Agent based simulation of the selected energy commodity market

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Abstract. A traditional macroeconomic approach to the analysis of commodity prices is usually based on the aggregate supply and demand as well as the abstract price elasticity of the demand. Unfortunately, this elasticity can be determined a posteriori (i.e. before a certain stimulus is experienced), which makes it difficult to predict even the most general market changes. The paper presents a simulation model developed by authors that incorporates major elements of the market, including customers, suppliers, storage, etc. The proposed simulation has an important advantage over a traditional approach, as it allows to predict the market behaviour on the basis of the model parameters which are identifiable and measurable a priori, i.e. infrastructure parameters and market participants behavioural parameters. that are acquirable with the use of existing sociological tools and models. The simulation model assumes the independence of action of every entity (agent) with certain regulatory and physical constrains, such as the supply routes capacity, environmental conditions, enforced minimal reserves, the individual customer priority over commercial entities, etc. The primary benefit of the model and the simulation environment is the possibility of observing the market under various hypothetical scenarios.

Keywords: agent simulation, energy market, consumer behaviour.

JEL classification: C63
AMS classification: 91B26, 68U20

1 Introduction

Forecasting and estimation of market behaviour under certain economic conditions has been a vital desire of many market analysts. For obvious reasons, however, it is not possible to conclude a scientific experiment in a controlled environment that would either prove or falsify certain economic theories. Therefore, the predictions and market analysis is often performed on the basis of similarities to the conditions observed earlier or the 'intuition' of the analyst. Now, however, there exists another option for predicting the behaviour of complex systems, namely, a simulation. For human behaviour modelling, agent-based [7] scenarios are often successfully employed [11], [1], [9].

In this paper a similar, agent-based approach inspired by [1] is utilised to simulate a national coal market. Specifically, the JADE [4] platform is used as a basis for the simulation. The agents implement basic economic behaviour, i.e. maximizing individual profits or minimizing the costs [3], [5]. Consumer models also include coal consumption rate which is calculated based on current external temperature and consumer's individual parameters (i.e. house heating requirements, preferred temperature).

The initial sections of the paper describe sellers and buyers models used for the simulation. The models were initially developed by the authors for the purpose of price dispersion analysis [12], and has been adjusted for the presented task. This paper also includes a new proposed model of a trader (middle man). Later on, selected simulation results obtained with the models described are presented. As can be seen, the collective intelligence represented by a set of virtual agents yields the results which are consistent with expectations, and can also be used to assess how the market could behave under certain conditions.

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2 The models of market participants

2.1 Consumers

For the purpose of the simulation, a single type of customer is considered. It is assumed that the customer utilises the coal for heating. Therefore, their daily usage will mainly depend on the environmental factors (the temperature outside, the size of the house). The model of the consumer (C) is a simplified version of the model proposed in [12] for the analysis of the price dispersion [2] and consists of the following elements:

$$C\{L, S, K, E(ps, hs, tc, ex)\} \tag{1}$$

Where:

- L is the location of the customer
- S is their current stock of coal
- K is the knowledge possessed by the customer (about traders' offers)
- E is their personality.

E_{ps} denotes their sensitivity to the coal price, E_{hs} is the unified equivalent of their house heating requirements, while E_{tc} is the preferred temperature inside. E_{ex} denotes certain customers' willingness to switch to other sources of heating. Although energy prices are somehow correlated [8], temporary differences can often trigger customers' decisions to switch to a different source. The usage of the coal is therefore calculated as follows:

$$\Delta S = \begin{cases} -e_f \cdot E_{hs} \cdot (E_{tc} - t_{curr}) & if \quad E_{tc} > t_{curr} \\ 0 & if \quad E_{tc} \leq t_{curr} \end{cases} \tag{2}$$

Where:

- ΔS is the change in consumer's coal stock
- e_f is the heating efficiency of the coal
- t_{curr} is the current temperature outside

Each customer evaluates their stock of coal (S) daily and with a probability equal to the stock 'emptiness' (S_a) investigates the market and gathers knowledge (K) by polling the available traders for price offers. Upon receiving the offers, the customer then decides to replenish their stock of coal with the following probability:

$$\begin{gathered} H = E_{ps} \cdot \left(a - b \cdot \frac{P_t p}{P_{atp}} - c \cdot S_a\right) \\ R_{cp} = (1 - d \cdot E_{ps}) + sign(H) \cdot H^2 \end{gathered} \tag{3}$$

Where:

- R_{cp} is the probability of purchasing coal from a trader (the value is limited to (0-1) range)
- S_a is the percentage of available (empty) stock space the customer currently has
- P_{tp} is the current best price of coal available from the traders
- P_{atp} is the averaged (over time) price of the coal purchased by the consumer
- E_{ps} is the customer's personality (sensitivity to the price of coal)

a, b, c and d are the parameters which are adjusted to provide a reasonable environment: i.e. a customer with an average E_{ps} will have R_{cp} close to 100% when his stock (S_{ta}) reaches 50%, while an extreme saver will only have 75% chance of deciding to buy coal even if his stock is empty if prices are 20% above the average.

2.2 Traders

Traders are the entities that purchase coal in bulk from producers and sell it to consumers. They tend to have a relatively large stock of coal and adjust rather quickly to the market conditions. Traders have to manage two sides of the transaction, i.e. purchasing the commodity and deciding on the price at which it will be offered to customers. Traders are modelled as follows:

$$T\{L, S, P, E(ta, tb))\} \tag{4}$$

Where:

L	is the location of the trader
S	is their current stock of coal
P	is the price offered
E	is their personality, denoting 'greediness' in terms of sensitivity to prices offered by producers

The purchase is determined by the current price of coal (compared to the long time average), and the current state of the trader's stock (he will be more pressed to buy if his current stock level is low). The probability and the amount of the purchase is defined as follows:

$$\begin{aligned} R_{tp} &= S_{ta} + t_a \cdot \left(100\% - \tfrac{P_{vp}}{P_{avp}}\right) \\ Q_{tp} &= S_{tt} \cdot \left(0.5 \cdot S_{ta} + t_b \cdot \left(100\% - \tfrac{P_{vp}}{P_{avp}}\right)\right) \end{aligned} \tag{5}$$

Where:

R_{tp}	is the probability of purchasing a delivery of coal by the trader (limited to (0-1) range)
Q_{tp}	is the amount (quantity) of coal requested
S_{ta}	is the percentage of the available (empty) stock space the trader currently has
S_{tt}	is the total size of the traders' stock space
P_{vp}	is the current best price of coal available from the producers
P_{avp}	is the averaged (over time) price of coal purchased by the trader
t_a and t_b	are parameters denoting particular trader's sensitivity to the purchase price

The traders conduct all transactions (provided they do have the stock to trade) if a consumer requests a purchase at the price offered by the trader. Each trader, however, can individually set their offer price. It is assumed that each trader's single and primary goal is to maximize the profits. Since the trader does not know how the market will respond to the offer in price change, during each evaluation cycle they take a risk and change their offered price taking into account the history. If the last change (e.g. decrease in the offered price) resulted in an increased overall profit for the trader, the trader will continue to change the price in the same direction (e.g. decrease the price further). If the last change (e.g. a decrease in the offered price) resulted in a decreased overall profit for the trader, the trader will change the price in the other direction (e.g. this time increase the price). In this case, the change is smaller in value (i.e. half of the previous change) to prevent artificial oscillations.

$$P(t_0) = \begin{cases} P(t_{-1}) + 1.5 * (P(t_{-1}) - P(t_{-2})) & \textit{if profit increased} \\ P(t_{-1}) - 0.5 * (P(t_{-1}) - P(t_{-2})) & \textit{if profit decreased} \end{cases} \tag{6}$$

2.3 Producers

Producers are the entities delivering the commodity (i.e. coal) into the market. For the purpose of the simulation, only one producer was used, since with such simple constrains (a single type of commodity, price based purchase decisions only), the producers end up following each other's pattern. Also, the external sources (importers) are not distinguished. In both cases, under a short-term scenario, the cost of producing (i.e. making available) a single unit of coal can be deemed constant. For internal producers this depends mostly on the cost of work. For importers it depends on the international prices (mostly governed as futures contracts) [6], [10]. It is also assumed that the production price is constant over the course of simulation. The producer is represented by the following model:

$$V\{S, P, G\} \tag{7}$$

Where:

S	is the producer's current stock of coal
P	is the price offered
G	is their capacity to produce (units/time)

As far as determining the offered price is concerned, the producers follow the same pattern as traders, i.e. they adjust the offered price on the basis of the results from a previous change, as described in (6). The ultimate goal of the producer is to maximize the profit.

3 Initial model validation

In order to assess the model, it would be prudent to see how it behaves under the so called 'normal' conditions. For that purpose a simulating environment has been set up as follows:

the number of customers:	1000
the number of traders:	4
the time of the simulation:	5 years (1825 days)

Customers' and traders' personalities ($C.E$ and $T.E$) were randomized (evenly distributed within 0-100% range for each parameter). Some of the results of the simulation can be seen in Fig. 1 and Fig. 2. The first one (Fig. 1) illustrates the market from the producer's perspective. As can be seen, after the initial period of stabilizing the market, the prices offered and the producer's stock of coal change periodically with the demand driven by the change of the temperature. (The temperature is an actual historical average temperature in Poland retrieved from a weather web site).

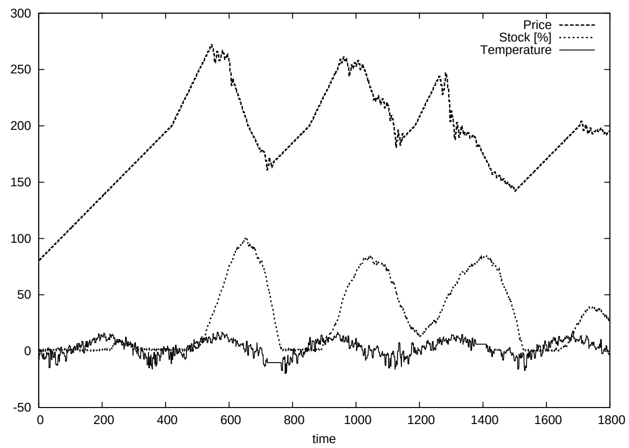

Figure 1 The price and stock of the producer compared to current outside temperature levels

Also, the behaviour of some consumers was illustrated in Fig. 2. Two specific customers were selected from the group of 1000: one with average parameters, and one with extremely 'greedy' personality (which means he would rather froze than pay a high price for coal).

These results indicate that the model, regardless of its simplicity, seems to work well and allows for reproducing the environment close enough to the real world. The results achieved are in line with what would be expected in real, unregulated market.

4 Hypothetical scenarios

In this section the results of some hypothetical scenarios will be given. These have a two-fold purpose. First, they allow for further verification of the applicability of the proposed model. Second, assuming the model has proven to be adequately close to the expectations, it gives us an insight into scenarios that can happen, but have not been experienced in real world yet.

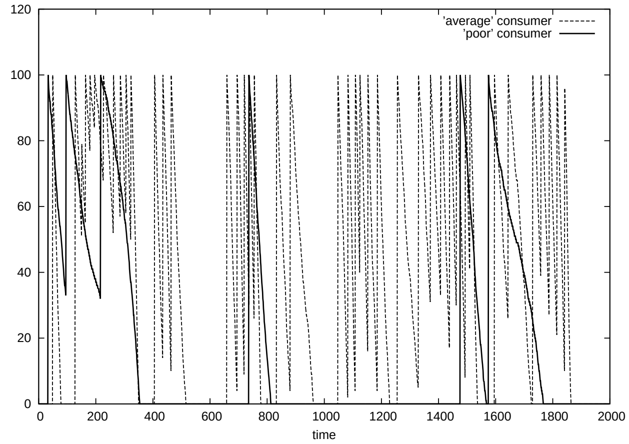

Figure 2 Coal stock (in %) of different types of consumers over time

4.1 No alternative, no limits

Under this scenario, there were no restrictions on the amount of money customers have to spend on purchases, nor do they have an alternative heating to switch to. They still, however, exhibit greedy behaviour - the probability of a purchase depends on the perceived attractiveness of the offer as in equation (3). The observed outcome is a steady rise in prices - even though customers try to purchase coal as cheaply as possible (and the price varies over time), the underlying condition of scarce commodity drives the prices steadily higher.

On the other hand, there is a single condition that may turn the scenario upside down. If the supply of coal is higher than the average demand, it drives the prices steadily down, down to the level of production costs. With no possibility to reduce the output, the prices are driven even further down, almost to zero. This is somehow a confirmation of the principle of the economy, i.e. that the rules of economic behaviour apply only to scarce resources.

4.2 Mass consumer flight

Another scenario that has been tested is a significant number of customers leaving the market (e.g. because of switching to another energy source). The results of this scenario are illustrated in Fig. 3. In this scenario, around half of the customers gradually leave between the t+1000 and t+1500 of the simulation. As can be seen, this results in a massive drop in prices and surge in producer's stock that is not being picked up by the traders. In Fig. 3, the producer's price *Price2* and their stock of coal *Stock2* is presented against a baseline scenario (*Price1* and *Stock1* respectively).

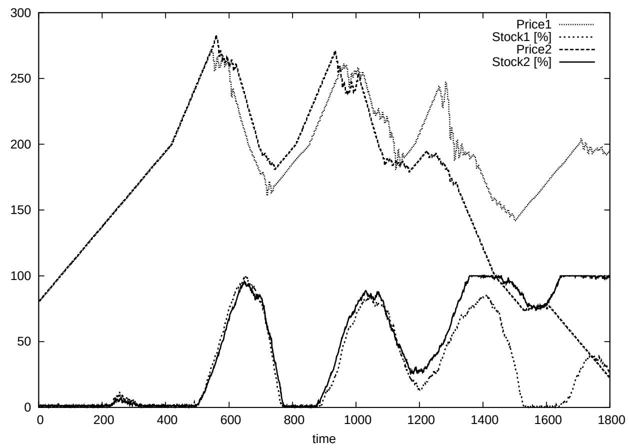

Figure 3 The results of a substantial number of customers leaving the market

4.3 Change in available stock sizes

Another scenario that has been tested is a change in the size of stock available to traders and producers. Surprisingly, a significant increase in the stock size (beyond a yearly turnover) resulted in the increased price volatility. This was likely due to a much lower number of individual transactions that do not let the traders 'keep in touch' with the market changes.

5 Conclusions

In this paper the use of agent-based models for simulating the behaviour of real markets is proposed. As has been proven, such environments behave in a way similar to the real world, provided that the models of the participants include key aspects of their behaviour. It has been demonstrated that relatively few constrains and behavioural scenarios are needed to implement a functional market.

Certainly, the primary requirement (and a basic validation of the models) is the similarity in behaviour of the artificial environment to the observations from the real world under typical circumstances. Yet, the real strength of the models is the possibility to observe the environment under certain set of unusual conditions.

Due to limited space, these hypothetical, unusual conditions have been discussed very briefly, yet they give an interesting insight into possible outcomes and prompt further research into the subject. Fortunately, the implemented simulation environment allows for relatively easy enhancement of the agents, which will allow for testing of more complex and sophisticated scenarios.

References

[1] Bonabeau E.: Agent-based modeling: Methods and techniques for simulating human systems, In: *Proceedings of the National Academy of Sciences*, **3(99)**, 2002, 7280–7287.

[2] Baye, M.R., Morgan, J., Scholten, P.: Information, Search, and Price Dispersion. In: *T. Hendershott, Editor, Handbook on Economics and Information Systems*, Elsevier, New York, 2006, 323–375.

[3] Begg, D., Begg, D.K.H., Fischer, S., Dornbusch, R.: *Economics*. McGraw-Hill, 2005.

[4] Bellifemine, F., Caire, G., Pogg, A., Rimassa, G.: JADE - A White Paper. In: *Telecom Italia Journal: EXP - in search of innovation*, **08**, Rome, 2003.

[5] Fishbein M.: Attitudes and Prediction of Behaviour. In: *Readings in Attitude Theory and Measurement*, John Wiley, New York, 1967, 477-492.

[6] Li, R., Joyeux, R., Ripple, R.D.: International steam coal market integration. *The Energy Journal*, **31**, 2010, 181–202.

[7] Lin, H.: *Architectural Design of Multi-Agents System*, Information Science Reference, 2007.

[8] Papiez, M., Smiech, S.: The analysis of relations between primary fuel prices on the European market in the period 2001-2011. In: *Rynek Energii*, **5(96)**, 2011, 139–144.

[9] Raberto M., Cincotti S., Focardi S.M., Marchesi M.: Agent-based simulation of a financial market. In: *Physica A: Statistical Mechanics and its Applications*, Elsevier, New York, 2001, 319–327.

[10] Smiech, S., Papiez, M.: Short-term predictions of import prices of steam coal in Poland. In: *Rynek Energii*, **2(99)**, 2012, 148–153.

[11] Was J., Kulakowski K.: Agent-based approach in evacuation modeling. In: *Agent and Multi-agent Systems: Technologies and Applications - Lecture Notes in Computer Science*, Springer-Verlag, 2010, 325–330.

[12] Zachara M., Piskor-Ignatowicz C.: Agent Based Simulation of Customers Behavior for the Purpose of Price Distribution Estimation. In: *Computational Collective Intelligence. Technologies and Applications - LNCS*, Springer, 2011, 211–220.