Territorial-sectoral modelling of the automotive industry in the Russian Federation

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Abstract. The paper describes a territorial-sectoral model for the development of the automotive industry. This model is based on a novel institutional-functional approach proposed by author. It explains the choice of the indicators assessing the main areas of human activity on the territory and the indicators evaluating the automotive industry that operates on this territory. The distinctive feature of the institutional-functional approach is that it includes both such variables as spheres of human life on the territory in which the automotive industry functions and variables of the automotive industry into the model. The model includes three levels, each of which has the system of equations, from 6 to 8 equations. At each subsequent level, the endogenous indicators of the previous level become exogenous. The model comprises a system of interrelated and interdependent econometric equations. Each equation is formulated as an ADL model. Within the system of interrelated and interdependent econometric equations, a correlation between endogenous and exogenous variables in the automotive industry and spheres of human activity in the territory is demonstrated. A three-level model for the development analysing of the Russian automotive industry is proposed. On the basis of the constructed model, a short-term forecast until 2020 is presented.

1. Introduction
The automotive industry, which encompasses the production of all kinds of machinery, equipment and appliances, is one of the most extensive industries of the Russian Federation. Currently in this area there are more than 200 manufacturers. The automotive industry comprises 31% of the total volume of machine-building complex in the world [1]. In developed countries, the car industry typically provides five to ten percent of total gross national production.

The automotive industry is directly related to the products of other industries (non-ferrous metals, electronic products, rubber, and others). The automotive industry is also related to trade and maintenance of vehicles, construction and repair of roads, etc. The car industry is a prime example of monopolistic competition, i.e. a huge number of companies produce differentiated products. Such goods are related but not completely interchangeable because they provide brand products different from their competitors.

The car industry is divided on the following grounds: the condition of the car (the market for new and second-hand cars); geographical (markets in USA, Japan, China, Russia and other regions); vehicle type (cars and trucks, special vehicles, buses, ATVs and motorcycles) [2].

According to Forbes magazine, 2018 is the third consecutive year when the world’s three largest automakers remain the same: Toyota Motor, Volkswagen Group and Daimler. The Russian company JSC "AVTOVAZ" entered the list of the reputable economic magazine ‘Forbes’ only in the middle of the two thousandths: in 2005 it took the 1836th place and in 2006 it rose to the 1653th place.
[http://www.oica.net]. Since the automotive industry is widely seen as one of the vital economic sectors for economic growth and social development, industry production is widely used as an economic metric. The automotive industry is developing towards modernisation of designs, reliability improvement, fuel economy improvement, reduced emissions and use of new materials as well as improvements in the computerisation of maintenance, management and security.

One of the tools for analysing the activities of the automotive industry is modelling [4, 5]. The purpose of the present study is to design a mathematical model for the development of the Russian automotive industry. The mathematical model should contain several interdependent equations. Each equation connects endogenous and exogenous variables. Such a model should be used both for analysis and for forecasting the growth indices of the automotive industry.

The local tasks of the study are the following: describe the object of research (the automotive industry); choose the type of mathematical model; describe the method of empirical verification of the model; check the model using the statistics of the automotive industry for 2000-2015.

2. Review of the problem research

There are many approaches used in the modelling of some object, including an industry or a territory. This is confirmed by the studies of M. Porter, David P. Byrne [6], Lucija Muehlenbachs [7], G. F. Romashkina [8], N. I. Didenko [9], D. F. Skripnuk [10], Murray Z. Frank [11], Jennifer F. Reinganum [12] and other scientists.

3. Approach to territorial and sectoral modelling

3.1. Institutional-functional approach to territorial-sectoral modelling

A distinctive feature of the institutional-functional modelling approach, on which the territorial-sectoral industrial development model is based, is that it includes both such variables as spheres of human life on the territory in which the automotive industry functions as well as variables of the automotive industry itself [13-16]. The institutional component is provided by an analysis of human activity spheres on the territory, while the functional component consists in an analysis of the automotive industry functioning in the area. This approach permits important data to be obtained, informing the future direction of development of both the territory and the industry.

3.2. The theoretical model and its characteristics

The model includes three levels, each of which comprises a system of between 6 and 8 equations. The model of the first level displays the production environment, i.e. the territory. In developing the model at the first level, each enterprise or industry is expressed through the manufacture function which has the following form: \( Q = f(A, L, K) \), where \( Q \) is the volume of shipped products of the enterprise/industry, \( A \) is the technology index (innovational development of the enterprise/industry), \( L \) is the number of employees, \( K \) is the physical capital (value of fixed assets).

The model of the second level displays the spheres of human activity taking place in the area (demographic, social, productive and economic, environmental, innovative-technological, political and spiritual). The model of the third level displays the correlation of the territorial-space industry with the national economy. In the model of each next level, the endogenous indicators of the previous level become exogenous.

A detailed model of the third level is presented below. As endogenous indicators, the following six variables were selected:

\[ y_{r1}^{31} \] – proportion of export of cars from Russia to the total exports of the Russian Federation;

\[ y_{r2}^{32} \] – proportion of export of lorries from the Russian Federation in the total exports of the Russian Federation;
$y_{33}^t$ – proportion of importation of cars from the Russian Federation in the total imports of the Russian Federation;

$y_{34}^t$ – proportion of importation of lorries from the Russian Federation in the total imports of the Russian Federation;

$y_{35}^t$ – proportion of the automotive industry relative to Russia's GDP;

$y_{36}^t$ – the specific weight of production volume of passenger cars in the total production of vehicles in Russia.

The exogenous variables for endogenous variable $y_{31}^t$ are:

- $x_{231}^t$ – volume of exports in the Russian Federation (in mln. US dollars);
- $x_{311}^t$ – volume of passenger cars' export (in mln. US dollars);
- $x_{312}^t$ – index of labour productivity in the automotive industry in Russia (%);
- $x_{313}^t$ – consumer price index for goods and services of the automotive industry in Russia (in %).

The exogenous variables for endogenous variable $y_{32}^t$ are:

- $x_{1}^t$ – volume of vehicle production (units);
- $x_{231}^t$ – volume of the Russian Federation exports (mln. US dollars);
- $x_{321}^t$ – export volume of trucks (mln. US dollars);
- $x_{322}^t$ – share of investments into the automotive industry relative to the total volume of investments in the fixed capital of the Russian Federation (in %).

The exogenous variables for endogenous variable $y_{33}^t$ are:

- $x_{232}^t$ – volume of the Russian Federation imports (mln. US dollars);
- $x_{331}^t$ – volume of passenger cars' imports (mln. US dollars);
- $x_{212}^t$ – level of motorisation (cars/1,000 people);
- $x_{313}^t$ – consumer price index for goods and services in the automotive industry in Russia (in %).

The exogenous variables for endogenous variable $y_{34}^t$ are:

- $x_{232}^t$ – volume of Russian imports (in mln. US dollars);
- $x_{341}^t$ – volume of trucks' import (in mln. US dollars);
- $x_{212}^t$ – level of motorisation (cars/1,000 people);
- $x_{313}^t$ – consumer price index for goods and services in the automotive industry in Russia (in %).

The exogenous variables for endogenous variable $y_{35}^t$ are:

- $y_{2}^t$ – contribution of the automotive industry to Russian GDP (in mln. US dollars);
- $x_{351}^t$ – GDP in Russia (in mln. US dollars);
- $x_{322}^t$ – share of investment into the automotive industry in the total volume of investments into the fixed capital of the Russian Federation (in %);
- $x_{352}^t$ – innovative activity of the organisations which produce vehicles on the whole in Russia (in %);
- $x_{252}^t$ – Scientific research expenditure (thous. US dollars).
The exogenous variables for endogenous variable $y_t^{36}$ are:

- $y_t^{1}$ – volume of vehicles’ production (units);
- $y_t^{11}$ – volume of cars’ production in Russia (in units);
- $x_t^{251}$ – number of patents (in thousand units);
- $x_t^{211}$ – average number of qualified personnel per year (in thousands of people);
- $x_t^{254}$ – number of innovation centres in Russia (in units).

The auto regressive distributed lags (ADL) model was selected as a specific type of dependency for each of the six equations.

$$y_t = a_0 + \sum_{i=1}^{n} a_i y_{t-i} + \sum_{j=0}^{q_1} b_j x_{t-j}^1 + \cdots + \sum_{j=0}^{q_l} b_j x_{t-j}^l + E_t \quad (1)$$

where $k$ is the quantity of exogenous variables;
- $q_i$ – the number of lags of the $i$-th exogenous variable ($i = 1,2,...,k$);
- $n$ – the depth of the lag within the endogenous variable;
- $E_t$ - residues forming the white noise process.

### 3.3. Data

The informational-operational base comprised data supplied by the Russian federal state statistics service [http://www.gks.ru/Rosstat]; Autostat [https://www.autostat.ru/tags/3/], the statistics of the international organisation of motor vehicle manufacturers (OICA) [http://www.oica.net/]; annual reports of the largest foreign and Russian automotive manufacturers [http://www.honda.co.ru/], [https://www.toyota.ru], [http://ford-rolf.ru], [http://www.lincoln.com], as well as legislative and regulatory acts of the Russian Federation.

### 3.4. Empirical model testing methodology

The technique consists of the following stages:

- a) Collection of statistical data for years 2000 – 2015.
- b) Presentation of the indicators in a comparable form.

To bring the indicators into a comparable form, the indexes of each indicator are defined according to the following formula:

$$I_i = \frac{x_i - x_{i}^{\text{max}}}{x_i^{\text{max}} - x_{i}^{\text{min}}} \cdot 100 \quad (2),$$

where $x_i$ is the actual value of the $i$-th index, $x_i^{\text{max}}$ and $x_i^{\text{min}}$ – are maximum and minimum rate of the $i$-th index, respectively.

- c) Inspection of the time series’ stationarity using Dickie Fuller test.
- d) Implementation of the procedures when composing each of the six equations: analysis of correlation between the endogenous variable of the last period and the exogenous variables; checking statistical multicollinearity; testing the significance of each equation using Fisher’s F-criterion and the coefficient of determination; finding the equation coefficients using regression analysis.
- e) The view of the model as a system of equations in a structural form. Empirical testing of the system of interrelated econometric equations.
- f) Definition of identification terms for each equation.
- g) Finding the coefficients of regression equations.
- h) Performing predictive calculations using the system of equations.
4. Empirical testing of the model
Statistical data is collected for years 2000-2015 for each indicator. The results are presented in a comparable form. The stationarity of the time series is checked. The stationarity testing revealed that all-time series are stationary, as when finding the coefficients of a regression equation coefficient $a$ is less than the unit for all-time series if the condition $t_{p.c.} > t_{maks.}$ , $p = 0.05$ is met.

An ADL model is created for each of the six equations. The outcome of the applied techniques was the creation of a system of linked econometric equations in a structural form.

Testing the compliance of the model structural form according to the conditions of identification showed that all the equations are over identified. This procedure was carried out for each equation separately. Therefore, in order to estimate the parameters of each of the equations, a two-step least-squares method was used.

The system of econometric equations with the discovered coefficients of the regression equations is written as:

$$
\begin{align*}
\chi_1^{31} &= -2.431 + 0.359 \cdot y_4^{31} + 0.118 \cdot x_{-2}^{23} + 0.2 \cdot x_{-1}^{31} + 0.018 \cdot x_{31}^{31} + 0.125 \cdot x_{1}^{33} \\
\chi_2^{32} &= -31.621 + 0.619 \cdot y_4^{32} - 0.243 \cdot x_{-2}^{23} + 0.433 \cdot x_{-1}^{31} + 0.127 \cdot x_{31}^{31} + 0.508 \cdot x_{1}^{32} \\
\chi_3^{33} &= 41.198 + 1.40 \cdot y_4^{33} + 0.603 \cdot x_{-2}^{23} - 0.644 \cdot x_{-1}^{31} - 0.918 \cdot x_{31}^{31} - 0.246 \cdot x_{1}^{33} \\
\chi_4^{34} &= 22.28 + 1.107 \cdot y_4^{34} + 0.537 \cdot x_{-2}^{23} - 0.455 \cdot x_{-1}^{34} - 0.643 \cdot x_{31}^{31} + 0.058 \cdot x_{1}^{33} \\
\chi_5^{35} &= 6.343 + 0.531 \cdot y_4^{35} - 1.03 \cdot x_{-2}^{23} + 1.014 \cdot x_{-1}^{31} + 0.791 \cdot x_{31}^{31} - 0.339 \cdot x_{1}^{32} - 0.21 \cdot x_{1}^{33} \\
\chi_6^{36} &= 32.006 - 0.072 \cdot y_4^{36} - 1.049 \cdot y_4^{31} + 0.015 \cdot y_4^{31} + 1.308 \cdot x_{-2}^{23} - 0.602 \cdot x_{-1}^{31} + 0.906 \cdot x_{1}^{32}
\end{align*}
$$

The accuracy of the model for prediction was determined by comparing the estimated projections for year 2016 with actual statistics of 2016. The deviation of actual values of the control year from the calculation and the forecast turned out to be insignificant, which proves the high accuracy of the model.

5. Use of the model to forecast automotive industry development in the Russian Federation
On the basis of the constructed system of equations and using derived trend equations, a short-term forecast was created up to year 2020. To do this, the following actions were performed:

a) Forecasting of exogenous indicators for the period of four years (2017-2020) was carried out using trend line equations. Forecast values of exogenous parameters are given in the table below (Table 1).

Forecasts of the indicators: "volume of exports in the Russian Federation", "volume of export of passenger cars", "production of vehicles in Russia", "volume of imports into the Russian Federation, "level of motorisation", "contribution of the automotive industry to Russia's GDP", "GDP of Russia", "innovative activity of organisations producing vehicles in Russia", "volume of car production", "number of patents" and "average number of highly qualified personnel" will have a positive trend in the next four years.

"Index of productivity", "consumer prices index for goods and services of the automotive industry in Russia", "volume of export of lorries in the Russian Federation", "share of investment into the automotive industry in the total volume of investments into the fixed capital of the Russian Federation", "volume of imports of passenger cars" and “volume of imports of lorries” will have a declining trend. The indicator "number of innovative centres in Russia" will hardly change over the coming years.

According to the forecast results, it can be concluded that the government needs to implement a number of activities, including: improving the quality and image of the Russian automotive industry, technological development in the field, training of employees producing motor vehicles, increase of investment into the automotive industry, expansion of innovation institutions, as well as updating vehicle fleets in the country.

| Table 1. Forecasted values for exogenous indicators |
|---------------------------------------------|
| Years | $x_{21}^{31}$ | $x_{21}^{31}$ | $x_{31}^{32}$ | $x_{31}^{33}$ | $y^{31}$ | $x_{31}^{32}$ |
|-------|---------------|---------------|---------------|---------------|--------|---------------|
| 2017  | 71.976        | 76.629        | 16.299        | 11.842        | 97.450 | 33.335        |
| 2018  | 74.328        | 80.618        | 11.365        | 8.709         | 101.871| 31.664        |
b) The obtained projected values of the exogenous parameters were used in the system of equations for obtaining the endogenous variables. The predicted values of the endogenous variables in years 2017-2020 are shown in the figures (Figures 1, 2, 3, 4, 5, 6).

According to the results of the forecast, the proportion of export of cars in Russia relative to total exports of the Russian Federation, the proportion of imported cars in Russia relative to total Russian imports, the proportion of imported lorries of the Russian Federation to total Russian imports and the proportion of the automotive industry in the total GDP of Russia will gradually grow.

While such indicators as the proportion of exports of lorries in the Russian Federation in total exports of the Russian Federation and the proportion of passenger cars’ production volume in the total production of vehicles in the Russian Federation will be reduced.

| Years | $x_{232}$ | $x_{331}$ | $x_{212}$ | $x_{341}$ | $y_{1}$ | $x_{351}$ |
|-------|----------|----------|----------|----------|--------|----------|
| 2017  | 95.065   | 1.892    | 106.25   | 19.580   | 61.735 | 106.379  |
| 2018  | 100.781  | 3.879    | 112.50   | 15.102   | 64.651 | 112.757  |
| 2019  | 106.498  | 9.650    | 118.75   | 10.625   | 67.566 | 119.136  |
| 2020  | 112.214  | 15.421   | 125      | 6.148    | 70.481 | 125.515  |

| Years | $x_{352}$ | $x_{252}$ | $y_{11}$ | $x_{251}$ | $x_{211}$ | $x_{254}$ | $x_{322}$ |
|-------|----------|----------|----------|----------|-----------|----------|----------|
| 2017  | 6.195    | 102.522  | 85.2     | 100.402  | 87.544    | 18.294   | 11.280   |
| 2018  | 0.625    | 105.043  | 89       | 100.402  | 87.544    | 18.294   | 11.280   |
| 2019  | 4.944    | 107.564  | 92.7     | 112.988  | 97.887    | 18.482   | 2.581    |
| 2020  | 10.514   | 110.085  | 96.4     | 119.280  | 103.059   | 18.575   | 1.768    |

Figure 1. Forecast values for the indicator $y_{31}$

Figure 2. Forecast values for the indicator $y_{32}$

Figure 3. Forecast values for the indicator $y_{33}$

Figure 4. Forecast values for the indicator $y_{34}$
6. Conclusion

A three-level model for analysing the development of the Russian automotive industry is proposed. The article analyses the third level of the model. The third level of the model is demonstrated the relationship of the automotive industry with the economy of the country. There are several exogenous variables for each endogenous variable of the model. The endogenous and the exogenous variables selected earlier were used to construct a system of equations in the structural form of the model. The structural form of the model is translated into the reconstructed form of the model. The solution for the reconstructed form of the model is demonstrated. Empirical verification of the model was carried out on the statistical data for 2000-2015. The degree of correspondence between the actual data and those calculated by the model is taken as the criterion for the accuracy of the model. The accuracy of the model was in the range of 5-7%.

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