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Technique of Design for Integrated Economic and Mathematical Model for Mass Appraisal of Real Estate Property. Study Case of Yekaterinburg Housing Market

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Abstract:

There are a number of economic and mathematical models designed for mass appraisal of residential real estate at the moment, which take into account their construction and performance characteristics but do not take into account the evolving macroeconomic situation in the country and in the world. The drawback of such static models is their rapid obsolescence, the need for constant updating and unsuitability for medium-term forecasting. On the other hand, there are dynamic models that take into account the current macroeconomic situation but are designed for predicting and studying the overall price situation on the market rather than for mass appraisal of real estate with their variety of construction and performance characteristics.

This paper proposes a technique of creating integrated models with properties of such static and dynamic models, i.e. taking into account both construction and performance characteristics of residential facilities and evolving macroeconomic situation in the country and in the world. Development of the technique and creation of models is carried out with the use of neural network technology on the basis of statistical data for the period from 2006 to 2016. In addition to its main purpose – the mass appraisal of urban apartments, the model is suitable for medium-term forecasting and identification of the patterns of the housing market. For example, the model was used to study the effect of the state financial policy on the housing market in Yekaterinburg. Computer experiments have shown that in case of growth in housing lending, the apartment prices will rise, and the rate of growth of luxury apartments with larger area will be about 2.2 times higher than the growth rate of cheaper apartments with smaller area. It was found that an increase in housing construction in Yekaterinburg up to 2,550 thous. sq.m. would lead to a further increase in value of apartments. However, with the increase in new housing above the 2,550 thous. sq.m. mark, the model predicts market saturation, prices growth cessation and their further decline. Similar studies and forecasts can be made for the real estate market in other countries and cities using the proposed technique.

Keywords: regional real estate market, mass appraisal, macroeconomic indicators, appraisal, forecasting, neural network.

JEL Classification: L70, L74, O12.

1. Introduction

According to the analysis of the literature, there are a lot of papers that note the importance and relevance of designing precise techniques of mass appraisal of real estate. For example, the paper (Hefferan and Boyd, 2010) provides an overview of the international literature, as well as interviews with government officials and appraisers from many countries, from which it follows that the systems of mass appraisal and property taxation are "an important and solid basis for increasing state revenues." The paper (Davis *et al*. 2012) notes that the existing property appraisal systems based on economic and mathematical models are "a useful tool for tax computation in a number of developing and emerging countries. The paper (Manganelli *et al*. 2014) reports that such models are "useful in the field of taxation and in supporting decision making in the planning of territorial transformations."

Reports of successful attempts to create systems of mass appraisal of real estate property on the basis of the new mathematical tool – neural networks – emerge in Western literature in the 1990s. Apparently, one of the first studies in this direction could be the 1991 publication of Tay and Ho (1991), who applied the multilayer perceptron trained by back propagation to determine the market price of real estate property in Taiwan. It was an alternative to the method of multivariate regression.

Evans, James and Collins (1991) used neural networks to appraise the residential property in England and Wales in the same year. As a result, they concluded that "the neural network model is best for appraisal of real estate."

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Do and Grudnitski (1992) published a report in 1992 that they used a perceptron with eight input neurons to input characteristics of the real estate property to appraise the US real estate property: building area, number of floors, area of land, etc. The perceptron had one hidden layer with three sigmoid neurons. It is reported that "the neural network model had twice the accuracy of the predicted values than similar regression model" on the test set of 105 houses. As a result, it was concluded that "the neural network is better suited for appraisal of real estate property than the multivariate regression model."

Further, since the mid-1990s to the present time, there have been a series of publications devoted to the development and application of neural network models for mass appraisal of real estate property, and many studies note the benefits of this advanced technology compared to regression modeling techniques. For example, the paper (Borst 1995) reports that its author has successfully trained a neural network to predict the value of real estate in New York. His neural network included 18 factors, including area of housing, availability of the fireplace, sanitary equipment, air conditioner, months since the last sale, etc. Results of 217 deals over the period from 1988 to 1989 with the price varying in between $103,000 to $282,000 were used for training.

McCluskey *et al.* (1997) notes that "the neural network, in contrast to the multivariate regression, ensures excellent predicative ability in predicting the Northern Ireland market." The paper of Curry *et al. (*2002) reviews the possibilities of a neural network approach to building the systems of property appraisal by its characteristics. The mentioned advantages of neural network approach include the neural networks using objective data rather than subjective assessment of the purchase and sale intentions. Guan *et al. (*2008) describe the attempt to implement an adaptive fuzzy neural network to predict the price of residential property. The data set consists of information on past deals in the US market and includes characteristic parameters of real estate properties and the relevant market price. Neural network modeling results are compared with the data obtained using the regression analysis systems. Kontrimas *et al. (*2011) carried out a comparative analysis of the application of techniques of mass appraisal of real estate in Lithuania and showed that "the best results were obtained using a multilayer perceptron." Mao *et al. (*2014) reported that in relation to Hangzhou (China), a predictive model was designed that used data on the housing market during 1999-2012. The model is based on neural networks with genetic optimization. It is noted that the model has high predictive accuracy, which, however, decreased due to the impact of national policy macro-control in the housing market.

Recently, Guan *et al. (*2014) notes the relevance of the creation of property appraisal systems based on the actual results of sales deals. It is noted that the "experience of using the method of regression analysis for the creation of such systems was unsatisfactory." Alternatively, the article proposes a method based on the use of neuro-fuzzy neural networks. It is noted that "this progressive method is undeservedly underused in the creation of systems of mass appraisal of real estate." Also, Zhang *et al. (*2015) reports on the use of neural network models for the study of China's real estate market cycles.

The first neural network system of mass appraisal of real estate in Russia was created in 2008 by L. N. Yasnitsky, and its description is set forth in the collective monograph (2008, 10-15). Multilayer perceptron allowed to create a system that provides an appraisal of apartments in Perm (Russia) with a highest relative error of 16.4%. The following were used as the model input parameters: area of the apartment, its condition, floor, house type, and distance from the city center. The studies of the neural network mathematical model revealed some patterns of practical interest for homeowners, realtors and investors operating on the housing market. For example, it was shown that the price for expensive apartments falls much faster than that of the cheap ones as the distance from the center increases. Examples were given showing that renovation of some luxury apartments leads to a substantial increase in their price, while the same renovation in the house more than 20 years old has almost no impact on its commercial value and therefore is unprofitable.

In the following 2009, Borusyak, Munerman and Chizhov (2009) reported that they have developed and successfully implemented a neural network software system for non-residential property appraisal in the Moscow City Property Department. They explain their success with the use of the set of techniques that allowed to identify and eliminate the outliers at the stage of information pre-processing, as well as the use of unconventional generalized regression neural network that has provided low average relative error of 20.0%, in their view. This technique of mass appraisal of non-residential property has found further development and application in the thesis of Munerman (2011) defended in 2011.

Summing up the review of the economic and mathematical models designed for mass appraisal of real estate, let's pay attention to their common disadvantage. They all quickly become outdated and require constant updating, because they do not take into account the constantly evolving macroeconomic situation in the country and in the world. We will hereinafter call such models *static*. This lack of static models is particularly true for

Russia and a number of countries, the market of which is under development and is therefore dependent on the evolving macroeconomic factors: oil prices, dollar rate, gross domestic product (GDP), stock indices, states policies, etc.

It should nevertheless be noted that there is a series of works devoted to the creation of economic and mathematical models that do take into account these macroeconomic parameters, but are designed only for modeling and studying the dynamics of the real estate market, rather than for the purpose of mass appraisal. *We call such models dynamic*. For example, in their paper Becker *et al.* (1999) have used such macroeconomic factors as inflation, economic growth, GDP, unemployment, etc. in the study of the dynamics of the real estate market. Links between macroeconomic indicators and the behavior of the real estate market were investigated in the paper of Greenwood *et al. (*1991).

Nevertheless, in spite of the fundamental nature of these studies, we must note once again that the *dynamic* models are designed primarily for the study of the dynamics of the market as a whole, rather than for mass appraisal of specific properties. Indices of value of apartments calculated in such models (average unit costs of apartments normalized to a square meter) can of course be translated into the cost of specific apartments based on their construction, operational, environmental and other parameters. However, such conversion can be done only using additional techniques, which are not usually used for the purposes of mass appraisal of real estate because of their inefficiency. The problem is that the unit price of apartments of the same type located in the same area, or even in the same building, may differ from each other. Therefore, it requires the use of a more differentiated approach.

Thus, on the one hand, we have a number of *static* models designed for mass appraisal of real estate property, which take into account their construction, operational, geographical, environmental, climatic, economic characteristics, but do not take into account the evolving macroeconomic situation in the country and the world, and therefore quickly becoming outdated, requiring constant updating and not suitable for medium-term forecasting. On the other hand, there are *dynamic* models that take into account the overall state of the economy but are designed to predict and study the overall price situation in the real estate market, rather than for mass appraisal of individual residential units. In this regard, the aim of this paper is to develop the technique of creating *integrated* neural network economic and mathematical models that have properties of *static* and *dynamic* models described above, *i.e.* taking into account both construction and performance characteristics and evolving macroeconomic situation in the country and in the world. The development of the technique and creation of the model is carried out by the example of the residential real estate market of Yekaterinburg, which refers to the developed cluster of Russian cities with the highest incomes and relatively high prices on the housing market.

2. Formulization of a mathematical model and its testing

The following factors that characterize the static construction and performance factors were included as input parameters in creation of the model of mass appraisal of residential property in Yekaterinburg: total area of the apartment, number of rooms, floor, number of floors, house type, walls type, availability of a balcony/loggia, district, distance to the city center, as well as a number of macroeconomic indicators: GDP, RTS quotes, Brent crude oil price, dollar rate, new housing supply, housing loans issued.

The output variable of the *y* model corresponds to the declared price of the property. Many examples for training and testing the neural network were formed on the basis of statistical data of the real estate market of Yekaterinburg over the last 10 years: from 2006 to 2016. Selling prices of apartments were taken from open sources. Thus, many instances included the data during economically calm times for Russia (2006), period of economic growth (2007 – mid-2008), crisis and turning point of the Russian and world economy (2008 – early 2010), period of recovery after the crisis (2010 – 2012), growth retardation (2013 – early 2014), strong fall in the background of Russian foreign policy, imposition of western sanctions, sharp drop in oil prices and ruble rate relative to dollar and euro, financial blockade and closure of access to international capital (2014 – 2016). During this decade, the RTS quotes have varied from 625 to 1,733, the price of Brent oil – from $40.11 to $126.90, the US dollar exchange rate –from 23.45 to 66.49 rubles, housing construction in Sverdlovsk region – from 1284.2 to 2483.7 thous. sq.m. issued mortgage loans – from 4,369 to 59,829 mln rubles, GDP – from 26,916 to 80,4125 bln rubles.

Overall, data on 2,360 properties was collected and processed. This set was divided into training, which contained 2,160 examples, and testing, which contained 200 examples. Optimal structure of the neural network was a perceptron shown in Figure 1.

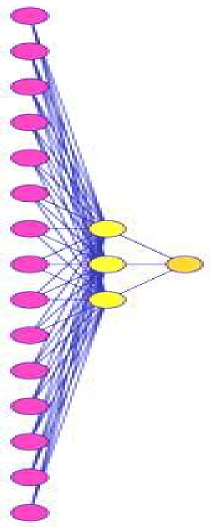

Figure 1 - Neural network – a perceptron with fifteen input neurons, one output neuron and three neurons in the hidden layer

Sigmoid functions were used as the activation functions of neurons in the hidden layer and the output neuron, so that computations of each i -th neuron (Figure 2) were carried out using the formulas:

$$S_i = \sum_{j=1}^{J} w_{ij} x_{ij}, \quad (1)$$

$$y_i = \frac{1}{1+e^{-S_i}}, \quad (2)$$

where: J – number of inputs of the i -th neuron, x_{ij} – input signals to the i -th neuron, y_i – its output signal,

w_{ij} – weighted coefficients (also known as forces of synaptic connections), computed as a result of training the neural network.

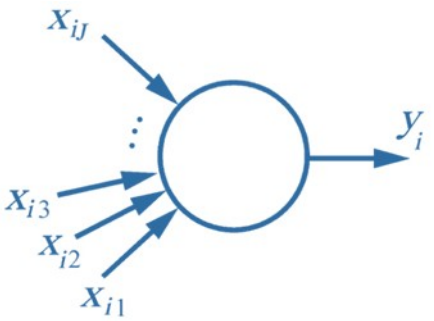

Figure 2 - Neuron of the perceptron performing conversion of x_{ij} input signals into y_i output signal using formulas (1) and (2)

To assess the quality of the neural network, the mean square relative error was used calculated using the formula:

$$E = \frac{\sqrt{\dfrac{\sum_{n=1}^{N}(d_n - y_n)^2}{N}}}{\max(d_n) - \min(d_n)} 100\%, \quad (3)$$

where: N – number of sample units, d_n – declared value of the n-th apartment, y_n – its value appraised by a neural network.

Moreover, this error was calculated both on training and testing sets.

Initially, the error of training the neural network was 11% and the testing error was 12%. Therefore, a technique was applied to the original data based on the fact that neural networks, which have a small number of degrees of freedom (hidden neurons), show the greatest error of training on the examples that are outliers (Yasnitsky 2005).

When applying this technique, we drew attention to the fact that the neural network filter often recorded the apartments located on the lower floors of buildings, as well as exclusive apartments worth more than 10 million rubles, as outliers. The reason is that the apartments located on the lower floors are often used for commercial activities in Yekaterinburg – for shops, offices, etc. The price of these commercial apartments is usually much higher than the apartments intended for housing, in view of the specificity of their purpose and, as a consequence, other pricing factors. Since the objective of research was to develop the technique of mass appraisal of real estate, as well as due to the fact that the information of purpose of the apartments (apartments for commercial purposes or for housing) was generally absent, we have decided to exclude all of these apartments located on the first and second floors of the buildings and marked as outliers from the set. In addition, data on the apartments with stated value exceeding 10 million rubles have been deleted from the set, as we do not attribute them to the mass market objects.

After removing these examples, the training error amounted to 6.2%, and testing error – to 6.5%. Moreover, additional checks on the quality of the network using multi-fold cross-validation method did not show any significant increase in training and testing errors. The coefficient of determination R^2 on the test set (between the predicted and observed values) was 0.87, which suggests that the constructed approximating model describes the market by explaining the input variables by 87%.

Education, optimization and testing of neural networks were carried out according to the procedure of the Perm scientific school of artificial intelligence (www.PermAi.ru). One of the results of testing performed on two hundred of test cases is graphically presented in Figure 3 (for clarity, the figure shows only 70 of the 200 test cases), which shows that the appraisal of apartments made by the neural network slightly differs from the actual (stated) values of apartments. Figure 4 shows another way to visualize the network test results – a scatterogram: the horizontal axis is the real values of the test set of apartments, the vertical axis is their appraisal performed by a neural network. This figure also shows that the neural network has learned the laws of the real estate market in Yekaterinburg and is quite acceptable, though not ideal.

Once again, we must note that the data about the apartments from the test sets were not used for training the neural network, *i.e. t*hey are new, and therefore the prognostic properties of the neural network are tested on them. Besides, the attention must be paid to the fact that the number of examples of the training set satisfies the requirement of representativeness (Yasnitsky 2005): it is much more than $7N_x$+15, where N_x is a number of input parameters.

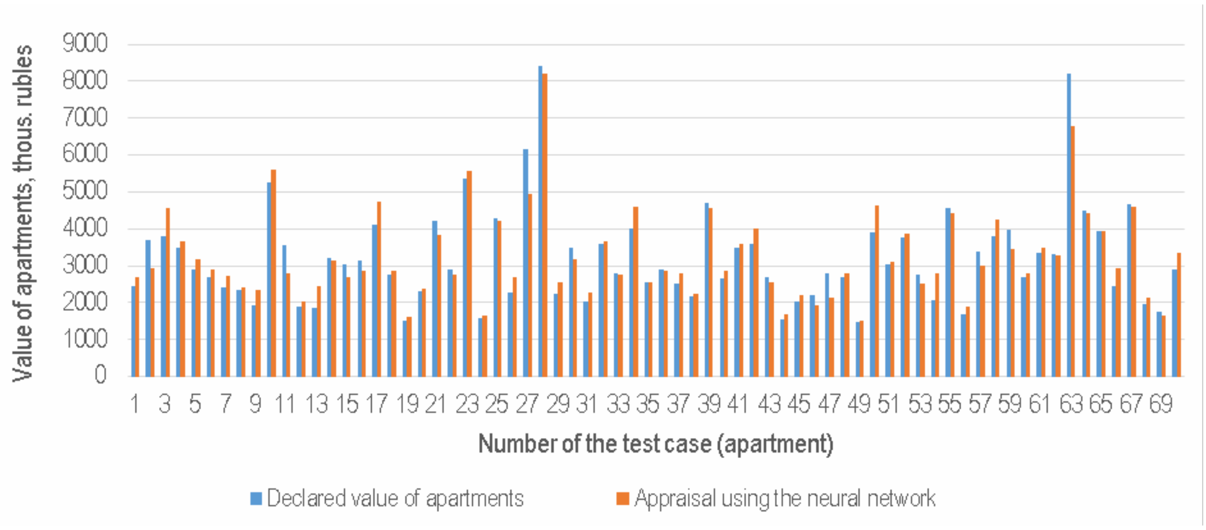

Figure 3 - Network test example: comparison of the declared values of apartments and those appraised using the neural network

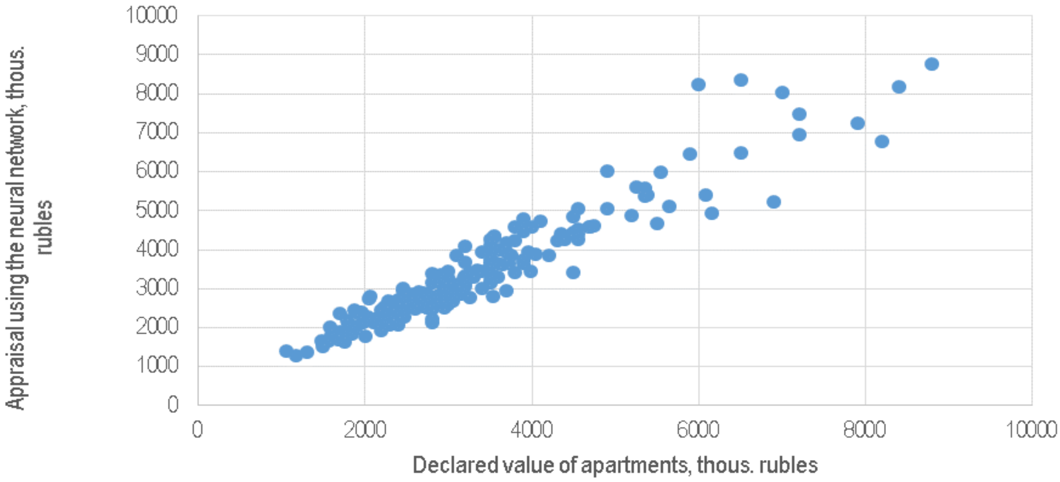

Figure 4 - Scatterogram

3. Computational experiments and discussion of results

After the work of the neural network has been checked in the test cases, and thus the adequacy of the mathematical model of neural network has been proved, we can begin to study it. The trained neural network model responds to changes in input variables and behaves in the same way as the subject field itself. Therefore, the dependence of the predicted values on the input parameters of the model can be explored using the neural network of the model.

The first question that can be answered using the models is to determine the degree of influence of its input parameters on the simulation result – the value of apartments in Yekaterinburg. The objective assessment of this influence can be obtained, for example, by the technique (Yasnitsky 2005) using the same neural network by alternate exclusion of input parameters and observation of the error of its testing. The higher the testing error is, the more significant the excluded parameter is. The histogram constructed in this way is shown in Figure 5. The height of the columns corresponds to the testing error obtained with the excluded parameter marked under the column. Moreover, the values of the column heights are scaled so that their sum totals 100%. The height of the columns is interpreted as the value of the parameter, which corresponds to the column. As can be seen from the figure, the following parameters were the most significant: GDP: 26.5%, Total area: 23.7%, New housing supply: 17.5%, Issued housing loans: 13.8%, Dollar exchange rate: 11.1%, Oil price: 4.8%, Distance to the city center: 1.2%.

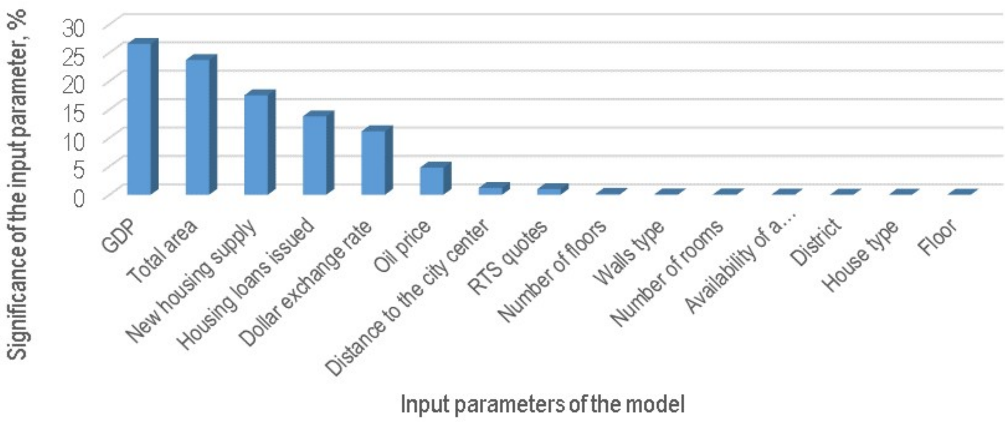

Figure 5 - Significance of the input parameters computed using neural networks

Figure 6 contains a histogram showing the value of Pearson coefficient module. Comparing the histograms in Figures 5 and 6, it can be seen that the distribution of the significances of the input parameters determined using a neural network quite significantly differs from the distribution of Pearson coefficient modules, which apparently is a consequence of a significant non-linearity of the studied patterns, which are not captured by the techniques of relevance assessment based on calculation of correlation coefficients.

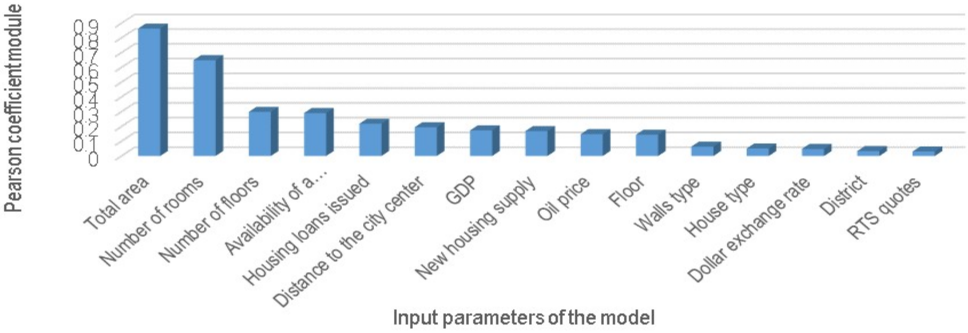

Figure 6 - Values of the modules of Pearson correlation coefficients between the input parameters and the value of apartments

As noted above, the neural network model is adequate to the modeled topical area, so it can be used to study the laws of the market of real estate in Yekaterinburg. This can be done, for example, through computations using the trained neural network along with a gradual change of either one of the input parameters and observation of computational results. Four apartments, which differ in their technical characteristics and district, were selected to perform computer experiments:

- one-room apartment with total area of 33 sq.m., located on the 8th floor of a 10-storeyed panel building with improved layout, with a loggia, the building is located in "Elmash" district of Yekaterinburg at a distance of 9.6 km from the city center.
- two-room apartment with total area of 59 sq.m., located on the 6th floor of a 9-storeyed panel building with the full-length layout, with a loggia, the building is located in "Uralmash" district at a distance of 9.9 km from the city center.
- three-room apartment with total area of 67.3 sq.m., located on the 6th floor of a 13-storeyed building of "gray panel" type, "Monolith" walls type, with a balcony, the building is located in "Avtovokzal" district at a distance of 3.7 km from the city center.
- four-room apartment with total area of 118 sq.m, located on the 7th floor of a 16-storeyed panel building with improved layout, with a loggia, the building is located in "Uralmash" district at a distance of 8.4 km from the city center.

The apartments were appraised at the time of the market condition in the 1st quarter of 2016, when the macroeconomic indicators had the following meanings: RTS quotes were 876; oil price was 42.93 US dollars; US dollar exchange rate was 66.49 rubles; new housing supply in Sverdlovsk region was 2,483.7 thous. sq.m.; issued housing loans were 40,822 mln rubles; GDP was 80,412.5 bln rubles.

Figure 7 shows the results of the virtual computer experiments performed in order to study the value of apartments depending on their location in the city. As can be seen from the figure, the value of all four apartments uniformly decreases with their virtual distancing from the city center. Moreover, the patterns are different in nature: the curve related to the 4-room apartment has a negative second derivative at all points, whereas the curves corresponding to one-, two- and three-room apartments have a positive one. This means that the rate of decrease in the prices of the 4-room apartment increases when distancing from the city center, whereas for the other considered apartments it decreases.

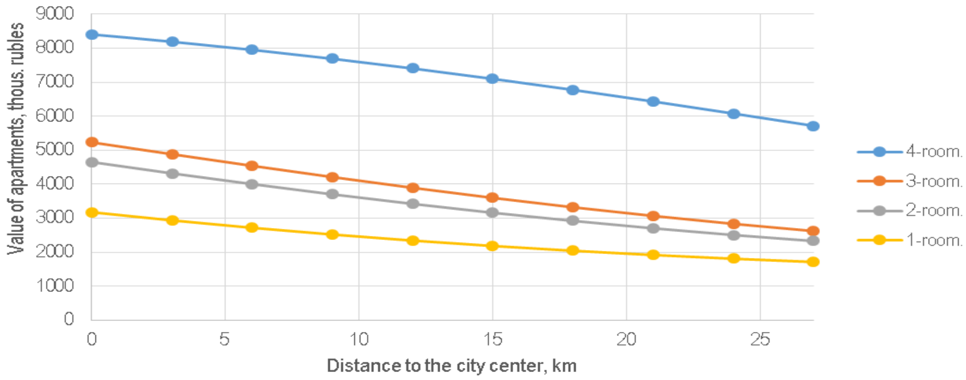

Figure 7 - Dependence of the value of apartments on their location in the city

Figure 8 shows the results of calculations obtained by changing the area of apartments. It can be seen that the computer experiments revealed an almost linear dependence of the value of all four apartments on their area. Moreover, the curves corresponding to one- and two-room apartments merged into a single line, and the curve corresponding to the three-room apartment located above the curve corresponding to the four-room apartment. This is explained by the fact that three-room apartment is located in a more modern house located much closer to the city center than the four-room apartment.

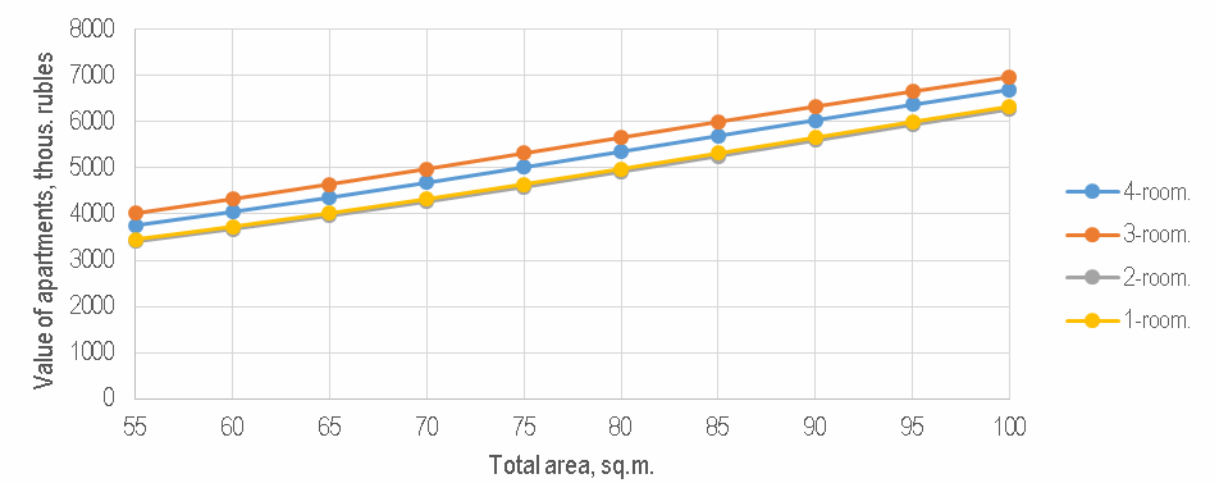

Figure 8 - Dependence of the value of apartments on their area

The next series of experiments is devoted to the study of the impact of the lending program implemented by banks on the residential real estate market in Yekaterinburg. This time, the computer experiments on neural network mathematical model were carried out through a virtual change of the input parameter "Issued housing loans", all other input parameters remain unchanged. Figure 9 shows the value of apartments in 2016 corresponding to the volume of loans issued in 2015, which amounted to 40,822 mln rubles, with the enlarged marker. As the figure shows, the simulation results predict an increase in the value of all four apartments with an increase in housing lending. In particular, for example, if the banks increase the volume of existing housing lending from 40,822 to 41,000 mln rubles, the value of the one-room apartment will increase from 2,249,000 to 2,550,000 rubles, *i.e.* by 2.4%, while the value of the four-room apartment will increase from 7,745,000 to 7,833,000, *i.e.* by 1.1%.

Thus, it can be concluded that an increase in housing lending in Yekaterinburg will lead to the rate of luxury apartments with a larger area growing about 2.2 times faster than the cheaper apartments with smaller area.

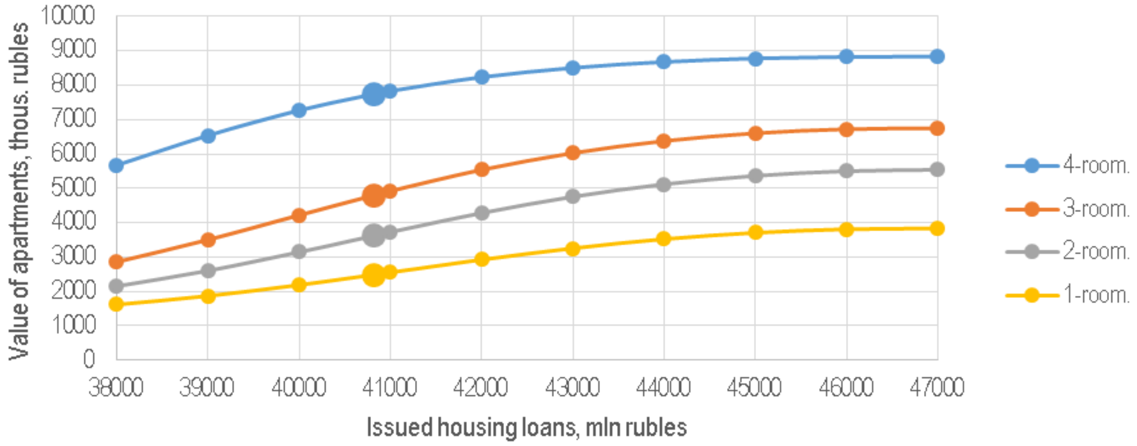

Figure 9 - Dependence of the value of apartments on the volumes of mortgage lending

Figure 10 shows the dependences of the value of the apartments under study on the volume of housing construction, obtained in a similar manner. The results are obtained through neural network computing by gradually changing the input parameter "New housing supply" and the preservation of all other input parameters unchanged. As before, the enlarged marker shows the value of apartments corresponding to the condition existing by the I quarter of 2016: level of new housing supply in Sverdlovsk (Yekaterinburg) region amounted to 2,483.7 thous. sq.m. As can be seen from the figure, with an increase in housing construction by about 2,550 thous. sq.m. there is an increase in the value of all four apartments under study. This is explained by the fact that the apartments in new buildings, as a rule, are more expensive than in older buildings. However, as follows from the figure, with an increase in new housing supply above the mentioned figure, the prices cease to grow, and then their decline begins. Thus, the results of mathematical modeling predict the saturation of the housing market in Yekaterinburg, which will occur if the volume of housing construction exceeds the mark of 2,550 thous. sq.m.

We shall note that this series of computer experiments was performed using the "freezing" technique – the volume of housing construction was virtually increased, while all the other macroeconomic parameters, and hence incomes, remained unchanged. We can therefore expect that in the case of non-compliance with this condition, the prediction results would have turned out different.

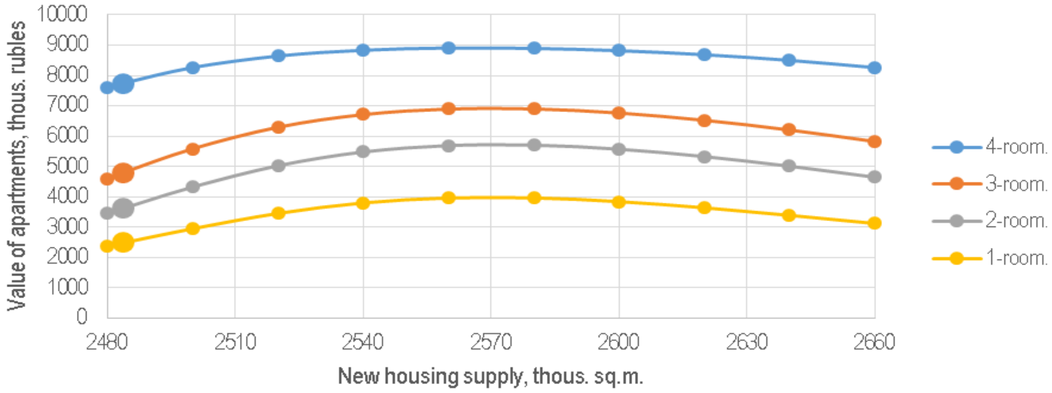

Figure 10 - Dependence of the value of apartments on the volume of housing construction

The developed neural network model could be used to study the effect of other macroeconomic factors on the real estate market in Yekaterinburg as well. For example, it can be used to see how the values of apartments calculated by the neural network will change following the change in oil prices, dollar exchange rate, RTS quotes, GDP, etc. However, you must remember that many macroeconomic indicators have a strong correlation between each other.

As is well known (Yasnitsky 2005), in contrast to the classical methods of regression analysis, which do not allow the presence of linear correlations between the input parameters, this requirement is not mandatory for the neural network technologies. It just requires to ensure that the values of variables applied to the neural network input comply with the proportions between them. For example, when changing the input parameter "Oil price", the input parameter "Dollar exchange rate" must also change (Pearson correlation coefficient -0.38), "RTS quotes" (0.45), "Issued housing loans" (0.35). Thus, in order to get a believable forecast using our neural network model, it is necessary to change not one, but several input macroeconomic parameters – not arbitrarily, but according to the existing interdependencies between them, which is a challenge. Therefore, in order to study the dependence of the investigated market on the values of the parameter "Oil price", it was decided to exclude all input macroeconomic parameters in which the Pearson correlation coefficient module with input parameter "Oil price" is more than 0.29. After exclusion of these input parameters, subsequent design, training and optimization of the neural network, its errors on the training and testing sets are 7.5% and 7.7%, respectively, and the coefficients of determination are 0.83 and 0.82.

Discussing the results of the computational experiments presented in Figure 11, we should note that, in the opinion of many experts, the situation on the oil market is an essential factor for the real estate industry as an integral part of the Russian economy. Oil prices determine the effective demand and the value of housing through a combination of factors: from the volume of housing lending and money supply of the population to the level of income and employment indicators. However, due to the fact that property prices in Yekaterinburg are not pegged to the US dollar (share of ruble deals in Yekaterinburg is more than 95%), we haven't considered the link between oil prices and the real estate prices in US dollars.

According to the analysis given in Figure 11, we can say that this dependence is not linear, and this non-linearity mostly refers to expensive apartments with large areas. In this case, it can be seen that the sharp drop in the value of the apartments is observed in the case of a sharp decline in oil prices from $100 to $90. Apparently, the cases of non-linearity found by mathematical modeling are the result of the crises of the Russian economy in 2008 and especially in 2014. The sharp fall in oil prices from $100 to $90 and the following devaluation of the ruble have caused panic among the holders of ruble assets and the desire to convert the latter into a more stable form. In particular, there was an increased demand for real estate, which has spurred the growth of housing prices.

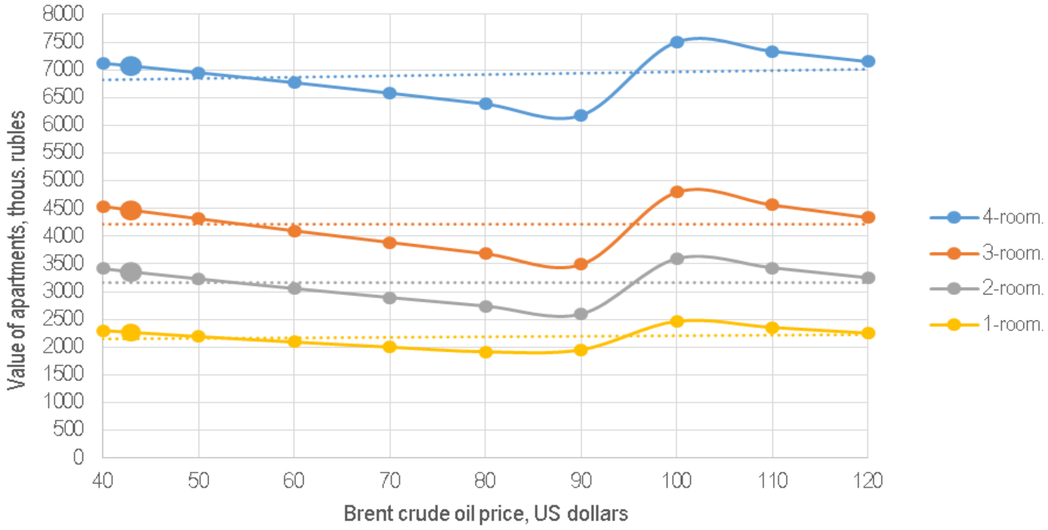

Figure 11 - Dependence of the value of apartments on oil prices

The predicting curves built in Figures 12-14 were obtained in a similar way.

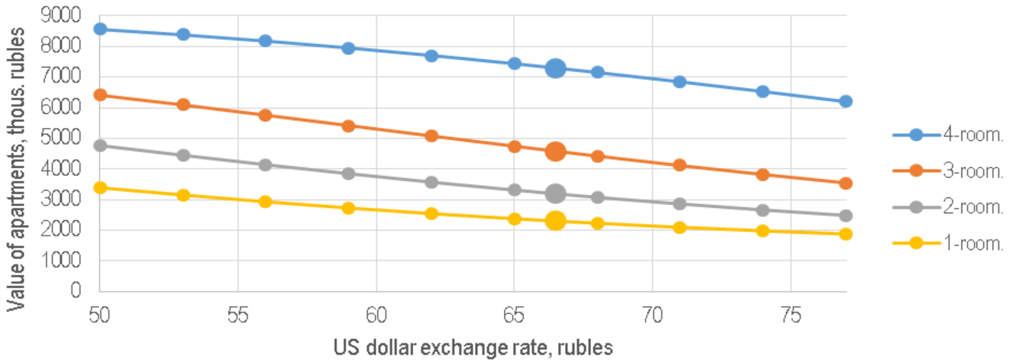

Figure 12 - Dependence of the value of apartments on the US dollar exchange rate

As seen in Figure 12, the growth rate of the US dollar is accompanied by a decrease in the value of apartments in Yekaterinburg, indicating a significant dependence of the Russian economy on currency.

Figure 13 shows the results of forecasting of prices for apartments in Yekaterinburg depending on GDP, the growth of which, as is known, was 16% over the past decade. As can be seen from the figure, an increase in GDP is followed by a smooth growth in prices for apartments, which indicates that in general, the growth pace of prices and turnover of property in Yekaterinburg have synchronized with the pace of overall economic growth.

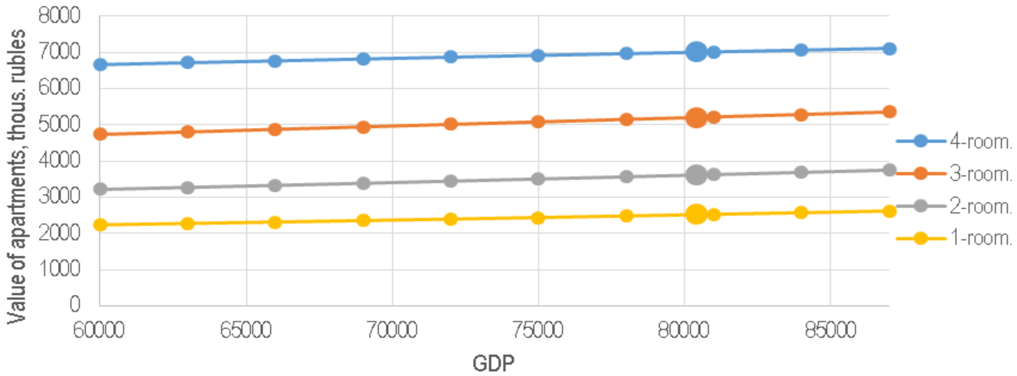

Figure 13 - Dependence of the value of apartments on GDP

The result of the analysis of the stock market impact on the real estate shown in Figure 14 reveals a weak dependence, which is a consequence of the lack of development of the Russian stock market and the lack of significant impact of this indicator on the prices of real estate in the regional market.

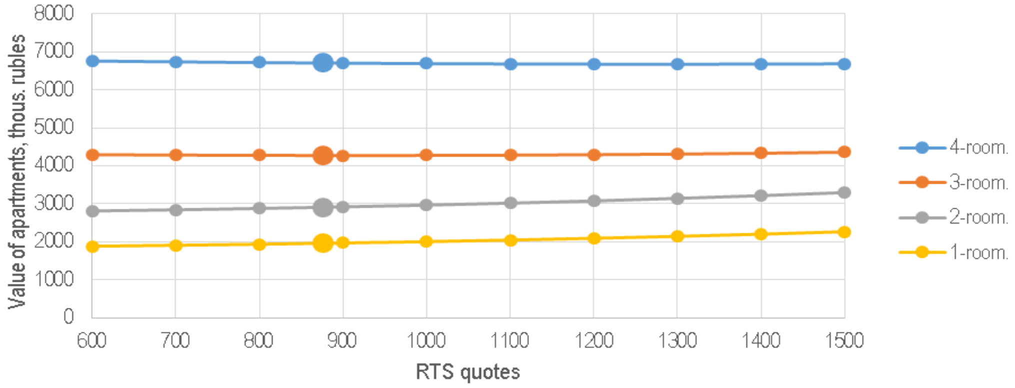

Figure 14 - Dependence of the value of apartments on RTS quotes

Concluding remarks

Thus, an integrated economic and mathematical model of mass appraisal of residential real estate in Yekaterinburg was created, taking into account both construction and performance parameters of apartments and the evolving economic situation in the country and the world. In contrast to the *static* economic and mathematical models that take into account only construction and performance parameters, the developed model does not require frequent updating and is also suitable for medium-term forecasting of the behavior of the real estate market in order to extract useful knowledge.

The developed integrated model has allowed us to conduct research of the residential real estate market in Yekaterinburg, identify patterns and perform some forecasts, the most interesting of which are the onset of market saturation effect with the increasing housing construction (Figure 10) and the effects of the increase in mortgage lending volumes (Figure 9).

In conclusion, we shall note that the proposed technique was demonstrated by the example of appraisal and prediction of the residential real estate market of Yekaterinburg, which refers to the developed cluster of Russian cities with the highest incomes and relatively high prices on the housing market. Similar studies and forecasts using the proposed technique can be made for other countries and cities.

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