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\*Corresponding author: Andrey G. Maksimov, National Research University Higher School of Economics, 25/12, B. Pecherskaya, Nizhny Novgorod, Russia  
E-mail: [amaksimov@hse.ru](mailto:amaksimov@hse.ru)

Reviewing editor:  
Bernardo Spagnolo, Università di Palermo, Italy

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## INTERDISCIPLINARY PHYSICS | RESEARCH ARTICLE

# Forecasting of the electricity price on the day-ahead electricity market in Russia

Andrey G. Maksimov<sup>1\*</sup> and Daria V. Shchurupova<sup>1</sup>

**Abstract:** After analyzing the characteristics and pricing models on the Russian wholesale electricity market, some important features for econometric modeling are introduced. This paper suggests econometric forecasting models developed to predict daily and hourly electricity prices on the day-ahead market for two price zones in Russia: European and Siberian ones. A set of 24 models, which are similar in nature but different in included regressors, are introduced. On the basis of the actual database for 2014, different modifications of price formation are offered and analyzed with the help of the Eviews econometric package. Dynamic forecasts on various distances (day, week, and month) are conducted and the most suitable models from the point of minimizing the norms of the vectors residuals are chosen. Constructed ARMA models have high predictive power and are able to reflect the price trend on the base of exogenous factors and the previous price values.

**Subjects:** Energy Policy and Economics; Econometrics; Economic Forecasting; Electrical Power Industries

**Keywords:** wholesale electricity market; forecasting models; econometric modeling

### 1. Introduction

The complexity of the wholesale electricity market from both technical and economic points of view and dynamic development of the industry make studying the mechanisms of pricing rather sophisticated. Energy is not only one of the most important consumer commodities, but also a major input for almost every industry. The electricity costs are included in any products' prices as key cost items which reflect the price level of the whole country. Though electricity pricing issue on the wholesale

### ABOUT THE AUTHORS

Andrey G. Maksimov is the head of the Department of Economic Theory and Econometrics in National Research University Higher School of Economics, Nizhny Novgorod, Russia. His research interests are connected with dynamic models, theory of differential equations, numerical simulation, and econometric modeling of economic processes.

Daria V. Shchurupova is studying to get a master's degree in Economics in National Research University Higher School of Economics, Nizhny Novgorod, Russia. She received a bachelor's degree with honors and continues her research connected with econometric modeling of electricity market. The sphere of professional interests is connected with econometrics.

### PUBLIC INTEREST STATEMENT

The pricing issues on Russian wholesale electricity market are relevant because of its recent reformation into competitive industry and an increasing role of electricity in general. To make accurate forecast of wholesale electricity price the features of the electricity market are distinguished: demand inelasticity, continuity of the production and consumption processes, impossibility of accumulation and storage. The task of making predictions becomes more difficult while taking into account Russian peculiarities: zonal division, structure of market and significant legislative control. Having studied three approaches to the price formation like calculation, game theory, and econometric models the research focuses on the time series analysis and creates models, which reveal interconnection between price dynamics and some exogenous factors.

market is of substantial significance for power producers, consumers, regulators, and a broad array of financial market participants, it is urgent not only for individual market participants but also for the macro policies of states (Stoft, 2006). Energy markets are taking an increasingly pre-eminent place in the global economy.

Nowadays, the pricing issues are becoming one of the primary fields for investigation because of the recent reformation of Russian wholesale electricity industry into competitive market. Vast literature pertains to the generalization of the foreign experience in pricing, whereas there is a lack of studies regarding the wholesale prices in Russia. It should also be noted that the effective Russian electricity market has two levels: wholesale and retail. The nature of economic relations differs significantly depending on whether they are formed as part of the wholesale or retail electricity market. In the wholesale market, electricity suppliers (generating companies, importers of electricity) sell to customers (guaranteeing suppliers, sales companies, large consumers, exporters of electricity) two commodities—electricity and capacity. The paper focuses on the wholesale sector of electricity commodity.

To forecast electricity prices accurately is crucial for producers, consumers, regulators, and a broad array of financial market participants (Nogales & Conejo, 2006). In particular, to self-schedule its performance optimally, the producer needs forecasts of prices before bidding time as the electricity costs are included in any products' prices as key cost items (Joskow, 2008). In spite of the urgency of wholesale electricity price predictions, the Administrator of Trading System provides only medium-term forecasts of semi-annual prices and the necessity of forecasting in the short run such as for a day, a week, and a month remains relevant (Nogales & Conejo, 2006). The importance of this research is also caused by recent reorganization of the electricity sector from the centrally owned and operated system toward the market-based decentralized market. The transitional stage of the wholesale electricity market operation ended in December 2010, and starting from 1 January 2011, the market has been working in under the new model.

Though the question seems to be mostly practical, it is vital to highlight the theoretical foundation. The understanding of the basic operations of the electricity markets is crucial for my research because factors affecting the price formation depend on the specifics of electricity as a commodity, internal characteristics of generators, and external factors such as climate conditions, the market structure, and features of analyzed country. Concentrating on the Russian wholesale market, its specific characteristics are essential to be noted before modeling processes on it because several peculiarities (Eisenberg & Filatov, 2013) make the domestic market different from foreign ones.

- Firstly, the territory of Russia has a zonal division in terms of differences in operating power systems: the price zones, where the pricing is based on the competitive market principles, coexist with non-price zones, where the trade is carried out according to the tariffs, and isolated power systems, which are not connected to the Unified Energy System of Russia. The first and second price zones are characterized by a large number of suppliers and purchasers of electricity, a developed grid infrastructure, which allows the competitive electricity market to function. In the non-price zones, the structure of generation and distribution of electricity does not allow to organize full-fledged market relations (The Official Website of the Administrator of Trading System, 2015). The analysis is narrowed down to the consideration of pricing within price zones.
- Secondly, a significant feature is the structure of the Russian wholesale market, which consists of four sectors: the segment of regulated contracts (RC), the sector of free bilateral contracts (FBC), the day-ahead market (DAM), and the balancing market (BM). As the overall market share of balancing and regulated sectors in total day trading are less than 6%, the current research is devoted to the processes on the day-ahead market. Formalizing the definition of the day-ahead market, we can characterize it as the system, which is matching the offers from the generators to the bids from the consumers at each node on an hourly interval separately for every region and is carried out by the trading operator.

- Also an important complication that makes the pricing issue particularly difficult to predict is the unique nature of electricity as a commodity, since it is homogenous, non storable, and has transport constraints because of limited bandwidth and long distances between nodes. The factors that determine the specificity of the electricity market are also the electricity generation technology, the uneven consumption, and short duration of peak loads. These features eliminate the buffering effect, and sudden large price changes and price spikes are more likely to occur.

## 2. Methodology

Dealing with existing literature, we have observed that pricing methods may be classified into three groups according to the approach. These are game theory, computational, and econometric models. They differ because they concentrate on various sides of pricing, such as behavioral, technical, and economic ones. But no matter how different the approaches are, each model investigates the determinants of the wholesale electricity prices.

A substantial body of literature applies tools of game theory. Within this methodology standardized oligopoly models including Cournot auction, first-price auction of supply functions, Vickrey auction, pay-as-bid and two-stage auctions are developed (Vasin & Daylova, 2013). However, recent focus in the literature has mainly switched to the application of the supply function equilibrium (SFE) approach and its linear modification (CSFE—conjectured supply function equilibrium) (Baldick & Hogan, 2002). Game theory tools create models which are too theoretical as lots of assumptions are made.

The computational methods include an applicable technical tool of Russian researchers Davidson and Dogadushkina, which is used by Trading System Administrator for the organization of wholesale electricity on the day-ahead market in Russia. The aim of this model is to solve complex optimization problem of social welfare function, taking into account the structure of the network connections in the system and nonlinear electricity flows. The issue of checking the results of the automated work of ATS is not within the scope of our interests, though it reveals potential difficulties of the econometric approach.

From the variety of approaches, we focus on the econometric one because its methodology allows creating unique regression models considering peculiarities of the Russian wholesale market and is more valid for predictions. An empirical study and the development of econometric models are becoming increasingly important because internal factors are compatible with external conditions.

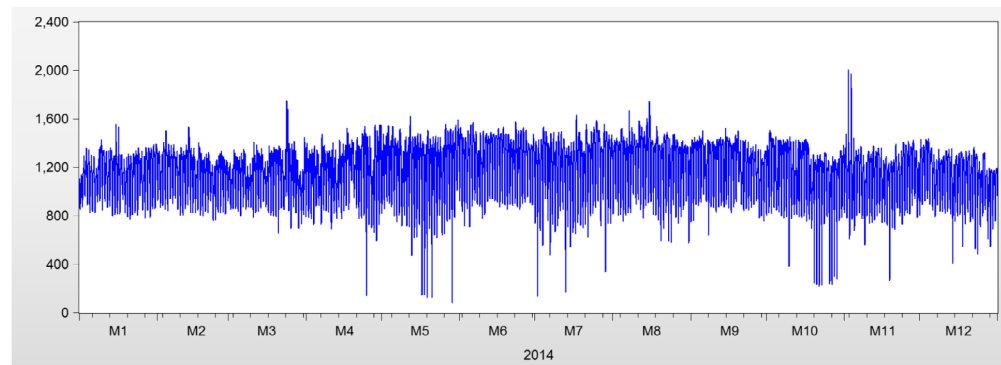
## 3. The data

The purpose of current study involves building time series models which indicate the dependence of daily and hourly electricity prices on the set of potential regressors for the first and the second price zones in Russia. This paper presents new evidence on the pricing, based on the datasets from the official website of the Unified Energy System (The Official Website of the Unified Energy System, 2015) for year 2014 and estimated with the use of econometric package Eviews.

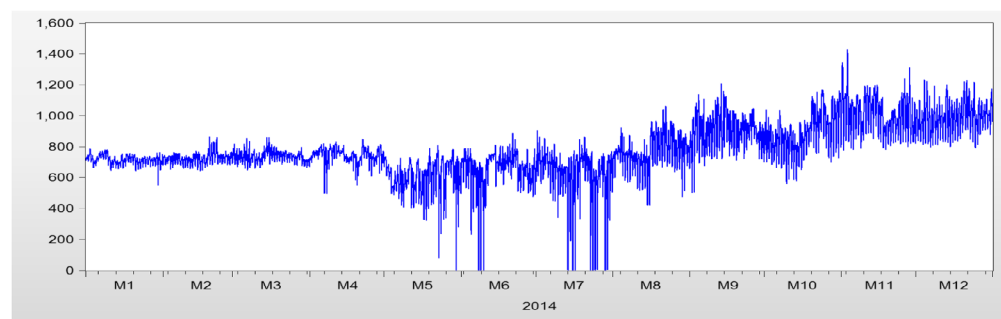
The price dynamics is characterized by nonconstant mean and variance, high frequency, high volatility, and the presence of outliers. The graphs of price dynamics in first and second zones prove these difficulties (Figures 1 and 2).

Moreover, in spite of similar mechanisms of functioning, the heterogeneity of price dynamics can be noticed. To understand why they appeared, we refer to the news. A strong impact on the dynamics between May and July in the second zone had extensive repairs of the network which result in excess generation and nightly rates were close to zero. On 15 August, restrictions on the flow between price areas were canceled and that caused a rise in prices on the spot market in Siberia and the convergence of prices in both zones. This information may help us while modeling. Potential explanatory variables, chosen for modeling, include the price dynamics of Urals crude oil, officially

**Figure 1. Dynamics of hourly prices in the first-price zone in 2014.**



**Figure 2. Dynamics of hourly prices in the second-price zone in 2014.**



announced dollar exchange rates, demand on electricity, the duration of daylight, hours, hourly and daily temperatures, days of the week and holidays.

#### 4. ARMA-models

The results indicate that the behavior of electricity prices can be well explained for both Russian price zones by the time series models, where the regressors are previous electricity prices and combinations of external parameters. A set of 24 models, which are similar in nature but different in included regressors, are introduced (eight models for hourly and four modifications for daily data) and the significance of the regressors is at least at 5% significance level. Obtained ARMA models demonstrate high predictive power because their coefficients of determination are more than 93%.

Main modifications for hourly prices in the first-price zone are presented in Table 1. It cannot be claimed that some of the models significantly worse than others from the created ones.

#### 5. Forecasting

The analysis of the predictive power reveals the best models from the point of minimizing the norms of the vector residuals. So for monthly and weekly forecasts of the electricity price in the first-price zone, the most appropriate is the eighth model, while for daily predictions the sixth one is more valid. As the models are built on the base of data for 2014, we decide to make predictions for January, a rather atypical period indeed. The graphs illustrate that even in this case the dynamic forecasts reflect main tendencies in price behavior.

Figure 3 illustrates the predicted and actual dynamics of hourly electricity prices in the first price zone on the base of dynamic forecast for the week and month ahead according to the best model from the point of minimal norm of vectors residuals (1) for chosen forecasting period:

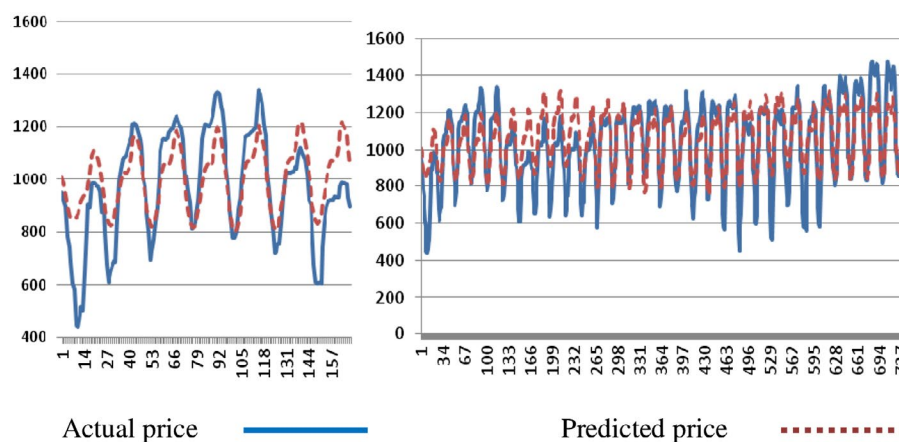
$$\|e\| = \sqrt{\sum (y^{\text{fact}} - y^{\text{forecast}})^2} \quad (1)$$

**Table 1. Modifications of models for hourly prices in the first zone<sup>a</sup>**

| Regressors     | Model 1 | Model 2 | Model 3 | Model 4 | Model 5  | Model 6  | Model 7  | Model 8  |
|----------------|---------|---------|---------|---------|----------|----------|----------|----------|
| C              | 735.5   | 743.6   | 753.8   | -1,088  | -1,817.9 | -1,670.5 | -1,532.5 | -1,186.7 |
| USD*URALS      | 0.058   | 0.073   | 0.069   | 0.085   | -        | -        | -        | -        |
| URALS          | -       | -       | -       | -       | 5.71     | -4.45    | -4,237   | 6.38     |
| HOL            | -       | -       | -       | -       | -        | -        | -        | 33.45    |
| HOUR(-1)       | -       | -       | -       | -       | -        | -        | 1.450    | -        |
| HOUR           | 44.31   | -121.48 | -125.52 | -44.35  | -        | -        | -        | -        |
| HOUR^2         | -1.64   | 27.47   | 12.11   | 5.85    | -        | -        | -        | -        |
| HOUR^3         | -       | -1.58   | 4.09    | 0.98    | -        | -        | -        | -        |
| HOUR^4         | -       | 0.02    | -0.63   | -0.18   | -        | -        | -        | -        |
| HOUR^5         | -       | -       | 0.03    | 0.009   | -        | -        | -        | -        |
| HOUR^6         | -       | -       | -0.001  | -0.0002 | -        | -        | -        | -        |
| DAYLONG        | -       | -       | -       | -       | -        | 93.07    | 88.74    | -        |
| TEMP           | 1.27    | -       | 1.12    | -       | 3.36     | -        | -        | 2.85     |
| TEMP^2         | -0.03   | -       | -       | -       | -        | -        | -        | -        |
| DEMAND         | -       | -       | -       | 0.022   | 0.027    | 0.02     | 0.02     | 0.02     |
| AR(1)          | 0.82    | 0.82    | 0.83    | 0.97    | 0.98     | 0.85     | 0.64     | 0.67     |
| AR(2)          | -       | -       | -       | -       | -        | -        | 0.14     | 0.11     |
| SAR(24)        | 0.44    | 0.4     | 0.352   | 0.348   | 0.35     | 0.67     | 0.70     | 0.77     |
| SAR(168)       | 0.42    | 0.37    | 0.329   | 0.255   | 0.25     | 0.17     | 0.15     | 0.15     |
| MA(1)          | -0.07   | -0.05   | -0.056  | -0.235  | -0.24    | -0.05    | 0.12     | 0.08     |
| MA(2)          | -0.05   | -0.05   | -0.066  | -0.198  | -0.20    | -0.05    | -        | -        |
| MA(3)          | -       | -       | -       | -       | -0.09    | -        | -        | -        |
| MA(24)         | -       | -       | -       | -       | -        | -0.37    | -0.42    | -0.5     |
| R <sup>2</sup> | 0.939   | 0.941   | 0.943   | 0.945   | 0.945    | 0.946    | 0.947    | 0.946    |

Notes: The designation here and beyond: C—constant variable; URALS—oil price in dollars; USD—dollar exchange rates; USD\*URALS—oil price in rubles; DAYLONG—the length of daylight; TEMP—hourly temperature in Moscow (for 1st zone) or Krasnoyarsk (for 2nd zone); DEMAND—the quantity of electricity wished by consumers on the wholesale market; MON, TUE, WED, THU, FRI, SAT—dummy for days of the week; HOL—dummy for holidays; HOUR—number of hour from 0 to 23; HOUR(-n)—value of the HOUR with lag n, Variable<sup>k</sup>—Variable<sup>k</sup> (value of the Variable in the kth power), AR(n)—autoregressive component with lag n (hourly price with lag n), SAR(n)—seasonal autoregressive component with lag n, MA(n)—moving average component with lag n in autoregressive models.

**Figure 3. Weekly (01 January 2015–07 January 2015) and monthly (January, 2015) forecasts.**

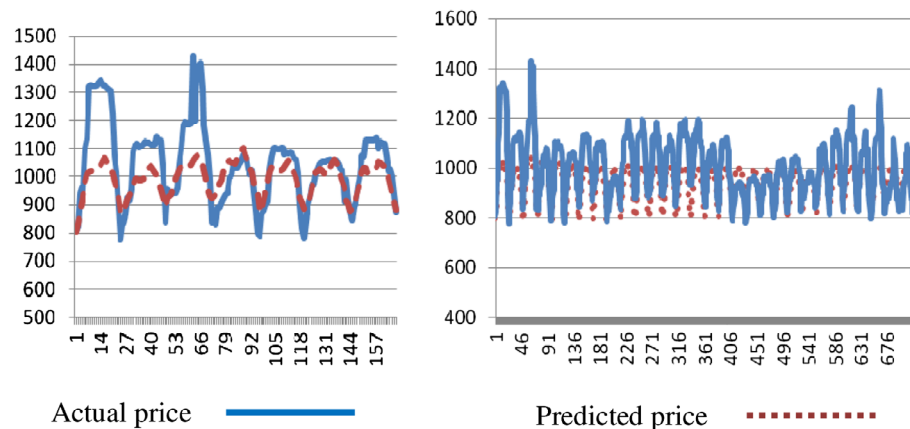


This modification is an example of successful application of ARMA models, which reflect the electricity price dynamics and its seasonality on the base of exogenous factors and the previous price values. Other models give rather similar predictions, but as the results do not differ significantly only one dynamic forecast are demonstrated.

**Table 2. Modifications of models for hourly prices in the second zone**

| Regressors     | M1       | M2       | M3     | M4      | M5     | M6     | M7     | M8       |
|----------------|----------|----------|--------|---------|--------|--------|--------|----------|
| C              | 1,263.02 | 1,242.33 | 506.19 | -245.90 | 207.83 | 384.73 | 811.35 | 1,290.14 |
| URALS          | 7.51     | 8.06     | 7.26   | 6.78    | 7.78   | -      | -      | -        |
| DAYLONG        | -100.05  | -101.76  | -      | -       | -75.87 | -      | -      | -46.99   |
| TEMP           | -        | -        | 0.75   | 0.873   | -      | -      | -0.97  | -        |
| DEMAND         | -        | -        | -      | 0.02    | 0.04   | 0.02   | -      | -        |
| HOUR           | 26.18    | 7.94     | -24.05 | -       | -      | -      | -      | -21.95   |
| HOUR^2         | -1.13    | 1.89     | 18.72  | 1.90    | -      | -      | -      | 17.93    |
| HOUR^3         | -        | -0.15    | -3.04  | -0.13   | -      | -      | -      | -2.88    |
| HOUR^4         | -        | 0.002    | 0.22   | 0.00    | -      | -      | -      | 0.21     |
| HOUR^5         | -        | -        | -0.01  | -       | -      | -      | -      | -0.01    |
| HOUR^6         | -        | -        | 0.00   | -       | -      | -      | -      | 0.00     |
| MON            | -        | -        | -      | -       | -      | -      | -19.23 | -12.70   |
| TUE            | -        | -        | -      | -       | -      | -      | -31.81 | -23.47   |
| WED            | -        | -        | -      | -       | -      | -      | -16.72 | -7.27    |
| THU            | -        | -        | -      | -       | -      | -      | -24.52 | -14.27   |
| FRI            | -        | -        | -      | -       | -      | -      | -30.52 | -21.04   |
| SAT            | -        | -        | -      | -       | -      | -      | 12.46  | 15.36    |
| HOL            | 32.92    | -        | 31.68  | 37.01   | 41.37  | 40.48  | 32.92  | 34.02    |
| AR(1)          | 1.80     | 1.80     | 1.80   | 1.79    | 1.80   | 0.80   | 0.56   | 0.81     |
| AR(2)          | -0.80    | -0.80    | -0.80  | -0.79   | -0.80  | 0.07   | 0.28   | 0.06     |
| SAR(24)        | 0.22     | 0.20     | 0.19   | 0.18    | 0.20   | 0.98   | 0.28   | 0.96     |
| AR(168)        | -        | -        | -      | -       | -      | 0.01   | 0.12   | 0.01     |
| SAR(168)       | 0.15     | 0.14     | 0.13   | 0.12    | 0.13   | -      | -      | -        |
| MA(1)          | -0.98    | -0.98    | -0.98  | -0.97   | -0.97  | 0.03   | 0.33   | 0.02     |
| MA(24)         | -        | -        | -      | -       | -      | -0.89  | -      | -0.87    |
| R <sup>2</sup> | 0.937    | 0.937    | 0.938  | 0.938   | 0.937  | 0.939  | 0.932  | 0.94     |

**Figure 4. Weekly (01 November 2014–07 November 2014) and monthly (November, 2014) forecasts.**



The price dynamics for the second price zone may be also well explained by external factors, though the most appropriate modifications are slightly different. Models are presented in Table 2.

Obtained models also show high predictive power, but forecasting prices for January are rather far from reality, though main trends are traced. If we focus on another period, for example November, then the forecasts become better as the typical period is chosen. The best predictive power for a week has the fifth model, though for monthly forecasts the sixth model is more appropriate.

The graphs, where predictive dynamics is demonstrated, are shown in the Figure 4. The forecasts take into account the main trends repeating real dynamics of prices for electricity but the meanings of expected prices may be smoothed as the model average some peaks in price dynamics.

## 6. Conclusion

Summarizing main findings, I want to conclude that the behavior of electricity prices can be well explained for both Russian price zones by the time series models, where the regressors are previous electricity prices and combinations of external parameters. The objective set in “The Energy Strategy of Russia up to 2030” (The Official Website of the Administrator of Trading System, 2015) manifests the importance of pricing mechanisms by “creating and developing highly competitive energy markets with fair trade principles,” it means that processes of competitive price formation are still going on and the questions of effective pricing are highly important. This work introduces a set of 24 models, which are similar in nature but different in included regressors, where the significance of the regressors is at high significance level. The significance of research is shown in ability to create adequate forecasts of wholesale electricity prices on various time periods in both price zones in Russia. However, the models are not perfect, so other variations of predicting price dynamics are going to be made in further work.

The significance of this paper is determined by the gap in analyzing electricity pricing mechanisms in Russia. The prospects for further studies are still open because the problem is distinguished by its complexity and the variety of approaches, every of which has its drawbacks and does not take into account all features of electricity prices behavior. Other modifications of time series models may be applied for predicting electricity price on the wholesale market in Russia.

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### Author details

Andrey G. Maksimov<sup>1</sup>  
 E-mail: [amaksimov@hse.ru](mailto:amaksimov@hse.ru)  
 Daria V. Shchurupova<sup>1</sup>  
 E-mail: [zeryk@mail.ru](mailto:zeryk@mail.ru)



<sup>1</sup> National Research University Higher School of Economics, 25/12, B. Pecherskaya, Nizhny Novgorod, Russia.

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