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Original Research Article

The asymmetry of price in the petroleum products market of Ukraine

Aims: The aim of this work is to develop of pricing mechanism's model in the retail market during price jumps in the wholesale market of petroleum products
Study design: Mention the design of the study here.
Place and Duration of Study: Faculty of Management and Marketing National Technical University of Ukraine "Kyiv Polytechnic Institute", between March 2015 and February 2016.
Methodology: One of the main factors that determine the behaviour of retail prices on commodity markets is the dynamics of wholesale prices. However, retail prices in most cases respond differently to the increase and decrease in wholesale prices on markets with homogeneous products and the oligopolistic price competition, in particular on the petroleum products market. In this work the main hypotheses regarding the nature of asymmetric behaviour of retail prices on petroleum products market were checked on the basis of heuristic mechanisms about the behaviour of the market and the developed multi-agent models.
Results: On the basis of the following assumptions about the nature of asymmetry of prices a multi-agent model for retail petroleum products market was developed that describes the behaviour of players both in terms of the tacit collusion and the behaviour of the market in terms of consumer search. For agent modelling and verification of the adequacy special software was developed. The verification of adequacy of models and parametric identification were made based on real prices of fuel.
Conclusion: Comparative analysis of behaviour models showed that both hypotheses about the nature of asymmetry of price could occur on the petroleum products market. The model shows certain qualitative and quantitative differences asymmetry in retail prices of petroleum products, depending on the reasons that led to the asymmetry prices.

Keywords: price asymmetry; petroleum products market; tacit collusion; price search; algorithm behavior; agent-based model.

JEL codes: D43,D22,C630,Q4

10 1. INTRODUCTION

11 The behavior of prices in any market is the subject of attention of market participants.
12 Accordingly, the task of forecasting prices will not lose relevance. In full it concerns
13 petroleum product market. This issue is devoted a significant amount of research in recent
14 decades, some of which are shown [1-3]. But the problem is far from being exhausted.

15 There is a large empirical literature on the subject showing that retail prices for petroleum
16 products, especially petrol, react quicker to the increase in wholesale prices than to their
17 decrease. This asymmetrical behaviour is not unique to the petroleum products market,
18 although this market has some the peculiarities of pricing in other areas.

19 Asymmetry in price has been discovered in many markets [4-6] (for example in the banking
20 sector, in the food industry, in supermarkets). But despite the generality of this phenomenon,
21 its nature is still a gap in economic theory [7]. However, in recent years there has been a
22 large number of studies, the purpose of which has been the attempt to present formal
23 models or the empirical determination of the characteristics of the retail market, which may
24 be responsible for the asymmetric price behaviour. Despite all the diversity of approaches,
25 all the researchers agree that the gap can be overcome only with considering behaviour of
26 the market agents after price disturbance. It is necessary to know the behavior of buyers and
27 sellers, that is, to attract the ideas of behavioral economics. Sellers may set prices either
28 independently, or coordinate prices, i.e. participate in tacit collusion. Since the buyer does
29 not have complete information about the state of the market, he is forced to deal with finding
30 fair prices based on the prices observed during previous sales, the value of which should be
31 "anchored" [8-9]. The methodological basis of behavioral economics is the study of the
32 impact of various natural mental states that are very difficult to see directly, but,
33 nevertheless, we can build a pretty convincing explanation of complex economic
34 phenomena based on heuristic assumptions about the behavior of market agents.

35 In the majority of publications the main causes of asymmetry are:

- 36 • The theory of tacit collusion;
- 37 • The theory of reference price search.

38 According to the theory of tacit collusion [10] retailers always have an opportunity to join the
39 tacit collusion in the market, which leads to higher prices not only after their increase, but
40 also after their decrease due to the fact that sellers fix prices at a higher level than in honest
41 competition. If all sellers, or a significant part of the sellers in the market coordinate their
42 pricing policy, then the loss of buyers is inevitable as a result of competition.

43 For pure tacit collusion theory, the behaviour of players in the market is as follows:

44 As soon as the marginal costs of the sellers in the retail market have increased significantly
45 compared to previous periods, they all raise prices after calculating the price that buyers
46 would agree to pay. Buyers in the case of pure tacit collusion continue to buy fuel in the
47 usual way, that is, as a rule, from the same provider. It is very easy to see that this
48 behaviour will lead to higher prices, even if the wholesale price of petrol has already started
49 to decrease. Since this phenomenon is not observed in the real market, we will make a little
50 easier conditions for buyers and sellers. Concerning the buyers we make the assumption
51 that each of them makes not one, but two attempts. Concerning the sellers we make the
52 assumption that when the wholesale price decreases, some of the participants of the secret
53 agreement stop coordinating lowering the price in the hope to get profit from this situation by
54 increasing the number of buyers. It encourages other vendors to lower their prices. Thus the
55 process of lowering of the overall price starts.

56 Search theory is based on an assumption that the reason for price asymmetry isn't the tacit
57 collusion of sellers, but the behaviour of consumers. The main idea is the incomplete
58 awareness of consumers about the state of the market at times of price jumps that give rise

to the phenomenon of asymmetry. As soon as the limit of costs providers begins to rise significantly compared to previous periods, each of the supplying companies independently sets higher prices after estimating the price expectations of the consumers. As soon as the buyers notice significant changes in prices, they try to find a new price acceptable for them. Since the buyers do not have complete information about the state of the market, they try to find the optimal price based on observations of prices during the previous purchases. As a result, if the price on the basis of previous purchases suits him, and the probability of finding a lower price is assessed as sufficiently low, then further search becomes unnecessary.

Thus consumers are searching not so carefully, when prices are lower than their expectations. The less intense consumer search is, the more companies face the inelasticity of demand, which leads to decreased competition. Obviously, expectations cannot determine price accurately, therefore, consumers are beginning to look for fair price for them. When all consumers in a search model may obtain the complete information, the model becomes the Bertrand model of homogeneous product where prices correspond to the capacity costs. When wholesale prices are significantly reduced and marginal costs of firms decrease, respectively, the firms try to reduce their costs sufficiently to allow the reduction of consumer search. Although the price in this case is still too high, the consumers are satisfied given the level of prices, and the companies do not have incentives for further price cuts, because they do not have significant opportunities to attract the customers by lower prices. Thus, it is an active consumer search during the growth of prices and no active search during their decrease that causes the asymmetry of prices.

As you can see, the pricing mechanism on petroleum products market is quite complex. The situation is even more complicated because of the possibility of the existence of both sources of asymmetry simultaneously.

Over the past decade the significant efforts to formalize the mechanisms of pricing and even to the greater extent the efforts to find a base price have been made in the works[8-10], who have made attempts of modelling the mechanisms through which the behaviour during the search can cause the asymmetric response of prices to changes in cost. The most significant results are reflected in the works of Lewis [14-15] where consumer behaviour is described as adaptable by price expectations. And although the described models differ in structure, their results are similar: the presence of asymmetric reactions, proactive search in case of increase rather than in case of decrease of prices.

2. METHODOLOGY

An important characteristic of the petroleum products market for the vast majority of countries is the presence of competition in the form of oligopoly. The problem of construction of the model lies in the difficulty of describing the collective interaction of agents in market dynamics.

Practically all the authors point to the fact that the approaches of theory of differential games can clarify the mechanism of asymmetry in the market of petroleum products. However, the problem of adequate pricing models for real markets of petroleum products to date have not resolved. Despite the very high level of methodological studies [16-17], the complexity of the problem still can not allow the practical application of the results in this field. Therefore to describe the relationship between wholesale and retail prices the dynamic econometric models are mostly used, the ultimate goal of which is the assessment of the fact how current and future prices react to changing value. Note that this method indirectly considers the internal market mechanisms and focuses only on data sets.

For a correct evaluation of the asymmetry of pricing is necessary to consider the complete set of delays. So in the works of Barron et al. [18] the options used to build the cumulative

109 response functions or CRF are evaluated that reflect the behaviour of the retail price at the
110 time of response to changes in wholesale prices by the currency.

111 In the works of Remer [19-20] a detailed study of the phenomenon of asymmetry of market
112 prices on petroleum products market of the United States has been conducted. The
113 peculiarity of the study is that it is not only the check of prices for asymmetry, but also the
114 way of finding out the nature of its origin. Using the large amount of research data he has
115 revealed the presence of asymmetry, but found little evidence in favour of the adoption of
116 tacit collusion as a determinant of asymmetric pricing. However, this does not mean that a
117 tacit collusion on petrol retail markets is absent, and only shows that the test methods do not
118 reveal the fact of the theory of tacit collusion or searching. This conclusion requires an
119 approach that would allow avoiding the difficulties that arise when using the differential
120 games theory.

121 **2.1 Agent model of asymmetric pricing**

122 For the evaluation of possible theories of the formation of the asymmetry of prices the multi-
123 agent approach has been used, which allows estimating the price reaction by describing
124 only the behaviour of a particular subject for the market as a whole. This approach has
125 shown its good suitability for modelling market not only in Ukraine [21]. The multi-agent
126 model of the retail market of petroleum products is based on the interaction of agents in the
127 conditions of oligopoly, when decisions made by a company affect not only its own income,
128 but also the competitors' profit. Thus in course of decision-making not only the financial
129 aspect but also the reaction of competitors to this action is taken into account.

130 Unlike simple econometric methods that operate only with a numeric series, agent models
131 reflect a mechanism of behavioural economics, where certain actions of subjects are
132 dictated by the behaviour algorithm depending on the internal situation and external factors.

133 To consider the phenomenon of asymmetry of market prices of petroleum products we first
134 need to construct an agent model of the petroleum products market. With some
135 simplifications the following classes describe the agent model:

- 136 •The consumer vehicle with a driver. Characterized by the type of fuel, the volume of the
137 fuel tank, the fuel consumption per 100 km and the average distance per day.
- 138 •The petrol station is a filling station, which provides services of the retail sale of fuel to
139 consumers. Characterized by the type of fuel, the available storage volume of fuel and the
140 geographical location.
- 141 •The chain is a subject that has one or more stations at its disposal. Characterized by the
142 presence of a brand and the list of petrol stations available. Sets the price of fuel.
- 143 •The petrol depot is a store of fuel which is produced in the country or imported.
144 Characterized by the type of fuel, its volume in tanks and price.
- 145 •The trader is an intermediary agent that sell fuel on the wholesale market.
- 146 •Characterized by cost of its services during transportation.
- 147 •The state sets the rules for the market players, regulates the tax and excise rates and
148 customs duties.

149 The relationship between the classes is shown in the chart. Based on it, you can develop
150 fairly sophisticated scenarios for interactions between agents in the market of petroleum
151 products. However, in our study of price asymmetry it is enough for us to know the
152 interaction of agents that are samples of classes with the consumer, the petrol station
153 PETROL STATION (PS) and the chain, while the presence of an agent of the petrol station
154 (PS) is required only because in reality refilling can occur only for specific stations, i.e., it is a
155 necessary element for the interaction of two agents: the consumer and the chain.

156 The basic agent in the model is the chain. It decides on price changes and the change of the
157 trader supplying petroleum products.

158 Each agent has its own algorithm for behaviour that is based on the notion of state.
159 Communication between agents takes place through the mechanism of messages. Thus,

160 the Consumer, being in the range of a petrol station gets information about the prices, and
 161 the Network gets the value of fuel prices from traders in the warehouse on request.

162

163 **2.2 Model of tacit collusion**

164 The model of the behaviour of agents is based on the rules proposed in [22-23]. The main
 165 agent is the chain, and all other agents perform their minimum actions and provide statistical
 166 information about wholesale pricing and taxes that they have. The logical expressions of the
 167 chain are selected in such a way as to stimulate a tacit collusion between agents. The tacit
 168 collusion continues until substantial changes take place in the market that may lead to
 169 increased profits without participation in a tacit collusion. The algorithm of agent's behaviour
 170 is the following:

- 171 • Set the price specified in the previous step.
- 172 • Collect the data about the neighbours.
- 173 • Collect the data about wholesale prices.
- 174 • Based on the current situation estimate the volume of consumption in the current period.
- 175 • Determine the cost of a litre of fuel given the fixed and variable costs.
- 176 • Build the consumption forecast taking into account the estimated cost of fuel and the cost
 177 of fuel in neighbouring chains.
- 178 • Check out positions of other chains concerning the possibility of a tacit collusion.
- 179 • Decide to change prices based on rules.
- 180 • Set the price for the next period.

181 Distribution of fuel consumption on the filling stations is based on the demand formation

182 features $D = \left\{ \begin{array}{l} D_{\max} \cdot N_{AZS}^i, \\ A - Bp_i + C \sum_{j \neq i} p_j \end{array} \right.$, that operates not only for the estimation of

183 demand for a particular chain, and also the maximum possible demand $D_{\max}$ depends
 184 on the price agents p_j .

185 Where N_{AZS}^i - number of fuel stations that belongs to network with index i ;

186 A, B and C – the demand curve approximation coefficients at a certain price level of other
 187 networks.

188

189 An important parameter in decision-making is the market price $P_{avg} = \frac{\sum_{i=1}^n \frac{p_i}{l_i}}{\sum_{j=1}^n \frac{1}{l_j}}$,

190 that is the distance l_j which is the distance to all stations located in a certain region and

191 their prices p_j including its own price. Depending on the distance the price can reduce

192 the impact of remote stations on the micro-market around certain stations, and if near to
 193 the station there is no competitor, the station becomes the monopolist, and the market
 194 price moves close to the price of the station.

195 The algorithm of consumer behaviour without searching is shown in Fig. 1.

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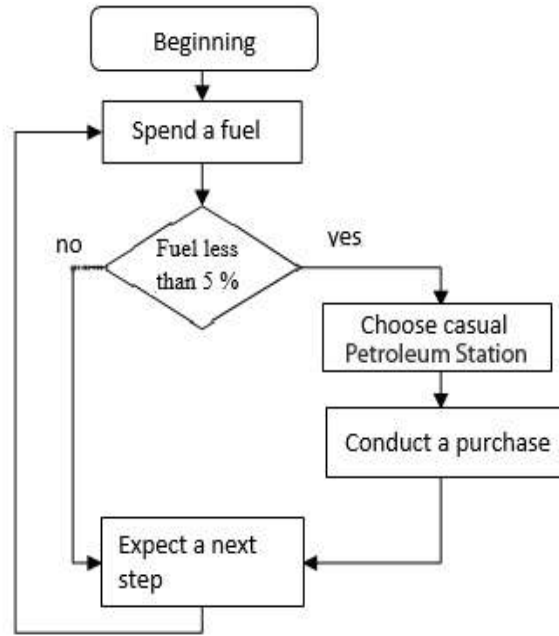


Fig. 1. Algorithm consumer behavior without searching

2.3 Reference price search model

In contrast to the model of tacit collusion behaviour of agents, the reference price search should be represented, basing on the concept of states. The model stresses the consumers' need of searching the PS the criteria based on the price, which is not much different from previous purchases. On this basis, the behavior of the agent can be described as follows:

Determine the amount of fuel consumed during the period.

- If the amount of fuel is lower than a certain mark, then find any PS nearby.
- If the price of fuel does not match the search criterion, search again for a few times.
- In case of absence in the course of finding PS that matches the criteria, choose the PS with the lowest observed price.
- Hold the buying.

The criterion of choice is the price level relative to the prior purchase of a consumer: the price must be higher than the previous one.

The behavior of the network is similar to the behavior in the model with the tacit collusion, however decision about the price change is based on conditions and the assessment of the demand for each station. The model contains the following States: following the market (S1), the change in strategy(S2), trading halt(S3), the return on the market(S4). Condition S1 implements the behaviour of the agent, if there are profits during periods of reduced prices and minor fluctuations in the periods of high margin. State S2 implements a vigorous reaction from the Agent to change the situation on the market: a jump in prices, a sharp decline in demand. States S3 and S4 implement exit strategies for the market in case of impossibility to conduct trade with profit and return to the market in the event of the emergence of such a possibility. Diagram of the decision-making agent network is shown in Fig. 2.

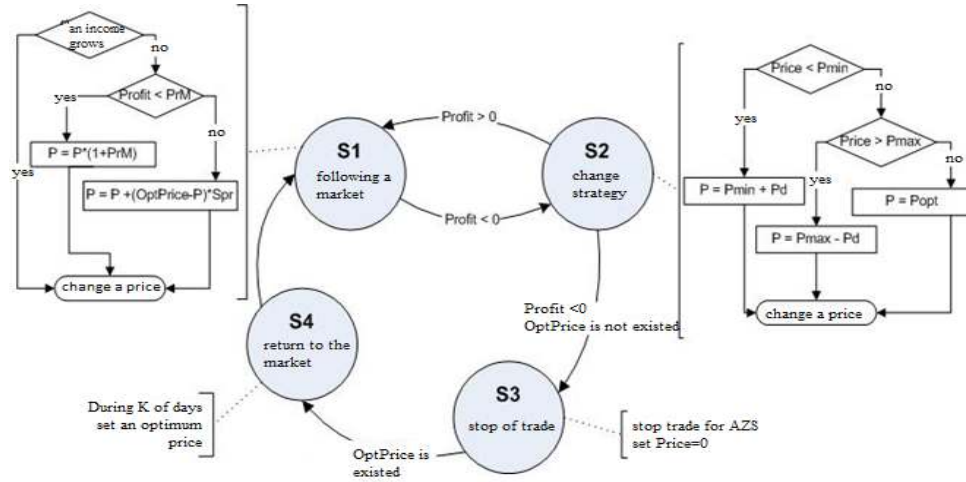


Fig. 2. State diagram of the mechanism of decision-making of agent Network

Also for the decision on price change agent Network is a basic evaluation of the optimal fuel prices. P_{opt} . This parameter is defined as the price that maximizes profit:

$$profit = D(P, P_{avg}) \cdot (P - Tax - Costs) \rightarrow \max \quad (1)$$

where $D(P, P_{avg}) = a_0 - a_1 \frac{P - P_{avg}}{P_{avg}}$ is the function evaluation of the volume of fuel

consumption in PS at a certain market price P_{avg} in the vicinity of that described in the previous model;

Where a_0, a_1 - coefficients of approximation functions demand a separate network, evaluated and refined at each step of the model on historical data.

Parameters of the function are specified at each step during the simulations on all petrol stations.

In addition, the same ratio shall be determined by the minimum (P_{min}) and the maximum

(P_{max}) prices of break-even. Pseudocode algorithm interaction network of agents is as

follows:

```

if(current status = S1)
    if(the profit is reduced)

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244     if(profit < Prms)
245         increase the price of Prms
246     else
247         change the price on OptimalPrice * Spr
248     if(profit < 0) current status = S2
249 if(current status == S2)
250     if(the price is lower than the minimum)
251         set the minimum price with min mark-up
252     else
253     if(the price is higher than the maximum)
254         reduce price below the maximum
255     else
256         establish optimal price
257     if(profit > 0) current status = S1
258     if(profit<0 and profitable price does not exist)
259         current status = S3
260 if(current status = S3)
261     stop trade
262     if(there is a profitable price)
263         current status = S4
264 if(current status == S4)
265     set over k days optimal price
266     current status = S1 .
267

```

Model the behaviour of consumers searching given in Fig. 2. The algorithm reflects the behaviour of agents for each state. In state S1, the price remains unchanged, as long as the profit is not reduced, otherwise it is adjusted according to the current market state. The market state indirectly affects the optimal price for the agent that is used in the adjustment algorithm. This happens due to the consumer search, which stimulates networks to determine the optimal price under demand changes. If the market changes too fast, the agents start acting under the strategy in state S2.

The depth of the market changes basically depends on 2 factors: changes in the cost structure and changes of consumer search depth. Fig. 3 shows the algorithm of consumers in a search. It shows that the increased number of consumer attempts entails the increased consumer influence on the price level.

Synchronizing of agents behaviour is shown in Fig. 4. At the beginning of each iteration, the algorithm implements consumer behaviour. Then it starts the process of pricing and fuel stations servicing. The decision to change the price ends iteration.

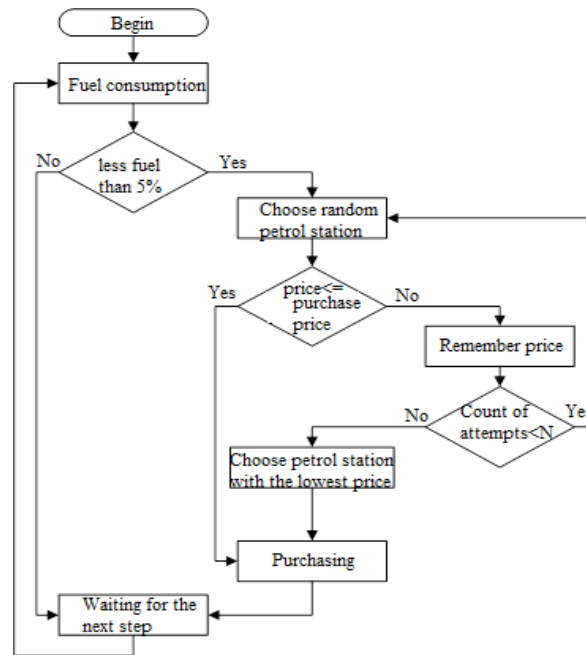


Fig. 3. The algorithm behavior agents by reference-price search model

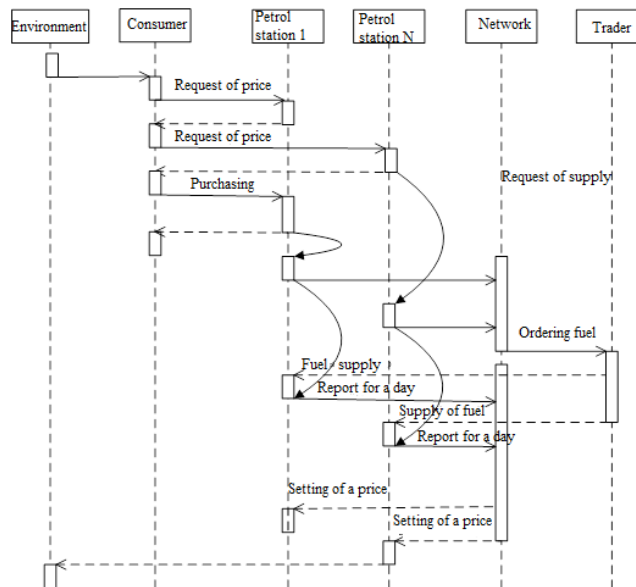


Fig. 4. Diagram of agents states

2.4 Software implementation

For successful implementation of the program presented by multi-agent models, it is required that there be a more complicated model introducing the classes that do not have a semantic load but are responsible for simulation and interface. Class Diagram software implementation that is given in the figure shows that the whole model is operated by class **MSimulation** that represents an abstraction of a separate simulation and provides a set of tools to work with the model class. **MInformSystem** represents an interface for communication between agents and their informational support and implements some functions of the state. The base class for each agent is **MAgent**. The agent is actually **MAgent**, there is a bridge between the classes that describe the subject area, and classes that implement the software interface and simulation.

This pattern is common for both models, but for models with tacit collusion distribution of demand and control the behaviour of consumers belong to a class **MInformSystem**, who also takes on the function of the environment.

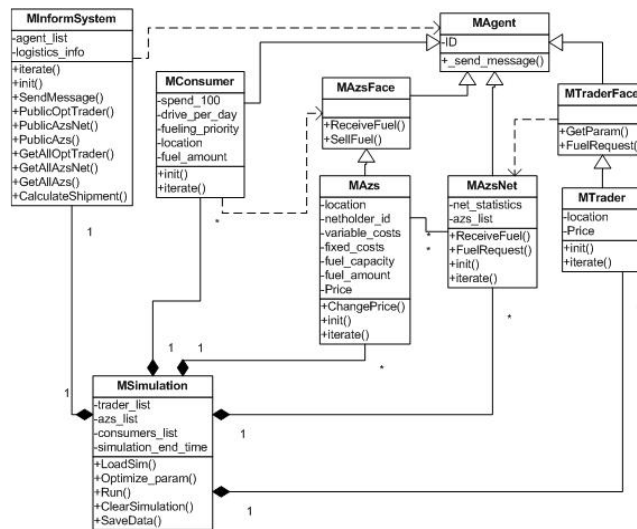


Fig. 5. Class diagram of multi-agent model

This pattern is common for both models, but for models with tacit collusion distribution of demand and control the behaviour of consumers belong to a class **MInformSystem**, who also takes on the function of the environment.

The model is implemented in C++ with its own framework for agent-based modeling. For the identification and optimization of model parameters was used a method of Nelder-Mead from the library GSL.

3. RESULTS AND DISCUSSION

3.1 Data and statistics

To compare results of calculations and real data, the retail petrol prices of more than 200 petrol stations in Kiev during the period from January to September 2012 are used. The price in Kyiv city and Kyiv region for the same period has been employed as the values of wholesale prices. This period of time was chosen due to the fact that at that time there were substantial fluctuations in prices of crude oil on the world market, which resulted in changes in wholesale prices and, as a consequence, changes in retail prices for petrol. The data source is the STC "Psichea", whose price monitoring covered more than 90% of the market of petroleum products in Ukraine.

To assess the adequacy of the model was carried out the procedure of identification of parameters of models describing the agent, i.e. sets of parameter values for which the value calculated by agent based model in general, the least deviated from the actual prices. Obviously, the build a relatively simple linear regression to estimate the parameters of multi-agent models is impossible. The reason is the way to obtain assessment price, which is established as a result of collective interaction of agents with defined parameters. This assessment can only be obtained through procedural computation. So we have a specific kind of non-linear regression, where the unknown is a clear relationship between the input and output parameters. This fact requires a non-standard approach to solving the problem identification and analysis of parameter estimation. First of all, it concerns a method to minimize the deviation function between the values of real values of prices and values calculated pomodeli prices. Calculate gradients in this case is almost impossible because the objective function to calculate the deviation can only be algorithmically, used bezhradiyentnyy simplex method Nelder - Mead (NMS)[24].

As a function of the deviation was determined standard deviation value sum of prices (SS) on real data from calculated. Many of software packages provide the output value of SS in the evaluation of the regression model, right next to R-squared. SS represents the average distance that the observed values fall from the regression line. This shows how wrong is the model that describes the average of the variable response units. The smaller values the better because it indicates that the observations are closer to the fitted line. Function SS deviation gives better intuitively understandable assessment of a model compared with the sum of R-squares. In addition, since the use of known criteria for regression models such as Durbin-Watson for the nonlinear case not proved, calculation SS makes possible to build the relationship between inputs and outputs with acceptable accuracy. The target function for NMS algorithm for the described problem, was defined as (2):

$$obj_function = \sum_{i=0}^N |P_i^{real} - P_i^{calculated}| \quad (2)$$

where:

N – the number of days for the evaluation jump of price;

P_i^{real} - actual prices in i-th day;

$P_i^{calculated}$ - price i-th day was calculated by the model.

Assessed values are those that affect the behavior of market agents, including:

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- PrM - minimum profit rate of network;
- Spr - the growth rate of prices in state S1;
- Pd - state parameter S2;
- azs_neighbor_radius - stations that are closer to your specifications and are seen as competitors, km.

Initial values were determined empirically when experimental model runs. This is a very important aspect for the solution of the problem of optimization, becose of algorithm could give only local optimum and each calculation of the objective function for certain parameters is a long computational procedure.

The results of calculation parameters agent models with initial values described in the zero line of Table 1 and the established value of average deviation of 0.04 UAH / liter.

Table 1. The parameters and functions deviations in the process of finding the optimum

Iteration	objective function value	PrM	Spr	Pd	azs_neighbor_radius
0	10,18	0,15	0,0005	0,3	7
1	8,11359	0,15	0,0005	0,3	8
2	6,85108	0,16125	0,00061 3	0,2925	8,125
3	6,85108	0,16125	0,00061 3	0,2925	8,125
4	6,76215	0,155625	0,00055 6	0,29625	8,0625
5	6,76215	0,155625	0,00055 6	0,29625	8,0625
6	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
7	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
8	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
9	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
10	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
11	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
12	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
13	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
14	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
15	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
16	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
17	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
18	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
19	4,55696	0,158438	0,00058 4	0,29937 5	7,84375

20	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
21	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
22	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
23	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
24	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
25	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
26	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
27	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
28	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
29	4,55696	0,158438	0,00058 4	0,29937 5	7,84375
30	3,97883	0,158433	0,00058 5	0,29935 2	7,84602
31	3,97883	0,158433	0,00058 5	0,29935 2	7,84602
32	3,88318	0,15843	0,00058 5	0,29937 4	7,84451
33	3,88318	0,15843	0,00058 5	0,29937 4	7,84451

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Fig. 6 shows a character climb to the optimum, while specifying parameters agent model in 33 iterations with an average accuracy deviation of 0.04 UAH / liter. With regard to the price level of the sample, which was 12 UAH / liter, can be considered a good result, and therefore multi-agent model can be used as a tool for price estimates behavior prices of retail for after jump wholesale prices.

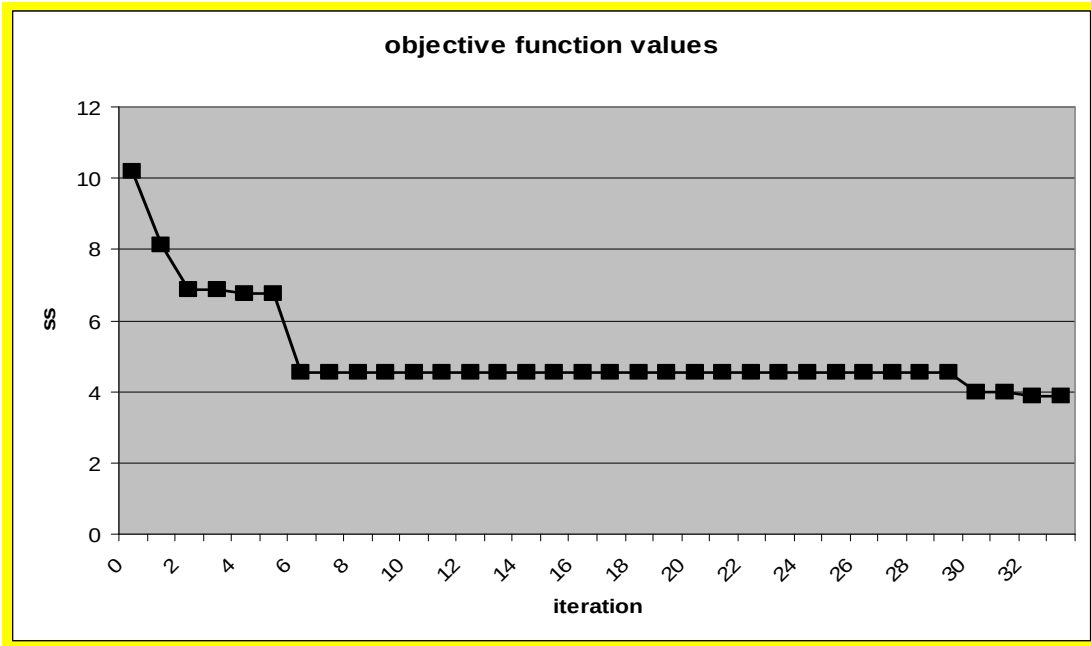


Fig.6 Progression of solution with number of iterations

Fig. 7 shows the results of comparing behaviour of retail prices after the jump in prices on the wholesale market for tacit collusion, and for the reference price search theory.

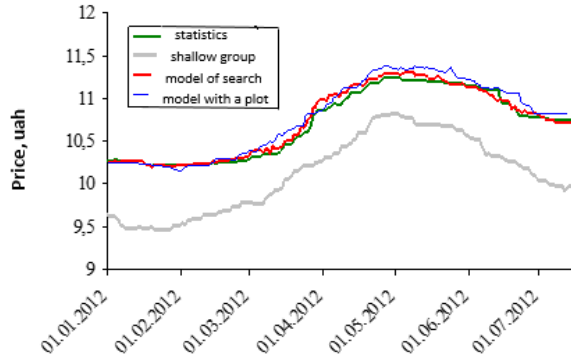


Fig. 7. Comparison of models with searching and collusion with real data

Calculations of parameters obtained from the identification procedure show that the dynamics of prices of petroleum products on both models, in general, similarly corresponds to real data for the retail market. This similarity indicates that both the underlying assumptions about the nature of asymmetry may be the cause of such behaviour of retail prices of petroleum products market.

Note, however, that the behaviour of consumers on the real market is slightly more complex in case of reference price search. As established in some studies, including [25], there is a certain asymmetry of a different nature, the asymmetry of needs of consumers, which means that we must provide consumers with a group that searches not among all stations within reach but only among brands. This explains the true nature of the initial distribution of prices across the network. In addition, the lack of brand clients in networks with high prices

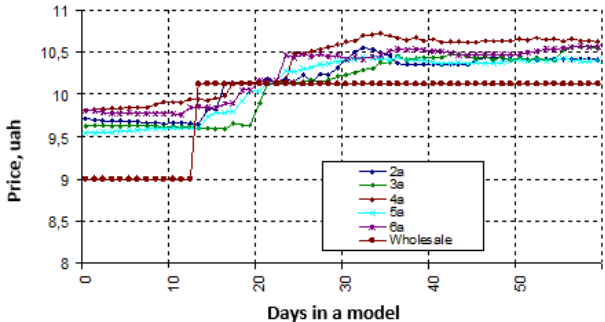
396 makes prices in a network are much lower. This leads to significant fluctuations in retail
397 prices, even in the absence of perturbations wholesale prices, which are almost never
398 observed. The introduction of such a group of consumers creates the necessary demand for
399 branded networks.

400

401 **A comparison of models of asymmetry**

402 The presence of asymmetry with a sudden jump in wholesale prices has been repeatedly
403 shown, and as the root cause of adverse pricing is called price coordination of a
404 significant number of suppliers in the moments of sudden changes of wholesale prices,
405 which in the literature are classified as conspiracy. In all countries, without exception,
406 such actions are contrary to the rules of fair competition and are violations of the law.

407 Further detailed focus on the model search. To assess the behavior of the model were
408 calculated situations with sharp changes in wholesale prices. So on the next chart we see
409 the response of the model with different number of petrol stations on the jump in
410 wholesale prices. In the Fig. 8 we see the reaction of price jumps in the wholesale market
411 for models with varying number of stations.

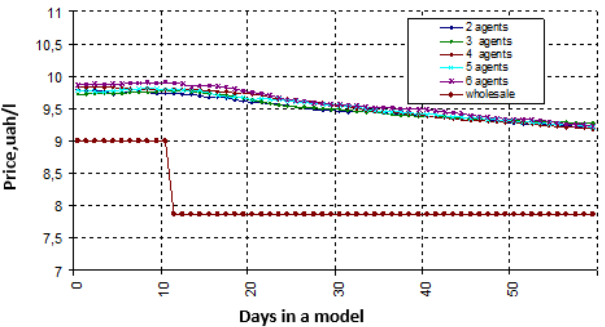


412

413 Fig. 8. The behavior of retail prices for models with a jump in wholesale prices up

414

415 A comparison of models of search and tacit collusion is provided in Fig. 9. We see that
416 the dynamics of prices during both the growth and decline is slightly different. After the
417 occurrence of a positive jump wholesale prices rise in retail prices in both variants (with
418 and without collusion) is caused by a desire to provide economically viable prices to the
419 retailers, so retail prices are sufficiently shaped. However, you will notice the difference,
420 especially at the ending stage of finding remunerative prices, apparently because of the
421 pricing policy coordination in case of tacit collusion. Therefore, the growth rate of retail
422 prices is slightly higher. In the model of reference price search, the price with the search
423 is calculated, which ensures the preservation of profits for sellers and buyers to reduce
424 losses. For models with a tacit collusion, participants hold the contractual highest
425 possible price for some time. Then the participants in the tacit collusion are forced to
426 reduce the price co-ordinately or to stop the collusion. Therefore, in case of tacit
427 collusion, the process of decreasing retail prices is more protracted.



428

Fig. 9. Behaviour of retail prices by model with lowering wholesale prices

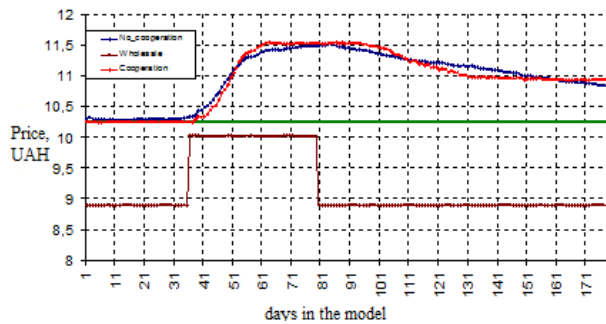


Fig. 10. Comparison of behaviour of models with tacit collusion and collusion during the jump

As you can see, there are asymmetric reactions to the jump-up and throw-down. There is a need to strictly assess the presence of asymmetric pricing criteria that should be adopted to highlight the impact of prior periods. We will do this using the concept of cumulative response functions [4,10,16], which reflects the change in retail prices in time, as a response to a one-time change of wholesale prices per a unit of currency, starting from the moment $T=1$, that is, at the time of the jump in wholesale prices.

$$CRF^+ = \sum_j \Delta p_j^+, \quad CRF^- = - \sum_j \Delta p_j^- \quad (3)$$

where:

CRF^+ , CRF^- – cumulative response function at the time of the positive and negative price shock, respectively;

Δp_j^+ , Δp_j^- – increase or decrease of prices in the range of time for the positive and negative price shock respectively.

The evidence of asymmetry in price is that the difference between the CRF with positive and negative shock should be positive.

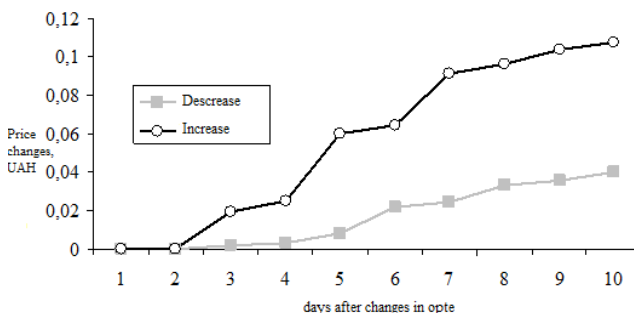
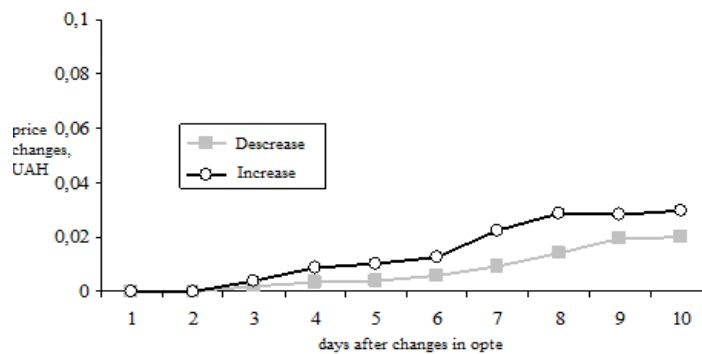


Fig. 11. CRF multi-agent model of tacit collusion

It should be noted that the evaluation of the CRF was performed on the source data that is used to identify when the jump in the wholesale price is 0.1 UAH, the margin level was quite high. So we can see the difference in the reactions of the model to the plot, where the level of margin does not affect behavior as in models with consumer search. It should be noted that CRF is a common criteria for assessing the asymmetry of prices as in the case of tacit collusion, and in the case of consumer search, and this figure is a clear economic sense. If

460 you look at Fig.11-12, the CRF figures is the area bounded by the sudden growth charts and
 461 the sudden descending wholesale prices, which is an estimate of the losses of consumers
 462 due to price shocks.
 463



464 Fig. 12. CRF multi-agent model search

465
 466 If asymmetry in retail prices was absent, you would see that the graphs of price changes for
 467 the sudden rise and sudden decline in wholesale prices matched.
 468 It is clearly seen that the value of the CRF for the case of tacit collusion consistently exceeds
 469 the value of the CRF without tacit collusion.
 470 Table 2 details the results calculated values for CRF case of tacit collusion, and in the case
 471 of consumer search, where an additional parameter is the number of traders in the market
 472 as reflected oligopolistic nature of competition in the markets petroleum products.
 473
 474

475 **Table 2. Comparison of CRF values under different number of agents in model**

476

<i>Number of agents</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>
<i>reference-price search</i>	0.558	0.478	0.458	0.373	0.316
<i>tacit collusion</i>	0.697	0.672	0.628	0.581	0.574

477
 478 It is easy to see that the value of the CRF for the case of tacit collusion, consistently
 479 exceeds the value of the CRF without tacit collusion. Perhaps further research will offer a
 480 criterion for the presence or absence of collusion. However, to make such constructive
 481 conclusions from this fact somewhat premature because data proved collusion of traders is
 482 not enough. This conclusion creates the idea that we should continue research in this area,
 483 both in terms of gathering empirical evidence and in terms of improving theoretical positions.
 484

485 4. CONCLUSION

486
 487 In this paper, a model has been developed, which explains the essential features of the
 488 mechanism of price formation for petroleum products market as an oligopolistic market with
 489 a homogeneous product. The model is based on the fact that incomplete awareness of
 490 consumers about the markets state leads to the empirically proven asymmetry in retail
 491 prices. Asymmetry in retail prices is a manifestation of a complex mechanism of price
 492 formation for petroleum products market, as buyers and sellers interact in the presence of
 493 price shocks on the wholesale market.
 494 Two hypotheses are examined, which explain the presence of asymmetry of retail prices: the
 495 theory of tacit collusion and the theory of reference price search. Both of these theories
 496 involve the postulation of specific heuristic rules of behaviour of market participants. For the
 497 purposes of constructing a model that would take into account these circumstances, the

general econometric methods are hardly suitable. A more relevant approach is a method of differential games, but, unfortunately, it is very difficult to apply to real markets. That is why the model is based on the multi-agent approach. Developed multi-agent model has enabled to show that, in fact, asymmetry in price occurs as for tacit collusion, and the expense of consumers' searching prices. The multi-agent model has been tested, basing on the real data of the Ukrainian petroleum product market and has showed its adequacy. In the process of simulation, some important differences in price dynamics depending on the pricing mechanism which operates, i.e. the reference price search or tacit collusion, have been revealed. However, it is as yet premature to argue that the analysis of the input data (jump in wholesale prices) and output data (the dynamics of retail prices) will enable to identify, whether there is a tacit collusion. For this as before is not enough data, especially where that has been legally was determined the existence of tacit collusion. If we had enough data, we could build a criterion of the presence or absence of collusion in the case of the jump in wholesale prices by analyzing price dynamics.

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