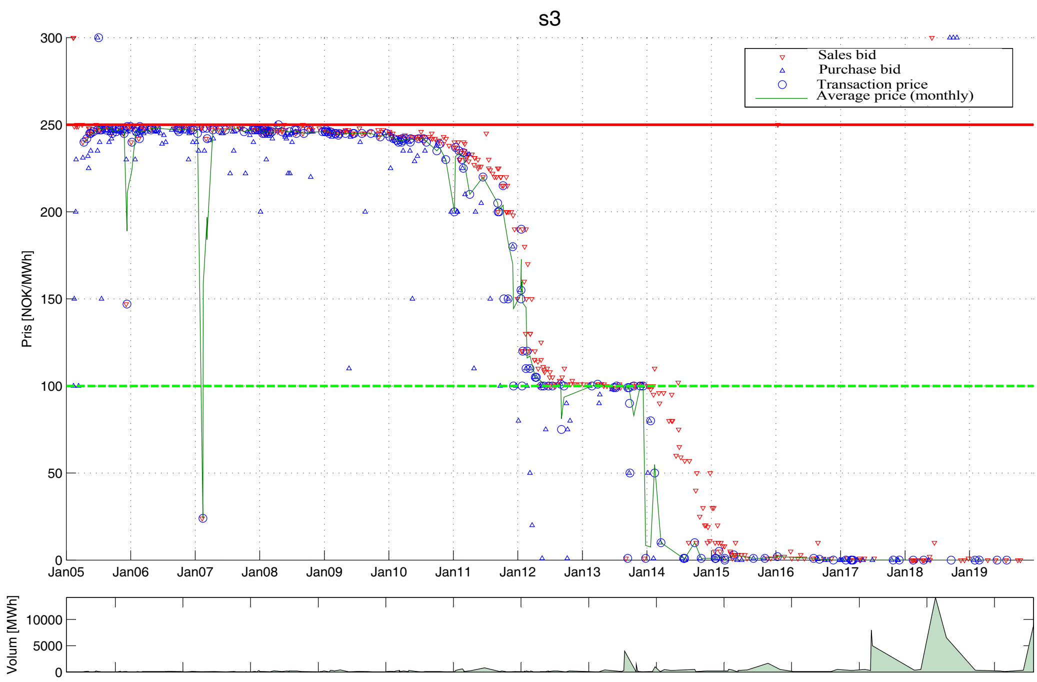
More realistic, we let individuals make investment decisions throughout experiment s4-s8. We do this by defining a group of two persons as a company, where one is responsible for investments, and another responsible for trading. The investor determines new investments in capacity, and the trader sell certificates from the installed capacity of the company. They share the same profits at the end of the simulation, and are co-located so that they can collaborate and discuss during the session. This set-up captures the dynamics of long-term and short-term decisions i the marketplace.

All of the experiments s4-s8 exhibit the same mode of behaviour: Initial high prices (similar to the Group I experiments), followed by a price collapse. The typical pattern is to order new capacity as early as possible. Excess production of TGC's is stored for later use towards the end, when old capacity withdraws. Excess supply of TGC's by the end of the year is in the range of one year's TGC quota obligation.

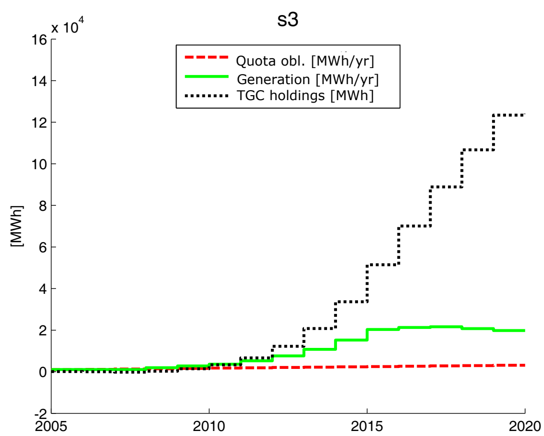
The experiments reveal a market with a tendency to overinvestments, resulting in price collapse. In some of the experiments runs, capacity developed in balance with demand, still prices collapsed. From these simulations, it appears that the long term price is likely to collapse.

Experiment S3

Our first experiment included investments based on adaptive expectation of profitability according to previous studies (Schaeffer and Sonnemans, 2001; Vogstad et al. 2003) If prices persist above the cost of new generation (LRMC), investments take place proportional to the replacement rate of existing capacity times the profitability multiplier table (see Appendix for details). Participants however, made buy/sell decisions as in previous sessions. The period of high initial prices gave rise to investments by far exceeding future quota obligations. Apparently, the high initial prices provide incorrect price signals for new investments. Moreover, producers still try to sell at prices above marginal costs even though there is large overcapacity.

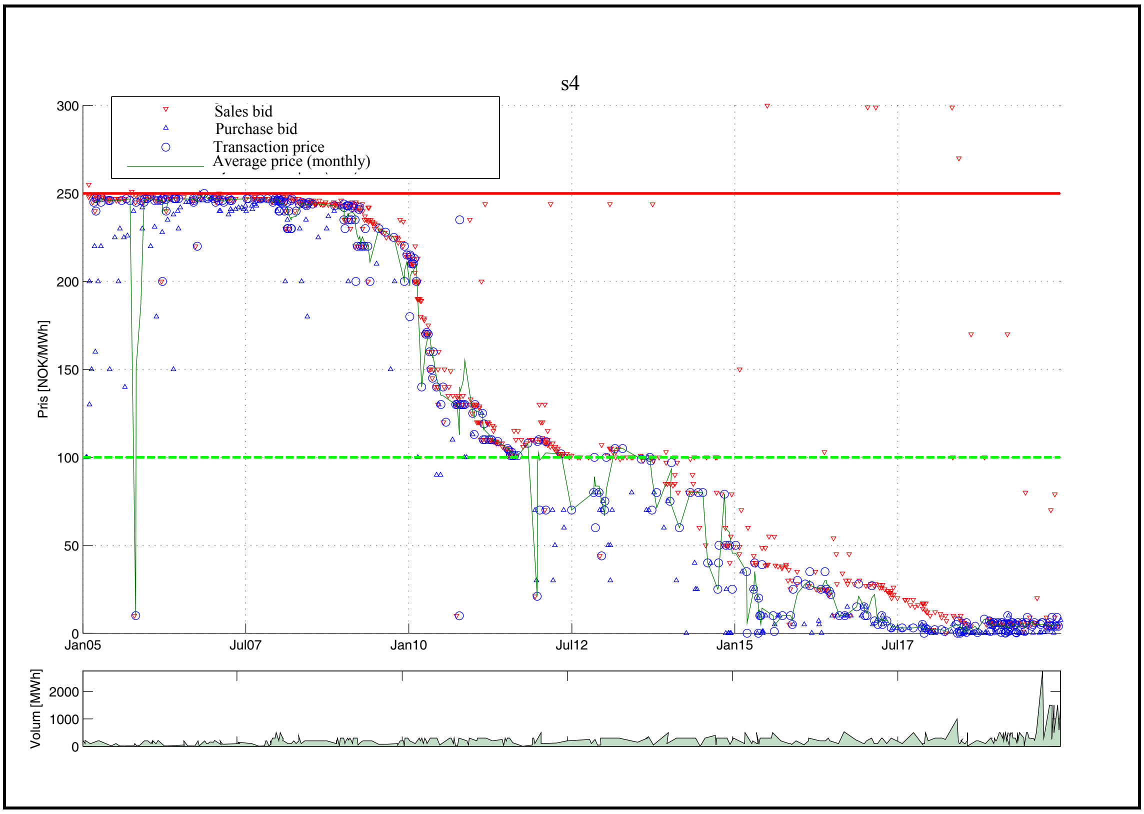


Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	5	5	PC	10
Quota obligations	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation			
Other	Computer make capacity investments			



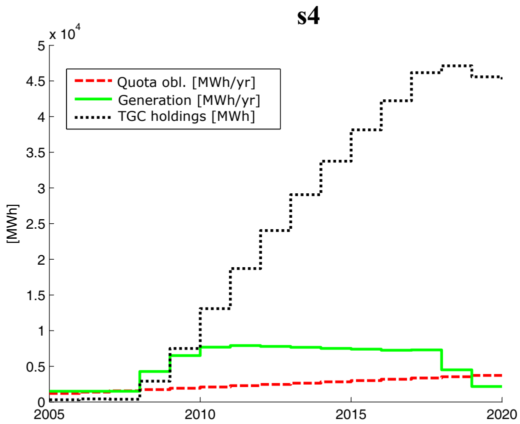
Experiment s4

Previous experiments by Schaeffer and Sonnemans (2001) and Vogstad et al. (2003) studied the price formation using the computer as investor. In this experiment, we replace the computer with a human investor. The investor collaborates with the corresponding producer that trade certificates in the market. Together, they represent one company and share profits at the end of the simulation. Investments still overshoots demand obligations and resulting market prices collapse sometime after dwelling by the marginal costs for a couple of years. Market participants did not receive any information about total installed capacity.



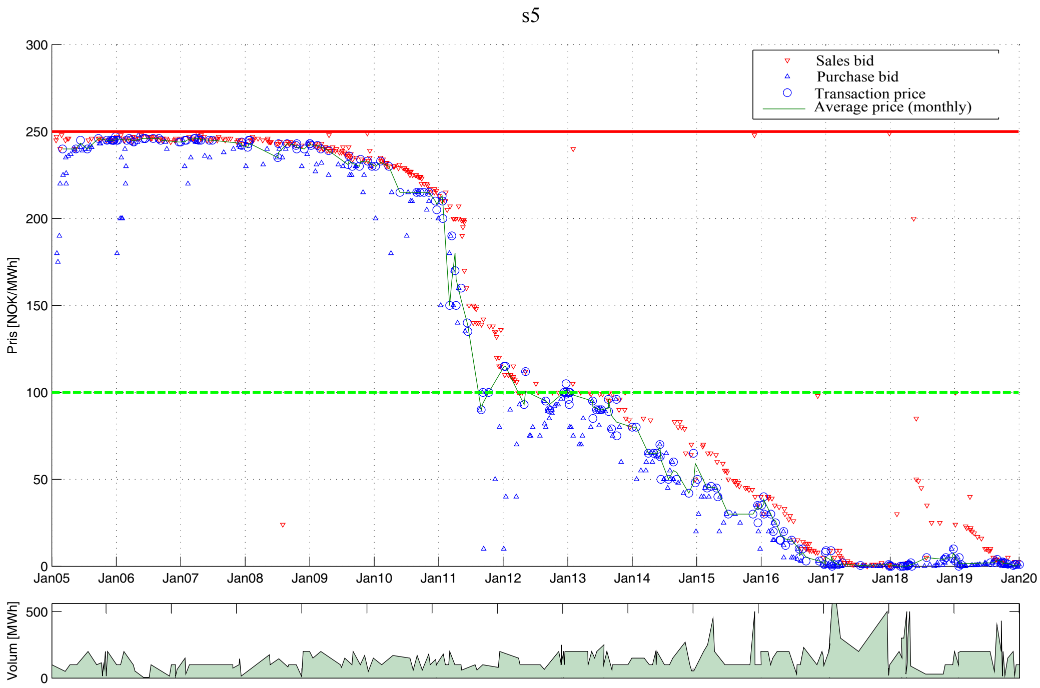
Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	3	3	3	9
Quota obligations	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation			

Other: Investors introduced. Collaborate with producer to form a single company.



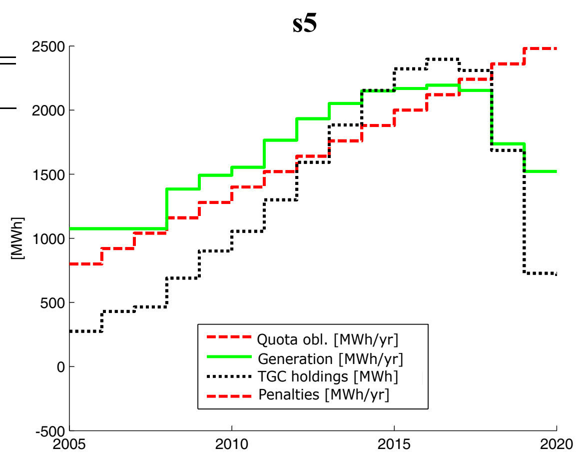
Experiment s5

Previous experiments did not provide information on total capacity. As the computer model was developed and tested in parallell with the experiments, the feature was not incorporated at this stage. In this simulation, we called out total installed capacity for each year. This simulation contains a fairly high number of market participants (20), a surplus of sellers. Still, prices remain high during the first years. The long time delays involved in capacity acquisition (~3 years) makes the first years' situation identical to the experiments in session 1-3. This experiments shows that capacity construction closely follows quota obligations, but are in excess until the last two years. TGC's accumulate over the simulation period, but the supply of TGC's are emptied during the two last years, when old capacity withdraws, and there are no incentives for new investments. Despite the near-perfect development of capacity and TGC holdings in terms of demand-supply balance, the market price collapse and investments later than 2009 are not profitable.



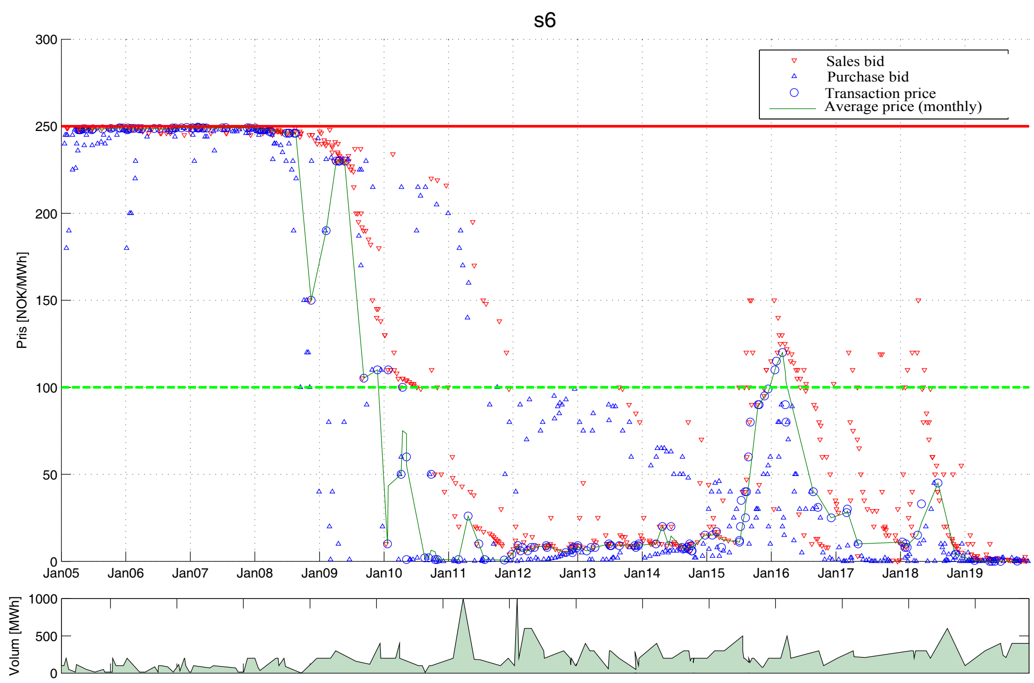
Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	6	7	7	20
Quota obligations	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation + Total Capacity			

Other: Initial surplus of TGC's. More sellers than buyer.



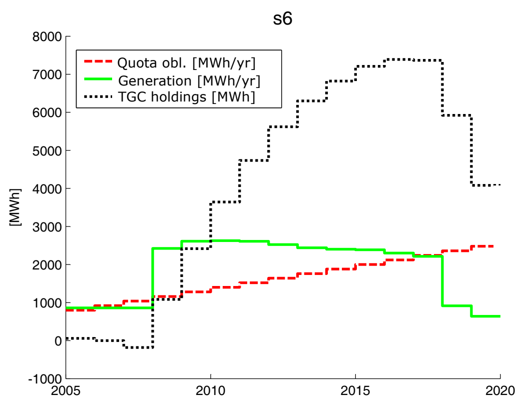
Experiment s6

Repetition of experiment s5 (with less players). Early investments were paying off in previous simulation runs, and some companies now pursued a strategy of early investments to capture market shares. The caveat is the danger of overinvestments, which is what happens in this experiment. By mistake, we reported too high installed capacity in 2015, which probably explains the price bubble in 2016. With the correct update on total production capacity in 2016, prices adjusted down to zero.



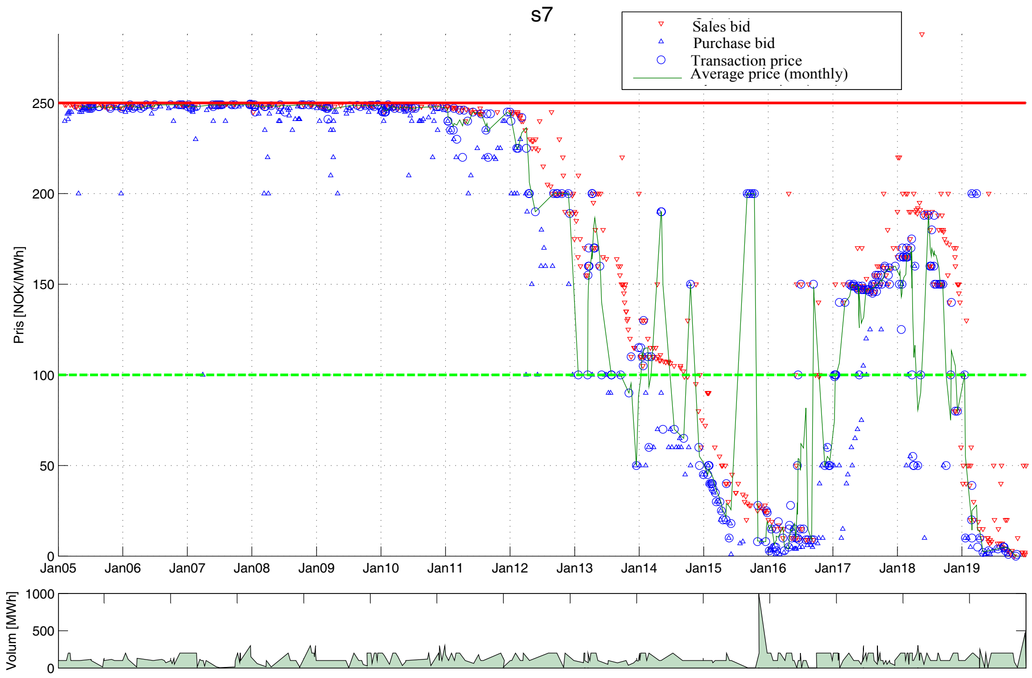
Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	4	5	5	14
Quota obligations	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation + Total Capacity			

Other: Initial surplus of TGC's.



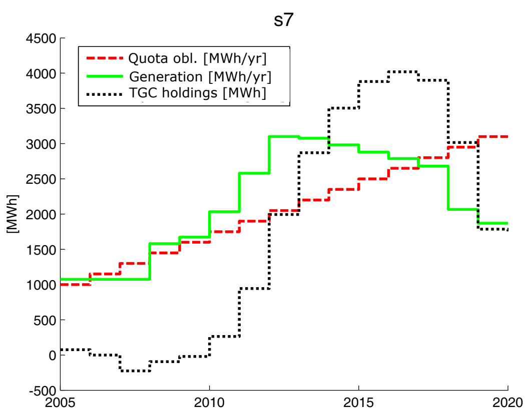
Experiment s7

In this run, companies are a bit more precocious to investment. Certificate prices remain high, but drops below marginal costs when capacity peaks at 3000 MWh. An upsurge in prices takes place at the end of the simulation, when old capacity withdraws. The lower graphs shows negative TGC holdings. At this stage, the model did not log penalties, and the TGC holdings are simply estimated as Total TGC's issued minus TGC obligations, without accounting for obligations not handed in.



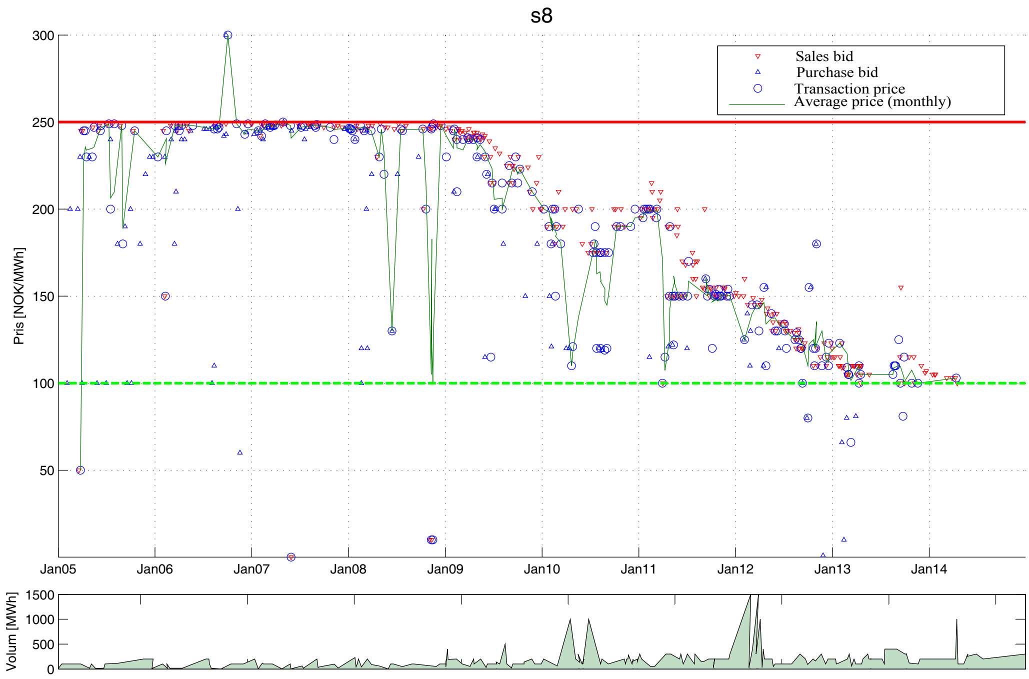
Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	5	5	5	15
Quota obligations	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation + Total Capacity			

Other: Mark information on total capacitance added to the Graphical User interface



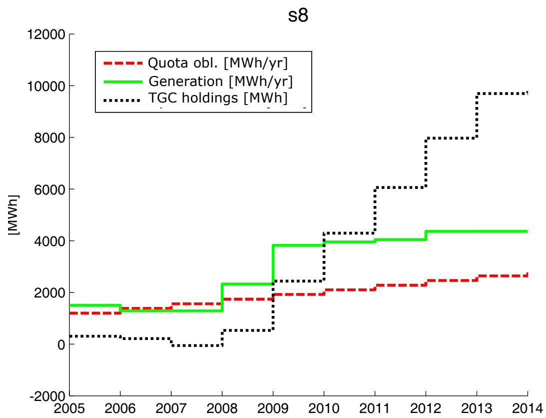
Experiment s8

This simulation repeats the previous experiments, but the experiment stopped too early by mistake. The price development follows the same pattern as previous experiments. There are overinvestments, and price collapse seems inevitable.



Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	6	8	8	22
Quota obligations	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation + Total Capacity			

Other: By mistake, simulation ended in 2014.



1 Group III experimental results (s9-s10)

Previous work Vogstad et al. (2003) and Schaeffer and Sonnemans (2001) concluded that the flexibility on the supply side should be improved. Borrowing of certificates was one way to increase the availability of TGC's for buyers. Borrowing TGC's from future production means that a producer can sell TGC's in advance of its production. An investor can issue TGC's for new capacity under construction. Another possibility is to allow for some of the demand obligations to be transferred to the next year. Both alternatives are being discussed, but none of these mechanisms have been favoured yet.

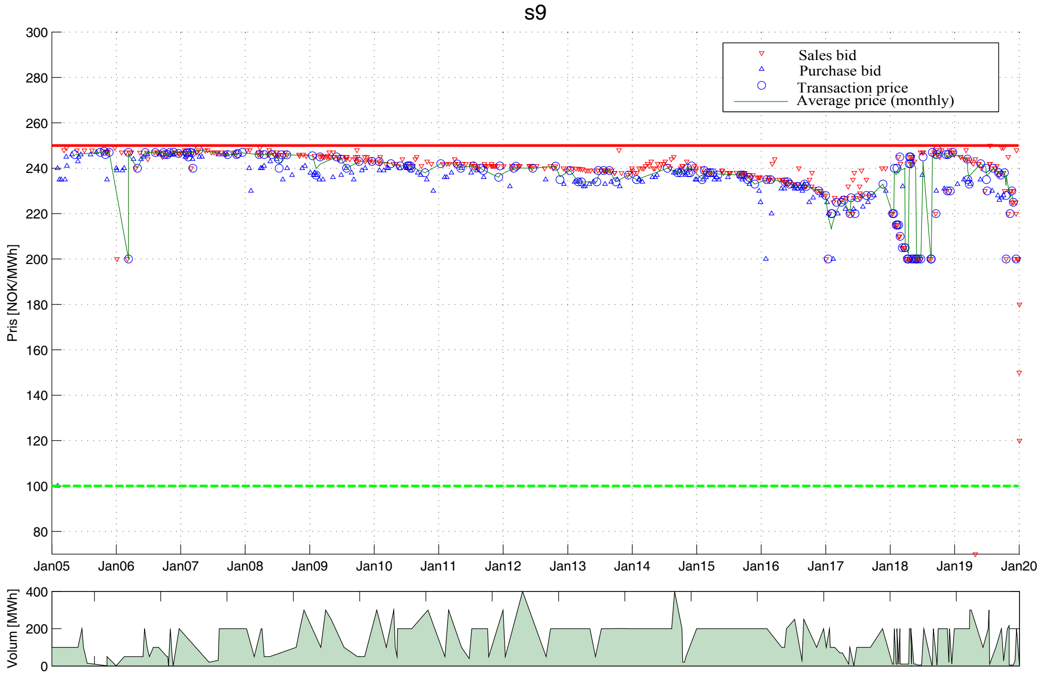
In these experiments, we allow traders with demand obligations to postpone up to 50% of their quota's to the following year, except for the final year. If the buyer believe prices will drop, he can then choose to transfer some of his obligations to the following year.

The results of these experiments were surprising. Our hypothesis was that this market design would create a downward pressure on prices, improving the bargaining power of buyers. Instead, prices remained high. In experiment s9, there is substantial overcapacity during the part of the simulation run. We ran this experiment with only three players of each kind (3 buyers, 3 sellers and 3 investors). We repeated the experiment in a later session that day with the same students. The results are shown in s10. Though there is a downward trend at the end of the simulation period the results are mainly the same, perhaps with some more penalties incurring.

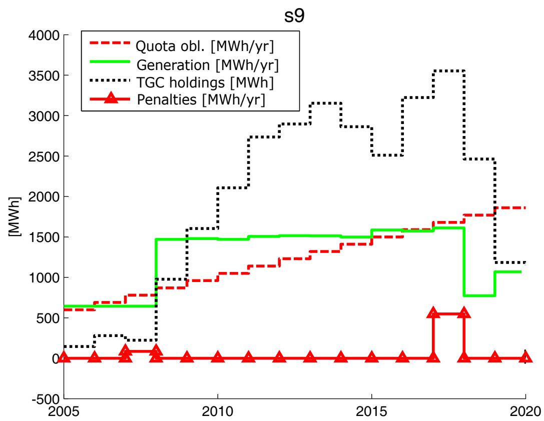
We did not find any plausible explanation for these results, and more experiments needs to be conducted. We believe however, that borrowing and transferring demand obligations to subsequent years induce different behavioural strategies for trading and investments that needs to be examined more closely.

Experiment s9

Our hypothesis was that yearly quota obligations force buyers to accept high prices to avoid penalties, whereas producers can bank excess certificates and sell them in subsequent periods. Offering buyers to postpone up to 50% of their obligations would give buyers some of the same flexibility and thereby improve their bargaining power against sellers. To our surprise, prices did not drop!   Instead, prices were kept close to penalty prices. The capacity development suggest significant overcapacity in the start, with some and accumulation of certificates (se lower most graph). At some occasions, penalties incur.

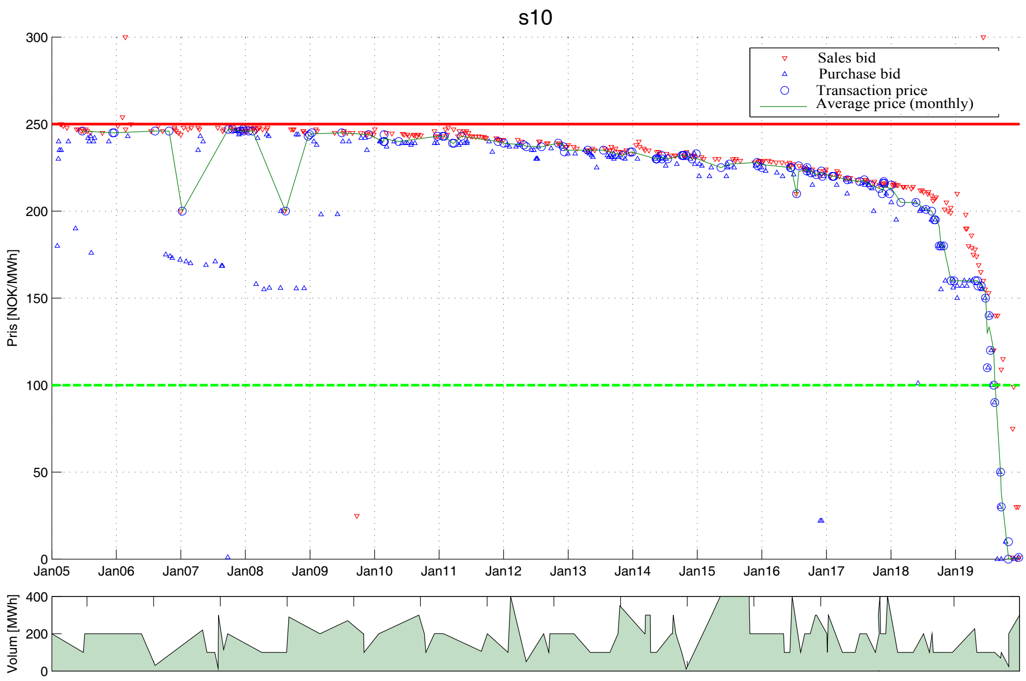


Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	3	3	3	9
Quota obligations	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	50%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation + Total Capacity			
Other:				

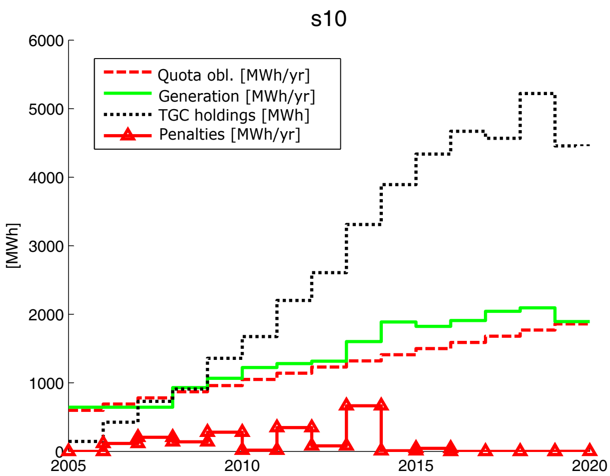


Experiment s10

Repetition of experiment s9 gave similar results. Penalties incur, and TGC holdings pile up. Capacity follows demand closely. To our surprise, the prices are on average higher than without the possibility of postponing quota obligations.



Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	3	3	3	9
Quota obligations	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	50%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation + Total Capacity			
Other:				



11 Group IV experimental results (s11,s12)

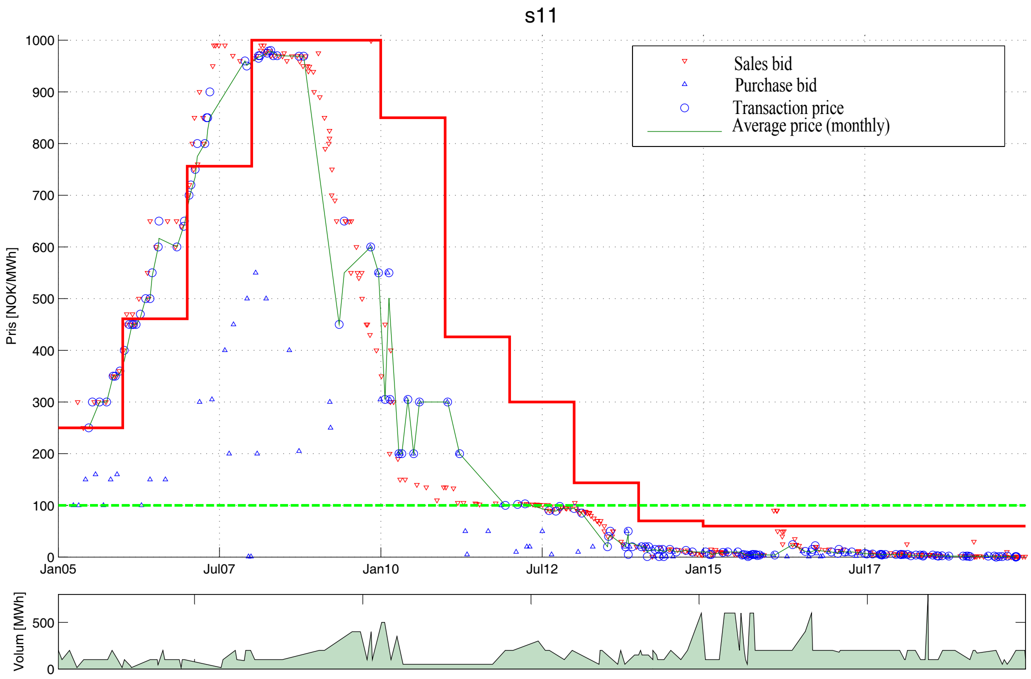
Instead of a fixed penalty price, the Swedish market has a penalty price that depends on last year's average TGC price. The penalty price P_t^{max} is defined as:

$$P_t^{max} = 150\% \cdot yearly\ average(P_{t-1}) \qquad \text{(i)}$$

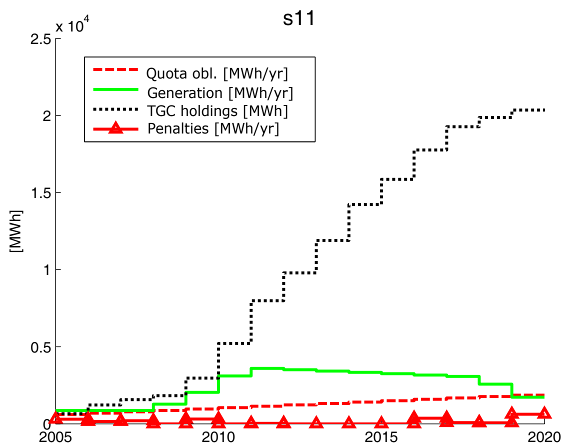
This market design (representing the current TGC market in operation in Sweden) shows that transactions are made above the year's penalty price, which contributed to a large increases of the penalty price. By the time new capacity comes on line, TGC prices peak at 1000 NOK/MWh in 2008. Overinvestments in the subsequent years makes the market price collapse. The adaptive penalty price reinforce the producers capability of increasing the prices. S12 seems to converge to equilibrium price after having prices escalated to 700 NOK/MWh.

Experiment s11

High bids initially drive the price cap up to 1000 NOK/MWh before dropping to below marginal costs due to over-expansion. Traders with quota obligations can transfer up to 50% of their obligations to the subsequent year.

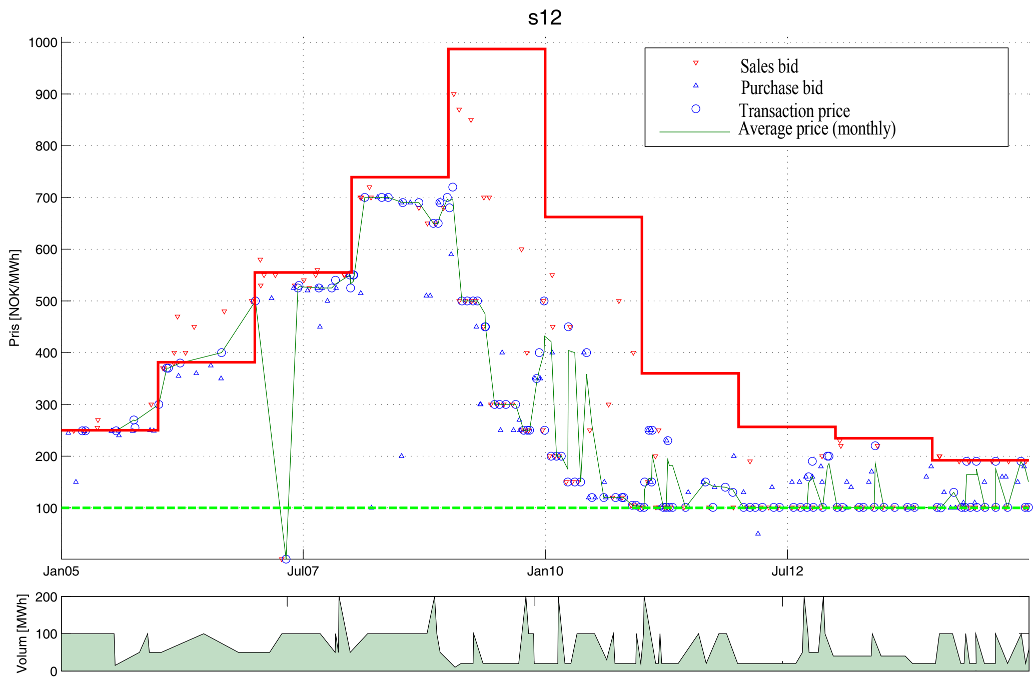


Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	4	4	4	12
Penalty price P^{max}	150% times previous year's average TGC price			
Banking	100%/yr			
Quota postponement	50%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation + Total Capacity			
Other:				

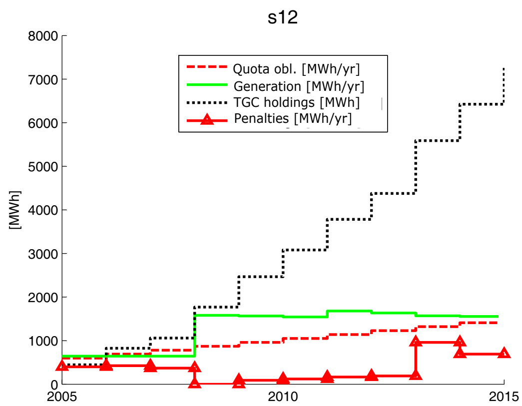


Experiment s12

We removed the possibility to transfer quota obligations to subsequent years. Prices increase towards 700 before dropping. The price does not seem to drop below marginal costs. By mistake, the simulation stopped too early.



Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	4	4	4	12
Penalty price P^{max}	150% times previous year's average TGC price			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	0%/yr			
Market information	Total quota obligation + Total Capacity			
Other:				



12 Group V experimental results (s13,s14)

Economists early pointed out that interest rates was important for the inventory management of certificates, but the interest rate was first incorporated in the last two experiments. Imposing 5% interest rates on capital (defined as accumulated profits, see Appendix B), we introduce an opportunity cost of holding TGCs, rather than selling the TGCs increase the capital stock. To hold TGCs traders must expect prices to rise more than 5% per year. Furthermore, investments become more expensive as well, as investments make a negative impact on the capital stock.

In reality, there are many incentives to realise the value of TGC's at an earlier stage, for instance payments on loans and other expenses. Introducing an interest rate on capital reflects these concerns.

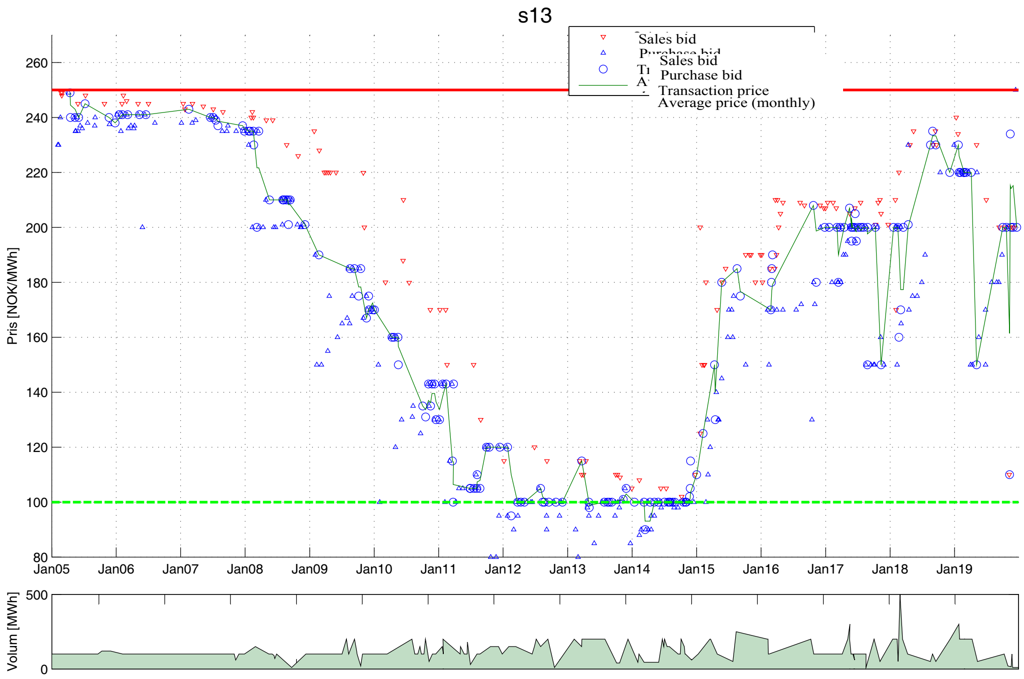
The first experiment s13 shows that prices drops down to equilibrium price half ways in the experiment, but rises towards the end of the simulation period. There are some overcapacity in the first part of the experiment, but the there is a deficit in capacity after 2015. The TGC holdings are still plentiful. Prices increase towards the end of the simulation period.

In s14, there is more overcapacity until 2015. Producers try to increase prices, it seems, but some of the buyers choose to take penalties here, and successfully seem to discipline producers from increasing prices further.

The price more or less settles on the marginal cost in s14, seems to be behaving as a near-perfect market. If we look at the supply and demand development, the penalties and the banking of TGC's, we doubt these that a stable market equilibrium can be attained with this design. The market price tends to either settle at the price cap, the floor, or at the marginal cost (the marginal cost line 100 NOK/MWh cannot be observed in the user interface, only the red line indicating price cap. Further studies are necessary to draw conclusions here.

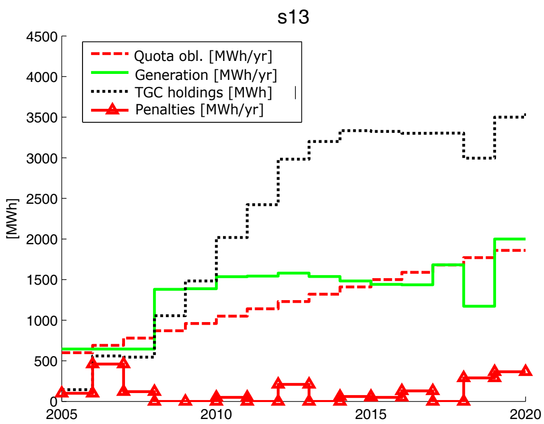
Experiment 13

Prices drop to marginal costs within 2012, but increase after 2015.



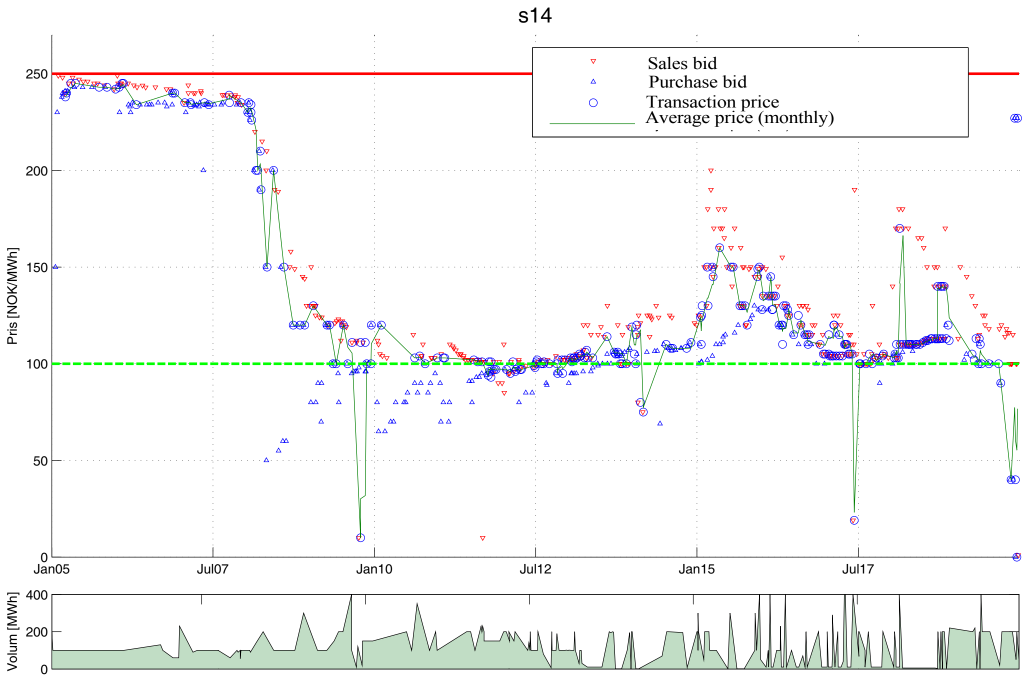
Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	3	3	3	9
Penalty price P^{max}	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	5%/yr			
Market information	Total quota obligation + Total Capacity			

Other: Interest on capital. Capital = accumulated profits x 1.05 1/yr



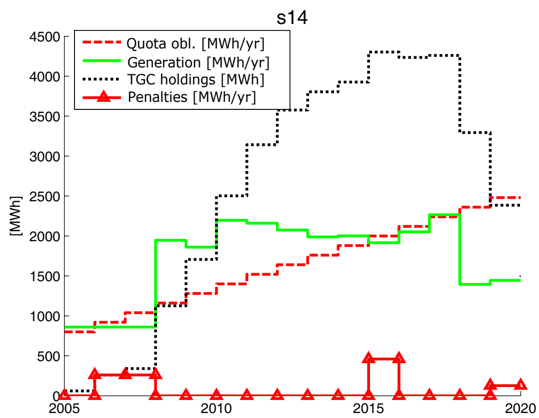
Experiment s14

Prices drop down to marginal costs around 2010. Possibilities to transfer quota obligations to next year is removed. In 2015, the excess supply is gone, and producers try to increase price, but some of the sellers oppose the price increase, and chooses to pay penalties rather tan committing buy at high prices. The equilibrium prices dos not appear to be very stable.



Parameter				
Buyer, **S**eller, **I**nvestor, **T**otal	B	S	I	T
	3	3	3	9
Penalty price P^{max}	250 NOK/MWh			
Banking	100%/yr			
Quota postponement	0%/yr			
Interest rate	5%/yr			
Market information	Total quota obligation + Total Capacity			

Other: Interest on capital. Capital = accumulated profits x 1.05 1/yr



14 Conclusion

An experimental economics analysis of the current Swedish green certificate market design has been conducted.

Experiment s1-s2 shows that market prices will be higher than theoretical equilibrium prices. We conjecture this to be a result of the possibility of producers to bank certificates to subsequent years, while trades with quota obligations must fulfil their quota by the end of each year. Banking creates an options value for producers. These results hold even if there is an excess production or supply initially.

Experiments s3-s8 showed that price crashes from overinvestments are the most likely long-term mode of behaviour for the TGC market. Our experiments assume sunk investment costs, but technologies where part of the costs can be recovered can reduce this problem. For instance CHP bio with possibility to switch fuels back to oil or coal makes such investments less sensitive to long-term price crashes.

Prices are initially high in all of the simulations, which is caused by the time delays involved in acquisition of new capacity.

Experiment s9-s10 shows that allowing for flexibility of transferring quotas to subsequent years do not necessarily reduce prices. We were not able to provide sound explanations for these observations.

Experiment s11-s12 shows that a floating penalty price depending on previous years average prices, will amplify the price increases during the first years. Floating penalty prices create possibilities for manipulation.

Experiments s13-s14 showed that including 5% interest rate on capital did have an impact on price development. In the last experiment, prices seems to converge towards equilibrium price. However, it seems that this equilibrium is unstable, more experiments are required.

The overall results are that the TGC market is not efficient with the proposed market designs. Prices tend to be either high (up against the penalty price), at the equilibrium or at the price floor, and unstable in the long term.

The possibility to bank certificates in combination with the sluggish dynamics on the supply side is responsible for the high prices.

As we mainly focused on testing the existing market design, we did not test alternative market designs that might alleviate these problems (for instance borrowing of certificates from future production), but we believe it is possible to improve the current market design with minor adjustments so that the changes can be implemented in practice.

References

Amundsen, ES og JB Mortensen, 2001: The Danish Green Certificate System: some simple analytical results. Energy Economics 23 pp489-509

Bye, T., O.J Olsen and K. Skytte 2002. Grønne sertifikater - design og funksjon. Report no. 11/2002, Statistics Norway. (in Norwegian)

Dales, JH 1968: Pollution, Property and Prices. Toronto, University of Toronto Press.

Dimitrovski A, M Gebremichael, K Tomsovic, A Ford and K Vogstad, 2004: Comprehensive modeling of the long term dynamics of investment and growth in electric power systems. Report presented at EPNES, Puerto Rico, July 12-14.

Econ 1999. Dokumentasjon av ECON's kraftmarkedsmodell. Econ note 4/99, Econ centre of economic analysis.

Friedman D og S Sunder, 1994: Experimental methods. A primer for economists. Cambridge University Press.

GJ Schaeffer and J Sonnemans 2000: "The influence of banking and borrowing under different penalty regimes in tradable green certificate markets - results from an experimental economics laboratory experiment", Energy & Environment 11, 2000 pp407-420.

Hindsberger, M., M.H Nybroe, H.F. Ravn and R. Schmidt 2003. Co-existence of Electricity, TEP, and TGC Markets in the Baltic Sea Region. Energy Policy, Vol 31(1).

Jensen, S.G, K. Skytte 2003. Simultaneous attainment of energy goals by use of green certificates and emission permits. Energy Policy Vol 31(1)

Jensen, S.G, K. Skytte, 2002. Interactions between the power and green certificate market. Energy Policy Vol 30(5).

Kampmann, CE 1992: *Feedback complexity and market adjustment: An experimental approach.* MIT thesis.

Kristensen, I 2003: *Use of Green Certificates in the Nordic Power Supply.* Hovedfagsoppgave ved Inst. for elkraftteknikk, våren 2003. www.stud.ntnu.no/~klausv

P.E. Morthorst, 1998: "*Capacity development and profitability of wind turbines*", Energy Policy 27 pp779-787.

Rassenti, SJ, VL Smith and BJ Wilson 2002: *Using experiments to inform the privatization/deregulation movement in electricity.* Cato Journal Vol 21(3), 2002.

Rassenti, SJ, VL Smith and BJ Wilson 2003: *Controlling market power and price spikes in electricity networks: Demand side bidding.* Proceedings of the National Academy of Sciences of the United States of America (PNAS), vol 100(5), March 4, 2003

REBUS 2001. Renewable energy burden sharing: Effects of burden sharing and certificate trade on the renewable electricity market in Europe. EU Report, May 2001.

RECeRT 2001. The European Renewable Certificate Trading Project Final Technical Report. Available [online] http://recert.energyprojects.net/

Risø 2002. Green Certificates and Emission Trading. Risø report no. Risø-I-1936(EN)

Schaeffer G.J & J. Sonnemans 2000. The influence of banking and borrowing under different penalty regimes in tradable green certificate markets - results from an expermimental economics laboratory experiment. Energy and Environment Vol 11(4).

Smith, VL 2002: Nobel prize in economics lecture. *Constructivist and ecological eationality in economics.* Tilgjengelig [online] http://www.nobel.se/economics/laureates/2002/smith-lecture.html

Smith, VL 1962: *An experimental study of competitive market behaviour.* Journal of Political Economy 70:2 (111-37)

SOU 2001: “Handel med elcertifikat - ett nytt sätt att främja el från förnybara energikällor” Svenska offentliga utredning. SOU 77:2001 (In Swedish)

STEM 2002. Yttrande över Elcertifikatutredningens betänkande, “Handel med elcertifikat”, SOU 2001:77 Statens energimyndigheter, yttrande. pp5-7 (In Swedish). Available [online] http://www.stem.se

STEM, 2004: Översyn av elcertifikatsystemet. Delrapport etapp 1.Svenska Kraftnät, 2004: www.elcertifikat.svk.se

Vogstad K, MM Belsnes, G Warland, JOG Tande og KS Hornnes, 2001: Integrasjon av vindkraft i det nordiske kraftsystemet Sintef TR 5447

Vogstad, K 2003: *Designing market-oriented environmental policy instruments: The case of Tradable Green Certificates* Proceedings, Marie Curie Workshop 22-23 okt, 2003, Petten, Nederland. www.stud.ntnu.no/~klausv

Vogstad, K 2004: Combining system dynamics and experimental economics to analyse the design of tradable green certificates. Paper accepted for IEEE HICSS 2005 conference, 2005. www.stud.ntnu.no/~klausv

Vogstad, K, I Kristensen and O Wolfgang, 2003: *Tradable Green Certificates: The dynamics of coupled electricity markets.* Proceedings, 21st System Dynamics Society International Conference, 20-25. Juli, 2003, New York, USA. www.stud.ntnu.no/~klausv

Smith, VL 1962: *An experimental study of competitive market behaviour*. The journal of political economy Vol 70(2).

Smith, VL 1990: Experimental economics. Edward Elgar, Hants England.

Sterman, JD 1989: Modeling managerial behaviour: Misperceptions of feedback in dynamic decision making experiments.

Diehl, E and JD Sterman 1995: The effects of feedback on dynamic decision making. Organisational behaviour and human decision processes. 62(2)

Paich, M and JD Sterman, 1993: Boom, bust and failures to learn in experimental markets. Management Science 39(12)

Moxnes, E 2000: Not Only the Tragedy of the Commons : Misperceptions of Feedback and Policies for Sustainable Development. System Dynamics Review 16(4)

Appendix A - Model equations

(1) Model equations for n buyers and investors, and m traders with quota obligations

1.1 $Construction_{n,t} = Construction_{n,t-1} + (Investment\ rate_{n,t} - Construction_{n,t-D})\Delta t$ [MWh/yr]

1.2 $Capacity_{n,t} = Capacity_{n,t-1} + (Construction_{n,t-D} - Capacity_{n,t-L})\Delta t$ [MWh/yr]

1.3 $D = 2$ [yr]

1.4 $L = 10$ [yr]

1.5 $Investor_{n,t} = GUI\text{-}Investor_{n}(*)\Delta t$ [MWh/yr^2]

1.6 $Investment\ rate_{n,t} = MAX(I_{max}, Investor_{n,t})$ [MWh/yr^2]

1.7 $I_{max} = 3 \times Capacity_{n,t}$ [MWh/yr]

1.8 $TGC\ holdings_{n,t} = TGC\ holdings_{n,t-1} + (TGC\ purchased_{n,t} - TGC\ sold_{n,t})dt + TGC\ issued_{n,t}\Delta t$ [MWh]

1.9 $TGC\ issued_{n,t} = Capacity_{n,t}$ [MWh/yr]

1.10 $TGC\ purchased_{n,t} = GUI\text{-}Trader_{n,t}(*)$ [MWh/yr]

1.11 $TGC\ sold_{n,t} = GUI\text{-}Trader_{n,t}(*)$ [MWh/yr]

1.12 $TGC\ holdings_{m,t} = TGC\ holdings_{m,t-1} + (TGC\ purchased_{m,t} - TGC\ sold_{m,t})dt$ [MWh]

1.13 $TGC\ purchased_{m,t} = GUI\text{-}Trader_{m,t}(*)$ [MWh/yr]

1.14 $TGC\ sold_{m,t} = GUI\text{-}Trader_{m,t}(*)$ [MWh/yr]

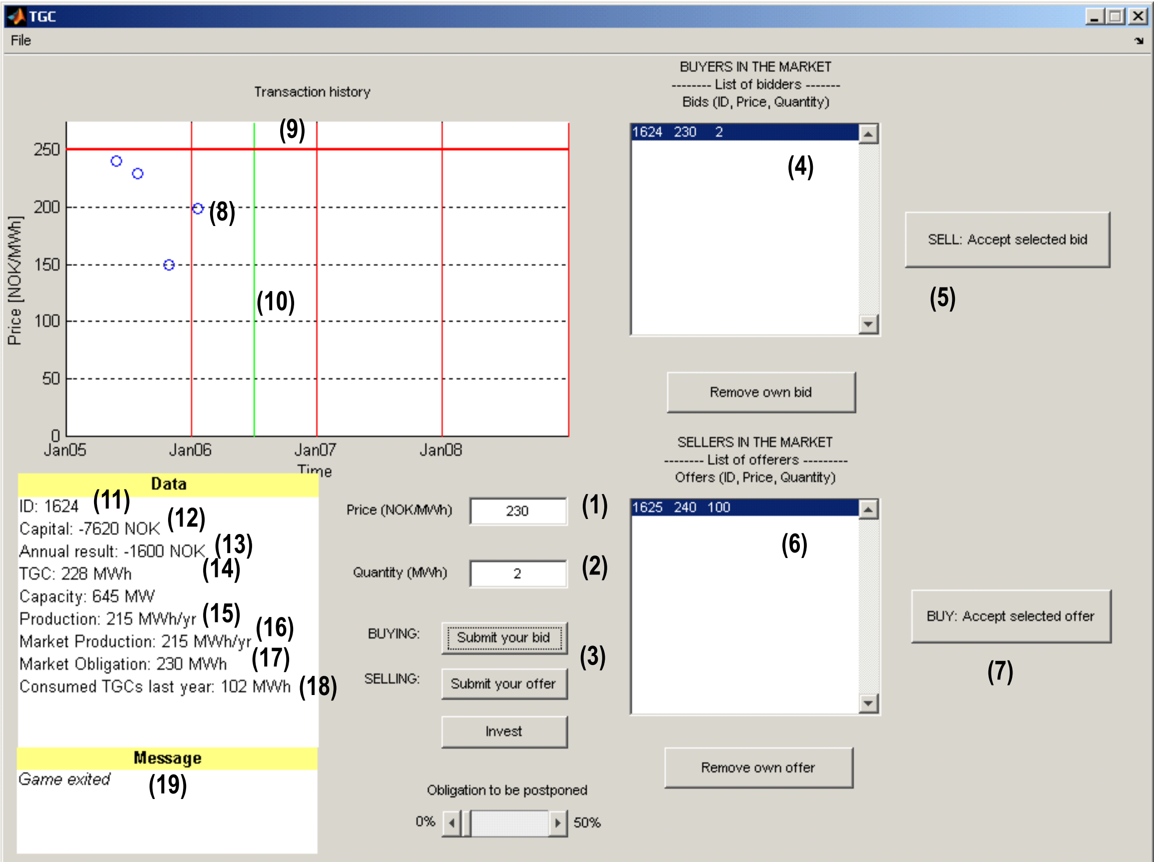
1.15 $TGC\ hand\text{-}in_{m,t} = \{200,230,260,290,320,350,380,410,440,470,500,530,560,590,620,650\}\Delta t$ [MWh/yr]

The operator *dt* denotes continuous time, *dt=1 second*, whereas expressions with the operator Δt *=1 yr* are updated by the end of each year. Computationally, the model was implemented in Matlab v7, as an interactive network simulation model.

$GUI\text{-}Trader_{m,t}$ *(*)* represents the decisions of the subjects, with access to information from the user interface (see Appendix B).

Appendix B - Graphical user interfaces

Producer



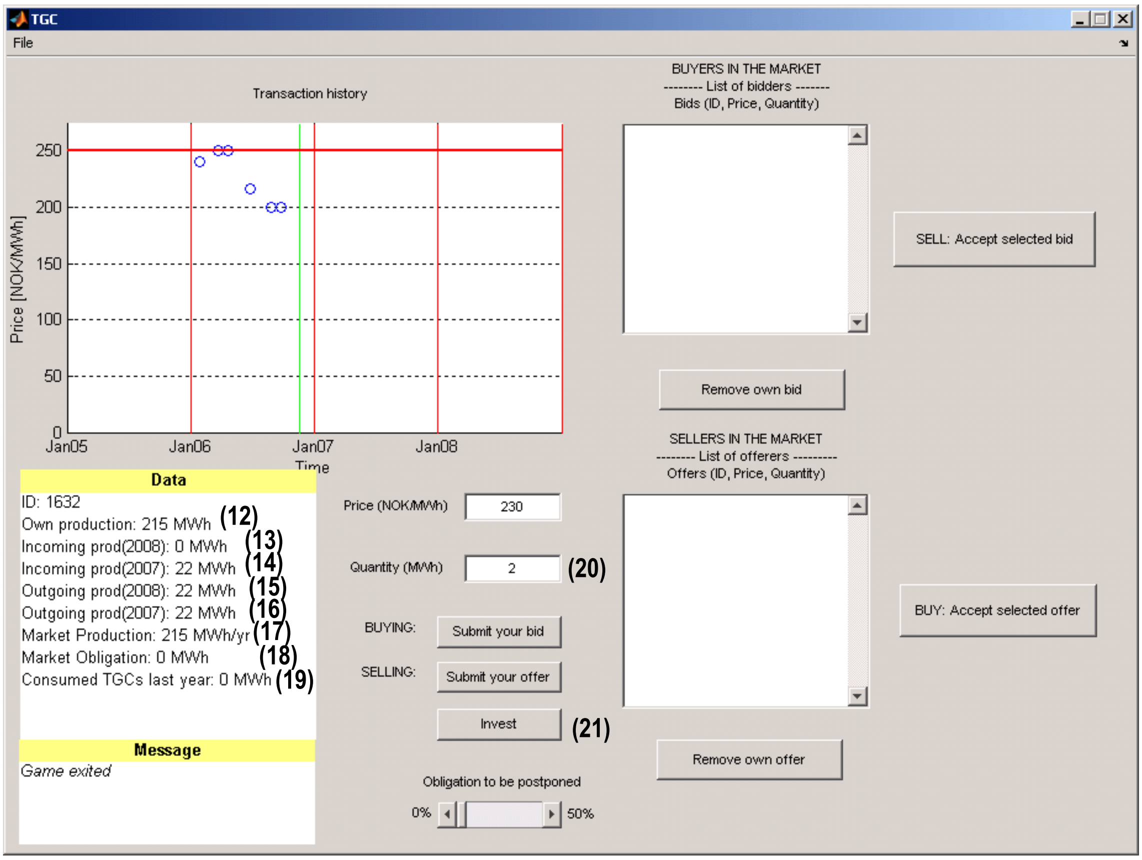
Figur 1 Producers Graphical user interface

(1) Enter bid/ask
(2) Specify quantity of bid/ask
(3) Submit bid/ask
(4) Observe list of bids
(5) Accept bid
(6) Observe offer
(7) Accept offer
(8) Price of transactions
(9) Penalty price
(10) Vertical green line shows current time, red vertical lines indicate end of each year (and deadline for quota obligation)

(11) ID-number
(12) Accumulated profits (Capital). Initial value is 0 NOK for producers
(13) Yearly result. Net profit from buying/selling TGCs minus yearly production costs (100 NOK/MWh).
(14) TGC (Tradable Green Certificates). Producers holdings.
(15) Producers yearly generation.

(16) Total yearly generation
(17) Total yearly TGC obligation in the market.
(18) TGCs handed in last year (if the consumer can postpone obligations)
(19) Messages (i.e. confirmation of transactions or error messages)

Investor

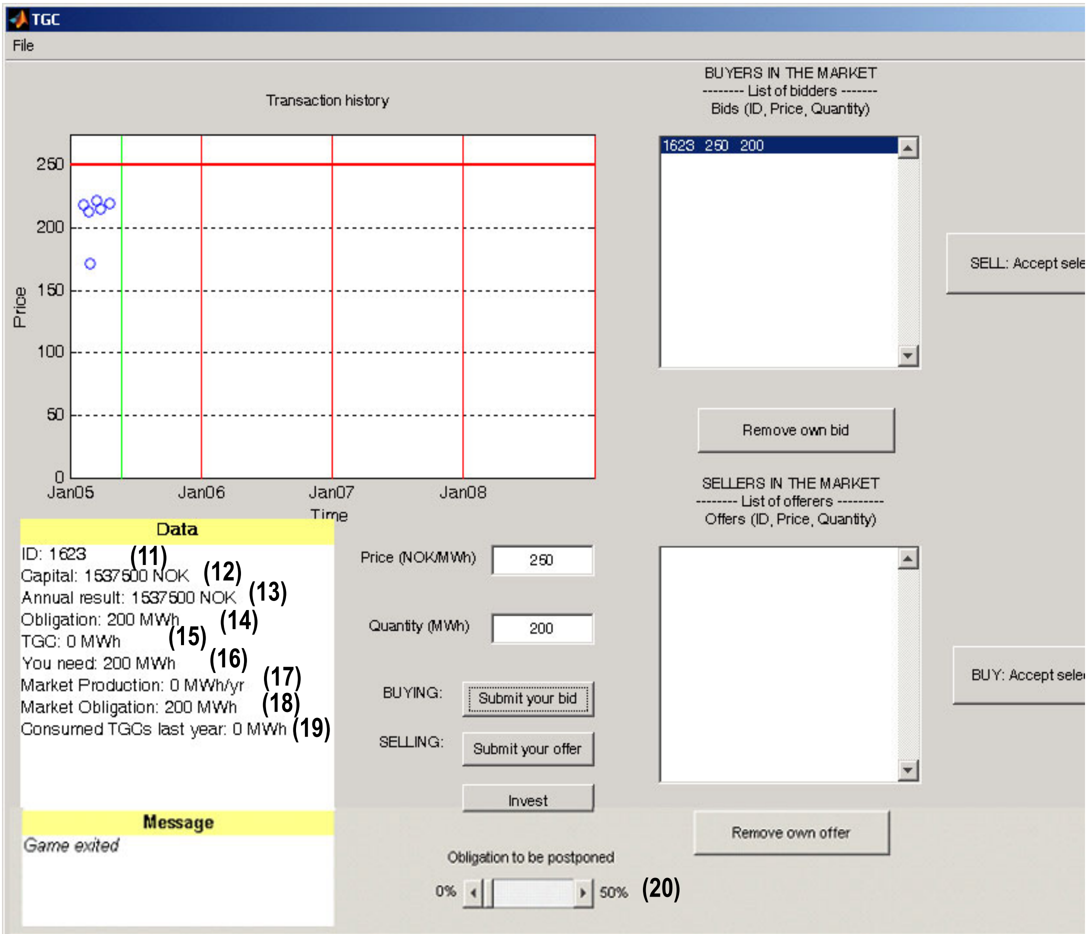


Figur 2 Investors Graphical user interface

(12) Own production capacity
(13) New capacity orders (on line within two years)
(14) New capacity orders (on line within one year)
(15) Production capacity decommissioning within two years
(16) Production capacity decommisioning within one year.
(17) Total yearly generation in the market.
(18) Total quota obligation in the market.
(19) TGCs handed in last year.

(20) Enter amount of capacity to order.
(21) Submit capacity order.

Consumer with quota obligations



Figur 3 Graphical user interface, consumers

(11) Players ID-number
(12) Accumulated Capital. Consumers start with 1.57 MNOK Capital initially, which is the cost of buying TGC obligations at penalty price over the whole simulation period.
(13) Yearly result: Net income from buying/selling TGCs.
(14) TGC (Tradable Green Certificates). Consumers holdings.
(15) Consumers holdings.
(16) Minimum TGC needed to fulfil quota obligations.
(17) Total yearly production in market.
(18) Total yearly market obligations
(19) TGCs handed in last year.
(20) Enter the percentage of this years' TGC obligation that you want to transfer to next year.

Appendix C Investment function for experiment s3

The investment function I_t in session 3 anchors on the equilibrium investment rate $\frac{K_{t-1}}{L}$ and adjusts by profitability indicator $f(\pi_t)$:

$I_t = f(\pi_t)\frac{K_{t-1}}{L}$, where $\pi_t = \frac{E[p]}{C}$ and $f(\pi)$ has the shape of the graph below

I_t - investment rate at t [MWh/yr^2]

K_{t-1} - Generation capacity [MWh/yr]

L=10 Lifetime [yr]

Profitability indicator π_t is the expected price $E[p(t)]$, divided on levelised energy costs, C=100 NOK/MWh.

If we denote $\hat{P}(t) = E[p(t)]$, then expected price is defined as:

$$\hat{P}(t) = P(t) + P(t) \cdot \frac{d\bar{P}}{\bar{P}} \cdot T_f$$

$$\bar{P}(t) = \bar{P}(0) + \int_{t-T_b}^{t} (d\bar{P})dt$$

$$d\bar{P} = \frac{(P(t) - \bar{P}(t))}{T_b}$$

, where $T_b = 1$ yr is backward time horizon for expectation formation, and $T_f = 1$ yr is the forward time horizon for trend extrapolation.

$\bar{P}(t)$ is exponential weighted over the period T_b.

Figure 4 Left: Assumed relationship between profitability π and investment rate $f(\pi)$. Right: Empirically observed relationship between profitability and investment rate. (Source: Morthorst, 1996).