THE AGENT-BASED MODEL OF REGULATION OF RETAIL PRICES ON THE MARKET OF PETROLEUM PRODUCTS

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Abstract: This article provides model of the retail gasoline market as multi-agent systems. The main factors, which affecting on the retail price of gasoline were determined. The authors found that using the agent approach, which takes into consideration the coalitions in the market, in particular, tacit collusion, it is possible to describe the behaviour of players correctly. An description of agent behaviour models and algorithms specific agent were done.

Keywords: petroleum products, market, oligopoly, game theory, agent-based model

Introduction

The role of the oil products market for any national economy is extremely high, the price of fuel affects the nature of the economy in total. Increasing of prices of fuel excites a chain reaction of negative consequences: increasing of prices for commodities, inflation rising, reduction of firms profitability, especially for power-intensive. Naturally, that the government that cares about the public good, can't be indifferent to the condition of the oil market and forced to apply the regulatory impact on the market. The costs of oil account as a component of transport costs, which in turn affect the prices of each goods of consumer's market. At the same time fuel prices in the internal market are sensitive to fluctuations in crude oil prices on world markets and a number of other factors. Another important factor, to which the price of fuel in the market is very sensitive, is the exchange rate of dollar to national currency [1].

Characteristic feature of modern oil market is the large number of economic entities, acting independently or in co-operating in terms which are far from the postulates of classical markets where there are laws of equilibrium. Stability of this market in the short period of time depends on the behaviour of market players, on their pricing strategy. Researchers of oil market in recent years have established the fact that different countries on their national market have one feature of prices dynamics, so-called asymmetry, because of gasoline markets are often suspected of the existence of cartel agreements on prices[4-6]. Such agreements are illegal in EU countries and other countries, including in Ukraine. So, appears the question of price regulation on the oil market, taking into account the factor of possible conspiracy.

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Characteristics of the oil market in terms of competitive mechanisms

Market structure totally depends on the number of firms in the market, their market power, and the level of barriers to market entry. If barriers for entry are high, then only a limited number of firms can coexist in the market. Extreme case represented only one monopolistic firm, which dictates the price. On the other hand, in oligopolistic markets (more than one firm), the decision of each firm also has an effect on the profits of competitors. Firms react to the actions of competitors and companies in every decision results not only in their incomes but also on the behaviour of competitors as a reaction to this decision. This so-called oligopolistic interdependence and it's the key difference between oligopoly and other market structures such as monopoly and free competition.

In the case of free competition or monopoly, economic theory provides explicit solutions for pricing decisions of firms. There is no universal model for the case of oligopoly, which can cover all the features and all possible cases. There are numerous models, each of them makes simplified assumptions (as well as in the case of free competition and monopoly) and responding to this or that kind of market. In this article we consider the theoretical models of oligopolistic markets with homogeneous product, because gasoline market is so.

One reason for this restriction is a tacit collusion as the most important case that influences on the prices behaviour in markets with homogeneous products, because establishing of tacit collusion for heterogeneous product markets is difficult to achieve. Therefore, secret agreements don't occur in such markets often. Another reason is our focusing on gasoline markets and gasoline may be considered as a homogeneous product. Carlton and Perloff specify the following basic assumptions and characteristics of oligopolistic markets with homogeneous products[2]:

1. Consumers are pricetakers (that's, there are many consumers who can't influence the price of the product).
2. Consumers suppose that products which produced by all firms are identical .
3. The number of firms constant within some time.
4. Few companies have market power together (i.e., they can set prices higher than marginal cost).
5. Each firm chooses its price or volume of.

Newer models of oligopolies markets limited of static interaction (one-off games) in which all firms take a simultaneously decision about the price or quantity[3]. The first was described of Bertrand model, the last - of Cournot model. If we want to take a solution of the game on a such model, we should use the concept of Nash equilibrium. There are numerous examples that illustrate the solution of the game. Though, even in this case there doesn't exist a universal solution for game of two participants. However, there is important case that this Nash equilibrium can be established when each firm makes absolutely rational choice and chooses the strategy that maximises its revenue, in comparing with other strategies. Therefore, it's the result of rational behaviour without any explicit agreement, especially secret.

Therefore, the difficulties of a model constructing on the game base for this task stipulate firstly for the large number of players (depending on the size of the region may be dozens of players), secondly - setting an appropriate kind of behaviour depends on the environment. Since the distribution of players in the region is not uniform, so each player must prescribe their own ways of reaction and variations of moves. But the biggest problem there is the possibility of a plot in the oil market. Nash equilibrium for games with two or more players is a such a set of strategies and payoffs, in which none of the participants may not increase the gain by changing the choice of strategy unilaterally, if other members don't change their choice. Indeed, the result of Nash gives hope for finding a solution, because it is proved that there is always exist a point of equilibrium for final game. However, this is rightly only for noncooperative games. Moreover, even in the case of noncooperative games there is no algorithm of searching such point in general, because it's very difficult to take into consideration the real constraints on the strategies of players. For coalitional games (conspiracy is a kind of coalition), claims about existence of equilibrium isn't proved in general, so we'll seek to solve this problem another way, just a method of agent modelling.

Agent approach

In oligopolistic markets (more than one firm), the decision of each firm also affects on the profits of competitors. Therefore, firms react to the actions of competitors and in every decision of the company consider not only direct effect on their income, but also the effects of reactions of competitors. It's so-called oligopolistic interdependence was laid in the basis for the building of market model as a multi-agent system. Agent-oriented modelling (hereinafter - AOM) - a special class of computational models based on the individual behaviour of a set of agents created for computer simulations. The basic idea underlying the agent-oriented models is to construct a "computational tool" (which is a set of agents with certain properties) that allows for simulation of real phenomena. The ultimate goal of the process for creating AOM - the impact of agents fluctuations which acting on the micro level to macro-level indicators[7].

Agent modelling requires a certain abstraction of the real world and actually investigated objects. In our case, such restrictions was imposed:

- the market of oil products are limited to a territory and isolated.
- there are agents in the market – retail nets which united in service stations.
- over the period of modelling none agent can to come out from the market, also excluded the possibility of appearing new agents in the market.
- the whole area of the market is divided into squares and each square is characterised by the number of consumers of fuel. Such factors as changes in legislation, political environment, changes in exchange rate and others don't affect the decision of agent pricing.

The network doesn't change the fuel suppliers for a modeling period.

– to obtain more profit agents can collude.

We can see at this level of abstraction that pricing decisions depend only on the network with the agent or the agents-neighbour. Such factors as changes in oil prices, exchange rate fluctuations and other factors don't directly affect the decision of an agent, but they affect the prices of certain fuel of certain network. Cause each network has its fuel suppliers, appears an opportunity to consider agents with different costs, which is more adequate to reality than of employment the same cost of all agents.

Feature of agent-based models is that they require more parameters in comparing to macromodels. Thus for our model we are using the location of each station in the region, and fuel prices for each network.

Input data for the following model: $\{M, PZ, PN, LOC, S\}$, where

PZ_t^m - prices for fuel purchasing m-network in time t;

PN^m - initial retail price m-network;

LOC_k^m - location of k-filling station of m-network;

$S_{i,j}$ - number of consumers of fuel in the square with coordinates (i, j);

M - the number of retail networks;

This data set allows to consider different changing of kinds of factors that affect the model through the input parameter PZ, and the reactions of consumers according to geography area, manifested in the parameters S and LOC.

Cause all actions based upon the location of agents in a particular area, so each agent is characterized by a specific location. An important consideration that affects the construction of agent-based model is accounting the strategy of collective behaviour, in particular the principles of grouping. For example in [8] there is an assumption that each station is represented as agent. However, such behaviour does not meet the realities of the market of oil products in many countries, particularly the oil market of Ukraine, where an agent is the retail network of company, that decides on the price of its gas stations.

Because the agent has several stations, it makes a recounting of location of each station, which sets on the average distance between stations of a certain agent. Separate station can't make a decision on the price, so the agent represents as a network of several stations. Therefore, for simplification of this model, making an assumption about the establishment of uniform prices throughout the network stations.

As basis of the algorithm of agent behaviour model is similar to [8] that represents itself as the algorithm which is built on rules. This is a rather intuitive way of understanding the task of agent behaviour.

Since each station can't decide the price, so a network represents as agent. Under this model, making an assumption of establishment the uniform prices throughout the network stations.

Introduction to the algorithm messaging provides capabilities for agents plot. Conspiracy valid until significant changes take place in the input parameters of agents.

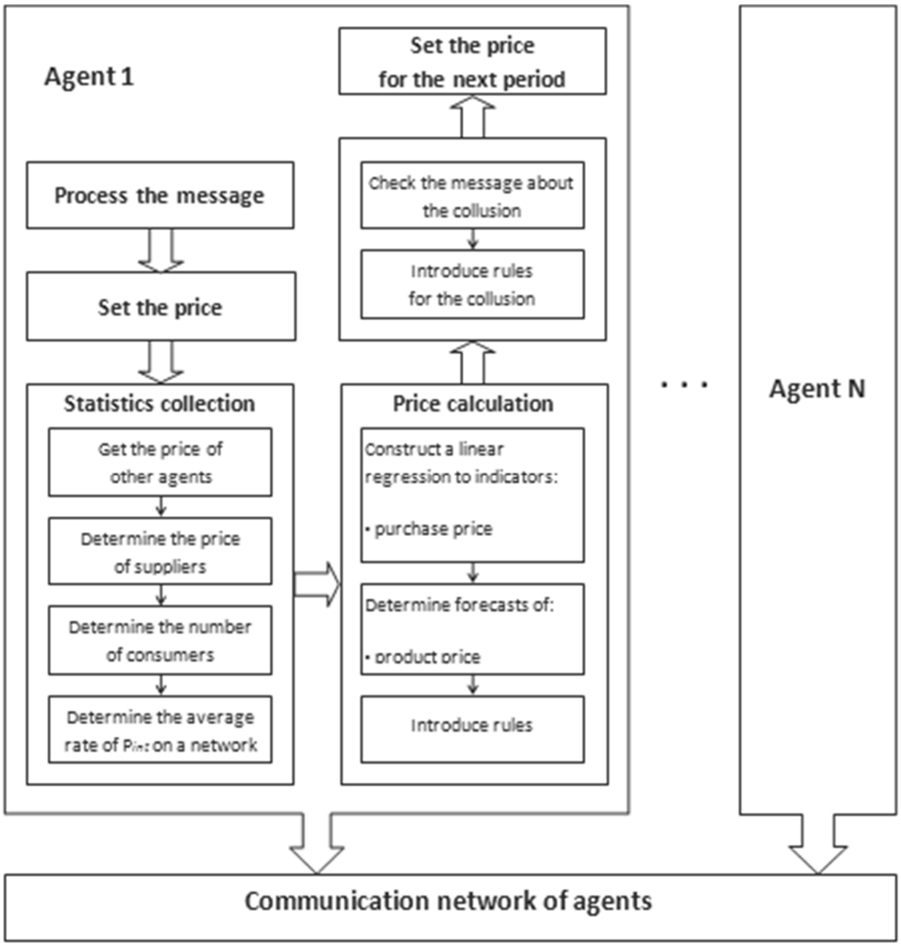

Figure 1. Conceptual diagram of model

Algorithm consists of rules for changing prices, which include rules for review of the benefits of collusion. The main index which appears in the rules is:

$$P_{\text{int}} = \frac{\sum_{i=1}^{n} \frac{p_i}{l_i}}{\sum_{j=1}^{n} \frac{1}{l_j}} \qquad (1)$$

p_i - price of *i*-neighbour agent and l_i - the distance from this agent to *i*-agent

This index is calculated for each station and calculate an average for the entire network.
The basic rules that each agent acts are:

- if you change your spending less than 10%, you must to adjust the price according to changes in costs.
- if you change the integral index of prices of 0-5%, you must to adjust the price in the same direction at less than 1% change in the integral index.
- when changing the slope of trend P_{int} for the last 4 days of 0,05-0,1, you must to adjust the price of the estimated value of this index in the last 3 days.
- if you change P_{int} more than 10%, you must to correct price for same amount.
- if you change your spending more than 10% and if adjusted price of costs is less than the P_{int}, you must to increase the price towards the cost increases.
- if you change your spending more than 10% and if adjusted price of costs is bigger than P_{int}, you must to set adjusted price.
- if you change the coefficient of slope of the trend P_{int} for the last 3 days more than 0.2, you must to set the price equal to $P_{\text{int}}*C_{up}$.
- if messages about establishing of monopoly prices was received, you must to accept those which received more.
- if the coefficient of slope of the trend P_{int} for the last 4 days and the last 7 days differ by not more than 0.05, you must to send messages to neighbouring agents t about establishing a monopoly price.
- when you accept a message about the establishment of monopoly prices of one type, you must to send all the neighbouring agents.
- while reducing demand by 10% and a simultaneous decrease of P_{int}, you must to set the equal price $P_{\text{int}}*C_{down.}$

The established numerical constants C_{up} and $C_{down\ necessary}$ requires based on real data from the studied region and the characteristics of asymmetry in prices. Experimentally established that they are equal 1.08 and 0.9 respectively.
Each agent has a module of the statistical analysis. In this case the model is responsible for maintaining the dynamics of input parameters, determines the behaviour of the data and predicts the appropriate parameters. Module is based on the method of least squares with linear function. In the corresponding model parameters established period of the forecast and the amount of data which constructed a prognostic value. The minimum value of this option - 3 days.
Each agent communicates via messages. Agents communicate their reactions only the neighbouring agents. Therefore, depending on the spatial location of messages can take place either immediately or on a chain of agents.

So far as at the different stations have different demand for fuel, so for the reliability model in introducing consumers to determine the distribution of demand for each agent. Fuel consumption in the current period is calculated for all agents and depends on the price of a particular agent and its location. The value of consumed fuel for i -agent is calculated by the formula:

$$C_i = \sum_{j,k} (\delta_i e^{-\alpha d - \beta p} S_{j,k} N) \quad (2)$$

where
C - amount of purchased fuel and agent
$S_{j,k}$ - number of consumers in the square with coordinates (j,k)
N - quantity of fuel, which need one consumer for a day
d - distance from the current square of territory to the agent
p - the current price of agent
In this case the coefficients α and β characterize the dependence of consumed fuel within an agent, and his price, and they are selected experimentally depending on the area where the model was investigated [5].

Model researching

We have developed a program realization of this model for one of the regional oil market of Ukraine. For checking the adequacy of models were used actual statistics for the period from 01.04.2010 till 11.20.2010 year [9],[10]. Note, that for the model used only one brand of gasoline - A95, because it holds the largest share of the consumer basket (about 40%). For introduction statistical data Kiev region was divided into squares 1×1 km and for each square was determined a location of stations of each agent and the number of consumers. How we can see, the model follows trends of real data, that indicating the adequacy of the model.
The next step is to research the impact of changing model parameters on the dynamics of prices.
There was created a few test pieces of data for analylisis the influence of parameters on the outcome model. All tests were conducted on the data length of 47 days. Initial price of the agent in all tests is 3 units.
For the study were selected such options:

- increase coefficient of price in case of its change- K_{up}
- coefficient of price recession - K_{down}
- forecast period - T

All these parameters are used in the rules of agent behaviour and accordingly are equal to such value as 5%, 2% and 4 days. These values are used to test on real data.

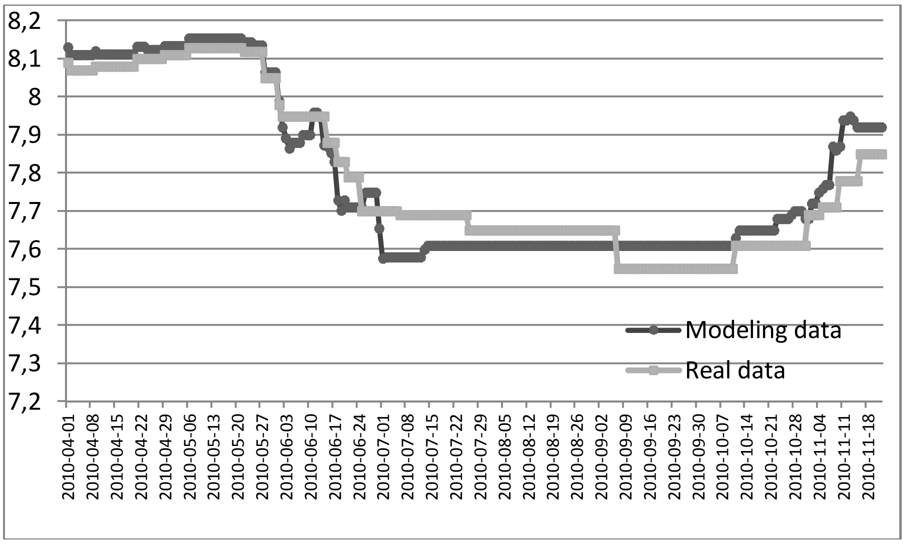

Figure 2. Comparison of simulation and real data

For tests were selected follow values:

1. $\{0.05; 0.02; 4\}$
2. $\{0.1; 0.07; 4\}$
3. $\{0.05; 0.02; 6\}$

First, the data were tested on verified without disturbance. As a result we don't see any dynamics over whole period. For further testing was used a number of other costs to jump from 3 to 5 units in length in 3 days.

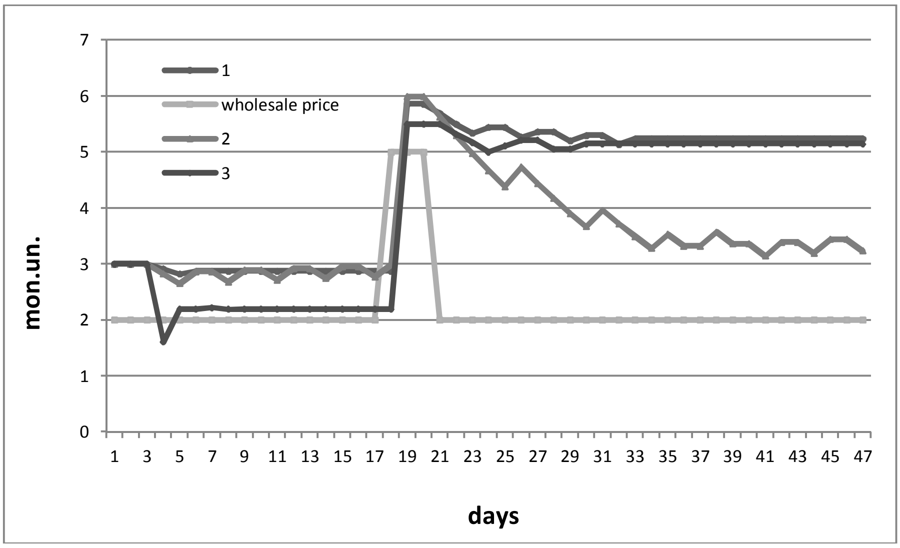

Figure 3. The test results of 3 sets of parameters and at 1 jumps in wholesale prices

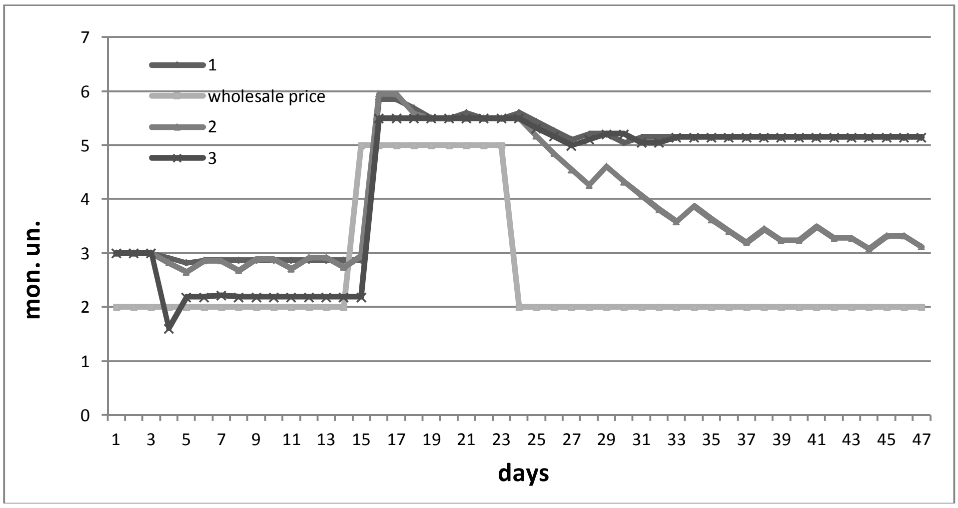

Figure 4. Behaviour model for different parameters at the length of the jump in 9 days

As we can see on fig. 3, sets of parameters 1 and 3 show approximately the same behaviour, except for the initial data, which is explained in deficient quantity of data for forecasting and leads to lower prices. With the increase of coefficients observed significant fluctuations in price, this is due to the increase (decrease) of prices in one step. This leads to the stabilization of prices at a lower level. When increasing the length of the jump in wholesale prices the situation doesn't change. We can see it in fig. 3. So, the selection of options should consider the following:

- when forecast period T increasing then we must properly set initial value prices, avoid deficient of data for forecast at the beginning of the model.
- the correction of price changes coefficients we must to take into account that in case of their increase appear fluctuations in price.

So far as this model was developed for understanding the mechanisms that operate in the market and, if necessary, for regulation of market methods, so we need to test the reaction of model in case of a controlled agent. Such agent isn't susceptible to collusion and sets the specified price.

For tests were selected a set of parameters that were studied in the preceding paragraph: $\{0.05; 0.02; 3\}$. During the whole period of simulation the controlled agent keeps the price equal of 3 units. It should be noted that each agent has a 1/9 share of market share of stations.

As we can see on fig. 5 the behaviour of model coincides with the behaviour in the absence of controlled agent (fig. 3).

In case of perturbation the behaviour of model changes: doesn't formed any collusion and the price decreases (fig. 5). In this case there is only one controlled agent. On the fig. 6 we can see the result of increasing the number of controlled agents to one third of the market.

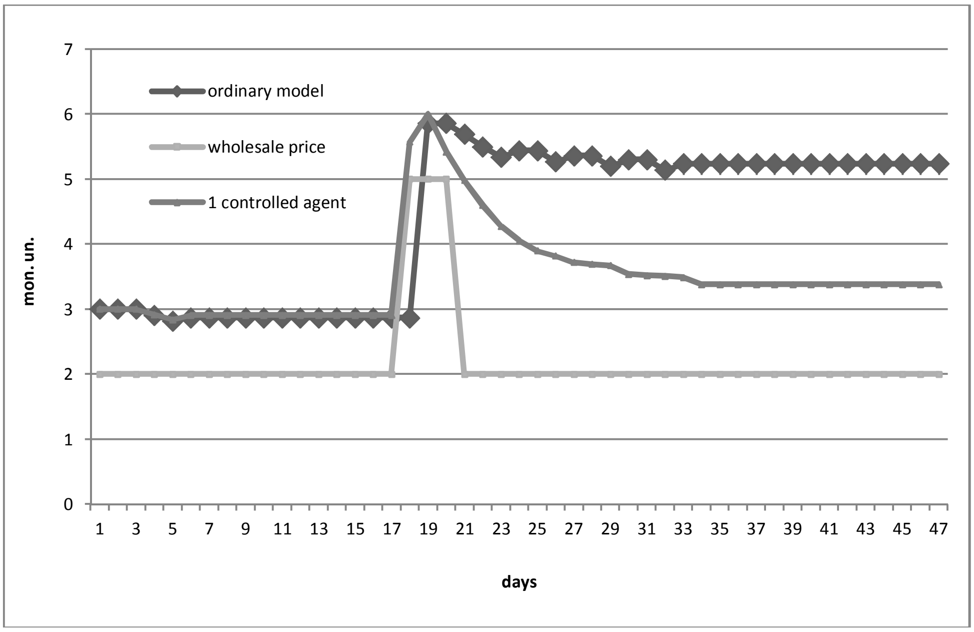

Figure 5. Behaviour in the presence and absence of controlled agent

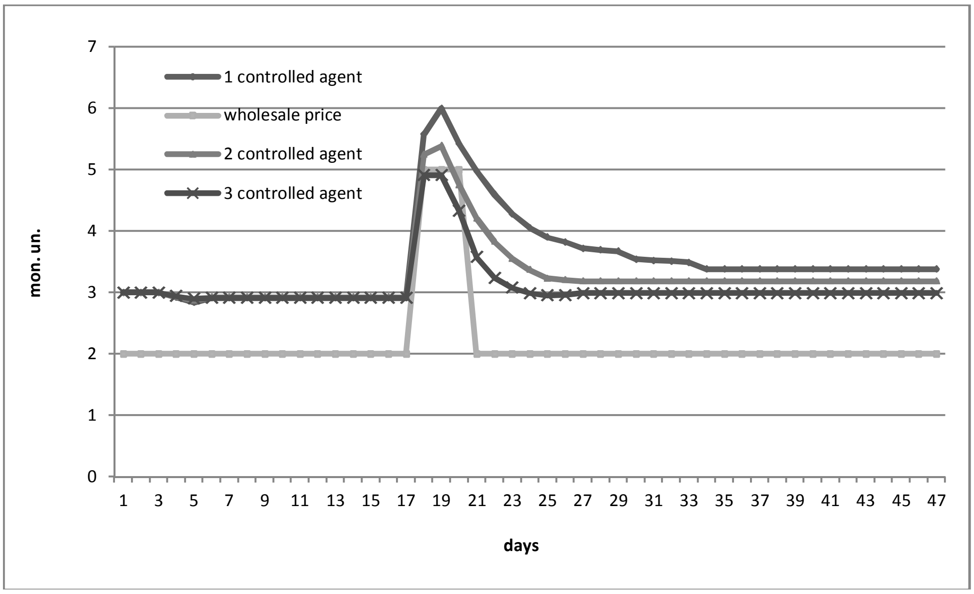

Figure 6. Behaviour model for different number of agents managed

As we can see on fig. 6, in case of increasing number of controlled agents, time for returning prices to a previous state decrease. So in this case, when third of agents set regulated prices the prices return to level of 3 mon. un. within 7 days.

Increasing the number of controlled agents leads to increasing of market share that is regulated by the state. So, the bigger share, the faster prices will return to normal levels.

Summary

In this paper we've presented the agent-based model of price regulation on the oil market. The possibility of some types of models was analyzed for describing the behaviour of the market, in particular the game-theoretic approach. As a result, we found that none of the models are able to quantitatively describe the behaviour of players in the retail market of oil products. The agent model of the oil market, which take into consideration the coalitions in the market, including secret combinations, was offered. We describe the basis of this model and algorithms behaviour of the agent. The model was tested on real data in the Kiev region. We determined, that in case of existence in a marketplace the object, which doesn't enter into a secret plot, and implements special price policy, in particular the state, the level of asymmetry in price significantly reduced. This situation affirms the possibility of price regulation.

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MODEL REGULACJI CEN DETALICZNYCH NA RYNKU PRODUKTÓW NAFTOWYCH BAZUJĄCY NA CZYNNIKACH

Streszczenie: Artykuł ten przedstawia model rynku detalicznego benzynowych systemów wieloczynnikowych. Określone zostały główne czynniki, które mają wpływ na cenę detaliczną benzyny. Autorzy stwierdzili, że stosując metodę czynników, która uwzględnia koalicje rynkowe, w szczególności zmowy milczenia, możliwe jest poprawnie opisanie zachowania graczy. Wykonane zostały, opis i modele zachowania określonych algorytmów.

石油市场零售价格规律的基于代理模型

摘要：本文提出了多代理系统的汽油零售模型。影响汽油零售价格的主要因素以被确定。作者发现可以运用代理联盟的方法特别是暗中联合来准确描述参与者的行为。代理行为模式的描述和代理算法细节已经完成。