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FORECASTING THE IMPACT OF CONTROL ACTIONS ON THE SECTORAL STRUCTURE DYNAMICS OF A LABOR MARKET BASED ON THE BALANCE MATHEMATICAL MODEL

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Abstract. This paper proposes an approach to considering control actions on the sectoral structure dynamics of a labor market when forecasting sectoral employment indicators. The forecasting scheme is based on the balance mathematical model of inter-sectoral labor resource movements. In the forecasting scheme considered previously, the trends of indicators characterizing inter-sectoral labor force mobility were determined independently of each other. In what follows, this forecasting scheme is modified by introducing a grouping method for the indicators of inter-sectoral labor resource movements and a criterion for determining the general trend of indicators within each group. The modified forecasting scheme is applied to calculate sectoral employment forecasts for the labor market of the Russian Federation in 2011–2016, and the forecasts are compared with the previous results. The expected employment rate is forecasted for the end of 2022 using sectoral employment and unemployment data for 2017–2021 according to the second edition of the All-Russian Classifier of Types of Economic Activity (OKVED). A method for determining the result of control actions is presented on an example of the Russian Federation labor market in 2017–2022: changes in the sectoral employment forecasts are demonstrated in the case of considering control actions on the agricultural and industrial sectors of the market.

Keywords: the sectoral structure of a labor market, balance mathematical model, inter-sectoral labor resource movements, control actions, the effect of control actions, employment forecasting, labor market.

INTRODUCTION

The need to control the sectoral structure dynamics of a labor market is due to the following factors: increasing the economic efficiency of labor market processes by control agents [1, 2], developing conditions for effective and stable employment of the population [3, 4], providing consistency between supply and demand for qualified labor resources [5], achieving a balance between the professional structure of graduates of the educational system and the demand for specialists with certain sets of competencies [6], eliminating acute shortages of personnel in market segments [7, 8], and preventing and overcoming crisis phenomena in the labor market [9, 10].

The state (government) is the main agent applying control actions, and they can take the following forms: subsidizing retraining programs for qualified specialists [11], correcting the educational standards of higher education institutions [12], providing financial support to businesses in different segments of the labor market [13], and stimulating R&D for the transition to science-consuming and high-tech industries [14].

The result of control actions selected must meet their goals; in this regard, it is necessary to forecast the efficiency of control [15, 16]. The main efficiency criteria are sectoral employment and unemployment rates [17, 18]. The impact of control actions on these criteria can be forecasted based on schemes considering control actions at the level of inter-sectoral interaction of labor resources and providing qualitative forecasts of sectoral labor market indicators.

Various formalizable and intuitive models of the sectoral structure dynamics of a labor market are used to forecast sectoral employment and unemployment indicators [19, 20].

Applying intuitive models may reduce the reliability of forecasts due to the subjectivity of forecasting schemes based on these models [21] and lead to counter-intuitive socio-economic, in particular market, processes [22, 23].

When forecasting sectoral labor market indicators using formalizable models, the reliability of results is negatively affected by the dual character of the sectoral structure dynamics forecasting problem. On the one hand, sectoral labor market indicators are highly aggregated [24], so direct forecasting by their values neglects the trends of the factors on which the indicators can be segmented [25]. On the other hand, due to the segmentation of aggregated indicators, the mathematical model possibly includes factors without any regular and objective statistics.

One solution of the duality issue in the forecasting problem is to segment sectoral employment and unemployment indicators using the balance mathematical model [27]. The following elements were developed for this model:

- a method and an algorithm for calculating the values of segmentation factors by the values of sectoral labor market indicators only, see [28] (note that the data provided by the Federal State Statistics Service (Rosstat) are sufficient for calculating sectoral labor market indicators [29]);
- a forecasting scheme in which the trends of factors segmenting labor market indicators are determined independently of each other.

This paper describes the general principles of considering control actions on the sectoral structure dynamics of a labor market when applying the forecasting scheme based on the balance mathematical model. Also, we modify this scheme to improve the expected forecasting quality when the trends of a group of factors segmenting the same labor market indicator are given by one trend selected for a particular group. The sectoral employment forecasting methodology based on the modified scheme considers the effects of control actions. It is tested for the labor market of the Russian Federation.

1. THE BALANCE MATHEMATICAL MODEL

To simplify the calculation of labor market indicators and the indicators of inter-sectoral labor resource movements, we introduce the following notations for possible states of each labor resource (person) of a market under study: $S_1^{(i)}$ means that the person is employed in sector i; $S_2^{(i)}$ means that the person is unemployed, and its last place of work was in sector i; $i=\overline{1,n}$, where n gives the number of sectors; $S_2^{(0)}$ means that the person has been unemployed in the labor market since the (last) appearance in it.

Consider the following labor market indicators: $N_j^{(i_j)}(t)$ is the amount of labor in the state $S_j^{(i_j)}$, j = 1, 2, $i_1=\overline{1,n}$, $i_2=\overline{0,n}$, at the end of year t. For the labor market of the Russian Federation, the values of these indicators can be calculated from Rosstat data.

The sectoral structure dynamics of a labor market are described by the general mathematical model

$$N_j^{(i)}(t+1)=N_j^{(i)}(t)+q_{j,\text{in}}^{(i)}(t)-q_{j,\text{out}}^{(i)}(t), \quad (1)$$

$$j=1,\ 2,\ i=\overline{1,n},$$

$$N_2^{(0)}(t+1)=N_2^{(0)}(t)+\Delta N_2^{(0)}(t)-q_{2,\text{out}}^{(0)}(t). \quad (2)$$

Here, $q_{j,\text{in}}^{(i)}(t)$ is the amount of labor in the state $S_j^{(i)}$ at the end of year (t + 1) and in a state other than $S_j^{(i)}$ at the end of year t; $q_{j,\text{out}}^{(i_j)}(t)$ is the amount of labor in the state $S_j^{(i_j)}$ at the end of year t and in a state other than $S_j^{(i_j)}$ at the end of year (t + 1); $\Delta N_2^{(0)}(t)$ is the inflow of labor resources to the labor market during year (t + 1) (the exogenous variable of the model); j = 1,2, $i,i_1=\overline{1,n}$, $i_2=\overline{0,n}$. The value $q_{1,\text{in}}^{(i)}(t)$ is called the input flow of labor resources into sector i during year (t + 1) whereas the value $q_{1,\text{out}}^{(i)}(t)$ the output flow of labor resources from sector i during year (t + 1); see [27].

The balance mathematical model of sectoral structure dynamics is built by specifying the values $q_{j,\text{in}}^{(i)}(t)\ q_{j,\text{out}}^{(i_j)}(t)$, j = 1, 2, $i,i_1=\overline{1,n}$, $i_2=\overline{0,n}$, to determine inter-sectoral labor resource movements in the studied market. Let us compare two specifications of the model. The first specification [26, 27] has the form

$$q_{1,\text{in}}^{(i)}(t)=\sum_{j=1}^{n}N_2^{(j)}(t)P_1^{(j,i)}(t)$$
$$+\left[\Delta N_2^{(0)}(t)+N_2^{(0)}(t)\right]P_1^{(0,i)}(t) \quad (3)$$
$$+\sum_{\substack{j=1\\ j\neq i}}^{n}N_1^{(j)}(t)P_4^{(j,i)}(t),$$

$$q_{1,\text{out}}^{(i)} = N_1^{(i)}(t)\left[P_2^{(i)}(t)+P_3^{(i)}(t)\right] + \sum_{\substack{j=1\\ j\neq i}}^{n} N_1^{(i)}(t)P_4^{(i,j)}(t), \quad (4)$$

$$q_{2,\text{in}}^{(i)}(t) = N_1^{(i)}(t)P_2^{(i)}(t),$$

$$q_{2,\text{out}}^{(i)}(t) = N_2^{(i)}(t)\sum_{j=1}^{n+1} P_1^{(i,j)}(t), \quad i=\overline{1,\ n}, \quad (5)$$

$$q_{2,\text{out}}^{(0)}(t) = \left[\Delta N_2^{(0)}(t)+N_2^{(0)}(t)\right]\sum_{j=1}^{n+1} P_1^{(0,j)}(t), \quad (6)$$

where $P_1^{(i,j)}(t)$ is the probability that during year $(t+1)$ a person will pass from the state $S_2^{(i)}$ (at the end of year t) to the state $S_1^{(j)}$ (at the end of year $(t+1)$); $P_2^{(k)}(t)$ is the probability that during year $(t+1)$ a person will pass from the state $S_1^{(k)}$ to the state $S_2^{(k)}$; $P_3^{(k)}(t)$ is the probability during year $(t+1)$ a person will pass from the state $S_1^{(k)}$ to the state $S_2^{(n+1)}$; $P_4^{(k_1,k_2)}(t)$ is the probability that during year $(t+1)$ a person will pass from the state $S_1^{(k_1)}$ to the state $S_1^{(k_2)}$; $i=\overline{0,n}$, $j=\overline{1,n+1}$, and $k,k_1,k_2=\overline{1,n}$, where $k_1 \neq k_2$. The transition to the state $S_2^{(n+1)}$ should be interpreted as the person's exit from the labor market under study.

By the definition of these probabilities,

$$P_1^{(i,j)}(t)\geq 0,\ \sum_{k=1}^{n+1} P_1^{(i,k)}(t)\leq 1,\ i=\overline{0,n},\ \ j=\overline{1,n+1}, \quad (7)$$

$$P_2^{(i)}(t),\ P_3^{(i)}(t),\ P_4^{(j,i)}(t)\geq 0, \quad P_2^{(i)}(t)+P_3^{(i)}(t) + \sum_{\substack{k=1\\ k\neq i}}^{n} P_4^{(i,k)}(t)\leq 1, \quad i,\ j=\overline{1,n},\ i\neq j. \quad (8)$$

Model (1)–(8) will be called the specified balance mathematical model.

As opposed to model (1)–(8), the balance mathematical model with a reduced level of specification (further called the nominal model) neglects the possibility of changing the sectoral affiliation of an employee within one year [28]. In other words, for the nominal model, we have $P_4^{(k_1,k_2)}(t)=0$, $k_1,k_2=\overline{1,n}$, $k_1\neq k_2$, in formulas (3), (4), and (8).

The probabilities under consideration are *the indicators of inter-sectoral labor resource movements* that segment labor market indicators within an appropriate balance mathematical model (specified or nominal).

In both cases, equations (1) and (2) of the balance mathematical model can be written as

$$N(t,\ t+1)=A(t)\ P(t), \quad (9)$$

where

$$N(t,\ t+1)=\left(\Delta_1^1,\ldots,\ \Delta_1^n,\ \Delta_2^1,\ldots,\ \Delta_2^n,\ \Delta_2^0\right)^{\mathrm{T}}, \quad (10)$$

$$\Delta_1^i = N_1^{(i)}(t+1)-N_1^{(i)}(t),$$

$$\Delta_2^i = N_2^{(i)}(t+1)-N_2^{(i)}(t), \quad (11)$$

$$i=\overline{1,n},$$

$$\Delta_2^0 = N_2^{(0)}(t+1)-N_2^{(0)}(t)-\Delta N_2^{(0)}(t); \quad (12)$$

$P(t)$ is the vector of inter-sectoral movement indicators used in a particular balance mathematical model; the matrix $A(t)$ is uniquely determined by the vectors $N(t,t+1)$ and $P(t)$.

Now we formulate problem (7)–(9): it is required to find a vector $P(t)$ satisfying equation (9) and inequalities (7) and (8).

The balance mathematical model (7)–(9) contains $(2n + 1)$ labor market indicators and $(n^2 + 5n + 1)$ or $(2n^2 + 4n + 1)$ inter-sectoral movement indicators (in the nominal or specified version, respectively) Therefore, problem (7)–(9) is ill-posed. The method for solving this problem was considered earlier; see [28].

2. FORECASTING LABOR MARKET INDICATORS BASED ON GENERAL INTRA-SECTORAL TRENDS

The forecasting problem of labor market indicators consists in calculating the values $N_j^{(i_j)}(t_0+k+1)$ by the known values $N_j^{(i_j)}(t)$, where $t=\overline{t_0,\ t_0+k}$, $j = 1, 2, i_1=\overline{1,n}$, and $i_2=\overline{0,n}$. Here, $[t_0, t_0+k]$ is the forecast base period, and $(k + 1)$ is the length of the forecast base period.

2.1. Approaches to Forecasting Labor Market Indicators

Consider the following approaches to forecasting:

1) directly by indicators: the value $N_j^{(i_j)}(t_0+k+1)$ of each indicator is calculated from its values by selecting and extrapolating its trend over the forecast base period; for an indicator, the selected

trend ensures the best-quality forecast in year (t_0+k) from the values of this indicator in years $t=\overline{t_0, t_0+k-1}$, where $j = 1, 2$, $i_1=\overline{1, n}$, and $i_2=\overline{0, n}$;

2) based on the nominal balance mathematical model (7)–(9) of inter-sectoral flows ($P_4^{(k_1,k_2)}(t)=0$, $k_1, k_2=\overline{1, n}$, $k_1 \neq k_2$);

3) based on the specified balance mathematical model (7)–(9).

The forecasting approaches proposed in [26] use the balance mathematical model and are based on determining the trend of each inter-sectoral movement indicator regardless of the trends of the other indicators. In this paper, the approaches also involve the balance mathematical model but are based on selecting the groups of inter-sectoral movement indicators that may have general trends.

These approaches are implemented by the following scheme.

1. The preliminary data acquisition stage. For $t=\overline{t_0, t_0+k-1}$, the k problems (7)–(9) are solved to obtain the vectors $P(t)$, $t=\overline{t_0,\ t_0+k-1}$.

2. The verification stage. For each inter-sectoral movement indicator, the optimal trend is selected from N predetermined ones.

The trend selection criterion. In the case of common intra-sectoral trends, for a group of inter-sectoral movement indicators specifying the indicator $N_j^{(i_j)}(t)$, the selected trend K ensures the smallest deviation of the forecast $N_{j,\text{frc}}^{(i_j)}(t_0+k)$ from the factual value $N_j^{(i_j)}(t_0+k)$, $t=\overline{t_0, t_0+k-1}$, j = 1, 2, $i_1=\overline{1, n}$, $i_2=\overline{0, n}$. The forecast $N_{j,\text{frc}}^{(i_j)}(t_0+k)$ is calculated from the following values:

– the corresponding component of the vector $N_{\text{frc}}(t_0+k-1,\ t_0+k)=A(t_0+k-1)\,P_{\text{frc}}(t_0+k-1)$, where the vector $P_{\text{frc}}(t_0+k-1)$ is obtained by extrapolating the vectors $P(t)$, $t=\overline{t_0, t_0+k-2}$, using trend K;

– $N_j^{(i_j)}(t_0+k-1)$.

In general, different trends may be selected for the same inter-sectoral movement indicators when forecasting different labor market indicators.

The verification stage is formally written as follows.

2.1. The vector $P_{\text{frc}}^{(i)}(t_0+k-1)$, $i=\overline{1, N}$, is calculated using trend I by extrapolating the time series formed by the components of the vectors $P(t)$, $t=\overline{t_0, t_0+k-2}$.

2.2. Different forecasts of labor market indicators in year (t_0+k) are determined based on the calculated vectors $P_{\text{frc}}^{(i)}(t_0+k-1)$, $i=\overline{1, N}$, by formula (9):

$$N_{\text{frc}}^{(i)}(t_0+k-1, t_0+k)=A(t_0+k-1)\cdot P_{\text{frc}}^{(i)}(t_0+k-1).$$

2.3. For each labor market indicator, a function $\alpha:\{1,..., 2n+1\}\to\{1,\ldots,\ N\}$ is defined to assign a trend extrapolating inter-sectoral movement indicators with the best forecasting quality of this indicator. In this case, for $i\in\{1,\ldots, 2n+1\}$,

$$\alpha(i)=K_i \Leftrightarrow \Big\| S_i\Big(N(t_0+k-1,\ t_0+k) - N_{\text{frc}}^{(K_i)}(t_0+k-1,\ t_0+k)\Big)\Big\|_{2,2n+1} \le \Big\| S_i\Big(N(t_0+k-1,\ t_0+k) - N_{\text{frc}}^{(j)}(t_0+k-1, t_0+k)\Big)\Big\|_{2,2n+1},$$

$$\forall j\in\{1,\ldots, N\},$$

where $\|\cdot\|_{2,2n+1}$ denotes the Euclidean norm in the space $\mathbb{R}^{2n+1}$; the matrix S_i has the block form

$$S_i=\begin{pmatrix} \Theta_{i-1,i-1} & \Theta_{i-1,1} & \Theta_{i-1,2n+1-i} \\ \Theta_{1,i-1} & 1 & \Theta_{1,2n+1-i} \\ \Theta_{2n+1-i,i-1} & \Theta_{2n+1-i,1} & \Theta_{2n+1-i,2n+1-i} \end{pmatrix},$$

where Θ_{i_1,i_2} is a zero matrix of dimensions $i_1\times i_2$. Then the ith component of the vector $H=S_i\Big(N(t,\ t+1)-N_{\text{frc}}^{(K_i)}(t,\ t+1)\Big)$ equals the ith component of the difference $\Big(N(t,\ t+1)- N_{\text{frc}}^{(K_i)}(t,\ t+1)\Big)$, and the other components of the vector H are zeros.

Thus, the labor market indicators are associated with the trend of inter-sectoral movement indicators that specify them. The verification results are used further.

3. The forecasting stage. Each labor market indicator is forecasted using the vectors of extrapolated inter-sectoral movement indicators. For each labor market indicator, inter-sectoral movement indicators are

extrapolated by the trend assigned to this indicator at the previous stage of the algorithm.

The forecasting stage is formally written as follows.

3.1. The vector $P_{\text{frc}}^{(i)}(t_0+k)$, $i=\overline{1, N}$, is calculated using trend i by extrapolating the components of the vectors $P(t)$, $t=\overline{t_0, t_0+k-1}$.

3.2. The forecast vector of labor market indicators is determined using the function $\alpha(i)$:

$$N_{\text{frc}}(t_0+k,\ t_0+k+1) = \sum_{i=1}^{2n+1} S_i\, A(t_0+k)\, P_{\text{frc}}^{(\alpha(i))}(t_0+k). \tag{13}$$

3.3. Labor market indicators are forecasted by formulas (11) and (12) from the expressions (10) and (13):

$$N_j^{(i)}(t_0+k+1) = \left(N_{\text{frc}}(t_0+k,\ t_0+k+1)\right)_{i+(j-1)n} + N_j^{(i)}(t_0+k),\ i=\overline{1,n},\ j=1, 2, \tag{14}$$

$$N_2^{(0)}(t_0+k+1) = \left(N_{\text{frc}}(t_0+k,\ t_0+k+1)\right)_{2n+1} + N_2^{(0)}(t_0+k) + \Delta N_{2,\text{frc}}^{(0)}(t_0+k), \tag{15}$$

where $\left(N_{\text{frc}}(t_0+k,\ t_0+k+1)\right)_i$ is the ith component of the vector $N_{\text{frc}}(t_0+k,\ t_0+k+1)$; $\Delta N_{2,\text{frc}}^{(0)}(t_0+k)$ is the inflow of labor resources to the market during year (t_0+k+1), which can be calculated by extrapolating the values $\Delta N_2^{(0)}(t)\ t=\overline{t_0,\ t_0+k-1}$. (According to the paper [28], the forecast of sectoral employment indicators is stable to the deviations of the value $\Delta N_{2,\text{frc}}^{(0)}(t_0+k)$ from $\Delta N_2^{(0)}(t_0+k)$.)

This scheme yields the forecasts of sectoral employment and unemployment indicators based on their values for the forecast basis period. Moreover, it considers the trends of inter-sectoral movement indicators in the labor market.

2.2. Validation of the Forecasting Scheme on the Statistical Data of the Labor Market of the Russian Federation in 2006–2016

According to the All-Russian Classifier of Types of Economic Activity (OKVED-1), which was in effect until 2017, the labor market of the Russian Federation consisted of twelve consolidated sectors: no. 1—agriculture, forestry, hunting, fishing, and fish farming; no. 2—mining; no. 3—manufacturing industries; no. 4—production and distribution of electricity, gas, and water; no. 5—construction; no. 6—wholesale and retail trade, repair of motor vehicles, motorcycles, household goods, and personal items, and hotels and restaurants; no. 7—transport and communication; no. 8—finance, real estate transactions, renting, and provision of services; no. 9—public administration, military security, and social welfare; no. 10—education; no. 11—health and social services; no. 12—other economic activities.

Using the Rosstat data [29], we calculate the forecasts of sectoral employment indicators for the labor market of the Russian Federation for 2011–2016 from the values of the labor market indicators in 2006–2015. Let the forecast base period be five years.

In this paper, we consider constant, linear, and nonlinear trends as possible trends of the time series of indicators [27]. According to empirical evidence, the trend $f(t)=c_1+c_3\sqrt{t}+c_2t$ on average provides a better extrapolation quality for the inter-sectoral movement indicators of the labor market of the Russian Federation in 2006–2011 compared to quadratic, logarithmic, power, and exponential trends. Therefore, we use the nonlinear trend $f(t)$ in the forecasting scheme.

The forecasting results are presented in a reliability table (Table 1): in this paper, a forecast is considered unreliable if and only if the forecasting error exceeds 2%. Unreliable forecasts are indicated by 1 whereas reliable ones by 0. The rows of this table correspond to the number of the labor market sector in OKVED-1 whereas the columns to the number of the forecasting approach used (see the beginning of subsection 2.1).

Thus, the forecasting approaches directly by labor market indicators, based on the nominal balance mathematical model, and based on the specified balance mathematical model yielded 29, 25, and 28 unreliable forecasts, respectively.

For the labor market under consideration, when for each inter-sectoral movement indicator the trend was determined independently from the trends of other indicators [26], the reliability of forecasting based on the nominal balance mathematical model and the specified balance mathematical model was characterized by 13 and 11 unreliable forecasts, respectively. Obviously, these figures excel the reliability results for the case of general intra-sectoral trends based on the corresponding balance mathematical models (25 and 28 unreliable forecasts, respectively).

Table 1

The reliability of forecasts of the 12-sector employment structure indicators for the labor market of the Russian Federation in 2011–2016

Sector no.	2011			2012			2013			2014			2015			2016		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	1	1	1	1	0	1	0	0	0	0	0	0	1	1	0	0	0	1
2	0	0	0	0	1	0	1	1	1	1	1	1	0	0	0	1	0	0
3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0
5	0	0	0	1	1	1	1	1	1	1	0	1	0	0	1	0	0	0
6	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
7	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	1
9	1	1	1	0	1	1	0	0	0	0	0	0	1	1	0	1	0	0
10	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0
11	0	0	0	1	0	1	1	1	1	0	1	1	0	0	0	1	0	0
12	0	1	0	1	0	0	1	1	1	1	0	1	0	1	1	1	1	0
Σ	**7**	**4**	**4**	**5**	**5**	**7**	**5**	**8**	**6**	**4**	**3**	**5**	**2**	**4**	**4**	**6**	**1**	**2**

2.3. Forecasting the Sectoral Employment of the Labor Market of the Russian Federation at the End of 2022

Since 2017, according to the OKVED-2 classifier, the labor market of the Russian Federation contains 20 sectors (excluding the activities of extraterritorial organizations): no. 1—agriculture, forestry, hunting, fishing, and fish farming; no. 2—mining; no. 3—manufacturing industries; no. 4—provision of electricity, gas, and steam, air conditioning; no. 5—water supply, water disposal, organization of waste collection and utilization, and pollution elimination; no. 6—construction; no. 7—wholesale and retail trade, repair of motor vehicles and motorcycles; no. 8—transportation and storage; no. 9—hotels and catering; no. 10—information and communication; no. 11—finance and insurance; no. 12—real estate transactions; no. 13—professional, scientific, and technological activities (excluding research and development); no. 14—research and development; no. 15—administrative activities and related additional services; no. 16—public administration, military security, and social welfare; no. 17—education; no. 18—health and social services; no. 19—culture, sports, leisure, and entertainment activities; no. 20—other services.

We apply the approaches of subsection 2.1 to forecast the sectoral structure indicators of the labor market in 2022 using a forecast base period of 2017–2021. Table 2 combines the resulting forecasts yielded by different approaches: column 1—directly by indicators, column 2—based on the nominal balance mathematical model, and column 3—based on the specified balance mathematical model.

Table 2

Sectoral employment forecasts for the labor market of the Russian Federation at the end of 2022, in thousand people

Sector no.	Forecasting approaches		
	1	2	3
1	4 490.60	4 415.15	4 525.81
2	1 164.18	1 128.94	1 141.79
3	9 974.40	10 199.10	10 007.60
4	1 583.00	1 551.72	1 571.58
5	708.80	692.27	693.90
6	6 392.16	6 780.43	6 523.50
7	13 236.30	13 677.49	13 176.74
8	5 672.68	5 786.95	5 755.62
9	1 840.48	1 878.01	1 836.16
10	1 592.43	1 583.03	1 613.71
11	1 263.18	1 257.77	1 242.46
12	1 899.50	1 943.15	1 866.99
13	1 942.30	2 053.27	1 939.61
14	753.04	733.95	755.70
15	2 036.12	2 073.33	2 077.08
16	3 638.20	3 606.33	3 633.87
17	5 320.70	5 279.67	5 259.30
18	4 483.72	4 463.71	4 417.04
19	1 144.80	1 137.59	1 138.65
20	1 583.60	1 571.87	1 562.26
Σ	**70 720.19**	**71 813.71**	**70 739.36**

According to Table 2, the highest absolute value of the difference between the forecasts of employed persons for one sector using different approaches is

500.76 thousand people (sector 7; approaches 2 and 3); the highest value of the difference relative to the average forecast is 5.91 % (sector 6; approaches 1 and 2). Thus, for the forecasting approaches based on the criterion of selecting general intra-sectoral trends of inter-sectoral movement indicators (and labor market indicators), it remains topical to assign an appropriate employment forecasting approach for each sector.

According to the theory of prognostics, a qualitative forecast of labor market indicators is obtained using their values for a forecast base period and the factors formalizing the expected external impact on labor market dynamics during the forecasting period [30, 31]. Such external impacts include managerial decisions with a significant effect on the sectoral structure dynamics of a labor market.

3. CONTROL OF THE SECTORAL STRUCTURE DYNAMICS OF A LABOR MARKET

The effect of a control action is any transformations in the components of the vector of inter-sectoral movement indicators of labor resources due to this control action. *The result of a control action* is any changes in labor market indicators.

The forecasting scheme based on the balance mathematical model (7)–(9) yields sectoral employment forecasts of higher reliability compared to those obtained directly by the sectoral structure indicators of a labor market; for details, see subsection 2.2. In addition, this scheme is modifiable: some versions of the scheme allow reducing twofold the number of unreliable forecasts on particular examples.

In this regard, the proposed scheme can also increase the forecasting accuracy for the impact of control actions. Section 3 describes an approach that incorporates the control of the sectoral structure dynamics of a labor market into the forecasting scheme of labor market indicators.

3.1. Transformation of Inter-Sectoral Movement Indicators under Control Actions

We introduce the following variables to determine transformations in inter-sectoral movement indicators under control actions on the sectoral structure dynamics of a labor market: $P_1^{(i,n+2)}(t)$ is the probability that during year $(t + 1)$ a person will not change its state $S_2^{(i)}$ observed at the end of year t (an unemployed person with the last place of work in sector i will remain unemployed); $P_4^{(i,i)}(t)$ is the probability that during year $(t + 1)$ a person will not change its state $S_1^{(i)}$ observed at the end of year t (an employee in sector i will remain employed in this sector). To generalize the transformations, we define additional variables: $P_1^{(n+i,j)}(t) \overset{\text{def}}{=} P_4^{(i,j)}(t)$, $P_1^{(n+i,n+1)}(t) \overset{\text{def}}{=} P_3^{(i)}(t)$, and $P_1^{(n+i,n+2)}(t) \overset{\text{def}}{=} P_2^{(i)}(t)$, where $i,\ j=\overline{1,\ n}$. Due to formulas (7) and (8),

$$P_1^{(i,j)}(t) \geq 0, \quad j=\overline{1,\, n+2},$$
$$\sum_{k=1}^{n+2} P_1^{(i,k)}(t)=1, \quad i=\overline{0,\, 2n}. \tag{16}$$

The variables of each equation in (16), $(2n + 1)$ equations in total, are the probabilities of events forming a complete group. The probabilities in equation i will be called the indicators of group i. Note that the indicators of group i characterize output flows from the segment of unemployed persons with the last place of work in sector i ($i \leq n$) or output flows from the segment of employed persons from sector $(i - n)$, where $i > n$. The sector number to which a particular output flow of labor resources is directed will be called the number of the corresponding indicator of group i. (Therefore, $P_1^{(i,j)}(t)$, $i=\overline{0,\, 2n}$, $j=\overline{1, n+2}$, is indicator j of group i.)

Let the effect of a control action be the expected variation of m_1 inter-sectoral movement indicators of group i with numbers i_j by $100\left(k_{i_j}-1\right)$%, where k_{i_j} is the variation coefficient of the indicator of group i with number i_j, $j=\overline{1,\, m_1}$, and $1 \leq m_1 \leq n+2$. For $\sum_{j \in L_1} k_j P_1^{(i,j)}(t) \leq 1$, $k_j \geq 0$, $j \in L_1$, where $L_1=\left\{i_j \,\middle|\, j=\overline{1,\, m_1}\right\}$, the transformed indicators of group i with given expected variations due to the control action are determined by

$$\dot{P}_1^{(i,j)}(t)=k_j P_1^{(i,j)}(t), \quad j \in L_1. \tag{17}$$

The non-zero values of the indicators of group i whose expected variations due to the control action are not specified can be determined from the condition

$$\frac{\dot{P}_1^{(i,j_1)}(t)}{\dot{P}_1^{(i,j_2)}(t)}=\frac{P_1^{(i,j_1)}(t)}{P_1^{(i,j_2)}(t)}, \quad j_1,\ j_2 \in L, \tag{18}$$

where $L=\{1,\, 2, \ldots,\, n+2\} \setminus \left(L_1 \cup L_2\right)$, and the set L_2 consists of the numbers of zero-valued indicators of group i. (Condition (18) expresses the equal ratios of the transformed and transformable values of the indicators.)

From formulas (17) and (18) we obtain the values of all transformed indicators of group i:

$$\dot{P}_1^{(i,j)}(t)=\begin{cases}0, & j\in L_2,\\ \dfrac{\left(1-\sum\limits_{j\in L_1}k_jP_1^{(i,j)}(t)\right)P_1^{(i,j)}(t)}{\sum\limits_{j\in L}P_1^{(i,j)}(t)}, & j\in L,\\ k_jP_1^{(i,j)}(t), & j\in L_1.\end{cases} \quad (19)$$

The linear operator R in the transformation (19) is uniquely defined by the following elements: number i (the group number of indicators); the set $M=\left\{(j,k_j)\middle| j\in L_1\right\}$ (the numbers of indicators of group i with given expected variations and the corresponding variation coefficients of these indicators); the vector of inter-sectoral movement indicators $P(t)=\left(P_1^{(0,1)}(t),\ldots,P_1^{(0,n+2)}(t),\ldots,P_1^{(2n,1)}(t),\ldots,P_1^{(2n,n+2)}(t)\right)$. The operator R can be written in the matrix form

$$R=R(i,M,P(t))$$

$$=\operatorname{diag}\left(\underbrace{1,\ldots,1}_{(i-1)(n+2)},\ p_1,\ldots,\ p_{n+2},\ \underbrace{1,\ldots,1}_{(2n-i)(n+2)}\right),$$

where $p_j=\begin{cases}0, & P_1^{(i,j)}(t)=0\\ \dfrac{\dot{P}_1^{(i,j)}(t)}{P_1^{(i,j)}(t)}, & P_1^{(i,j)}(t)\neq 0.\end{cases}$

If the effect of a control action is an expected variation in the values of indicators of groups i_j, $j=\overline{1,m}$, the operator R specifying the transformation of the vector of inter-sectoral movement indicators is uniquely defined by the following elements: the group numbers of indicators, i_j, $j=\overline{1,m}$; the sets M_j (the numbers of indicators of groups i_j and the corresponding variation coefficients in groups i_j, $j=\overline{1,m}$; the vector $P(t)$. In this case, the operator has the form

$$R=\prod_{j=1}^{m}R(i_j,M_j,P(t)). \quad (20)$$

3.2. The Results of Control Actions

If a control action affects the forecast (13)–(15), then the linear operator R_i (20) must be defined for each $P_{\text{frc}}^{(i)}(t_0+k)$, $i=\overline{1,N}$, under fixed i_j and M_j, $j=\overline{1,m}$: $R_i=\prod_{j=1}^{m}R\left(i_j,M_j,P_{\text{frc}}^{(i)}(t_0+k)\right)$, $i=\overline{1,N}$. (Here, N is the number of trends under consideration.) In this case, the result of a control action (the forecast of sectoral employment indicators) can be calculated by formula (14) from the forecasting vector of labor market indicators

$$N_{\text{frc}}(t_0+k,\ t_0+k+1)$$
$$=\sum_{i=1}^{2n+1}S_i\,A(t_0+k)R_{\alpha(i)}\,P_{\text{frc}}^{(\alpha(i))}(t_0+k). \quad (21)$$

In general, at the instant of implementing a control action, its effect is unambiguous. Each of L expected effects will be called a scenario. Then scenario l, $l=\overline{1,L}$, is determined by the linear operators $R_{l,i}=\prod_{j=1}^{m}R\left(i_{l,j},M_{l,j},P_{\text{frc}}^{(i)}(t_0+k)\right)$, $i=\overline{1,N}$, and the corresponding forecasting vector of labor market indicators $N_{\text{frc}_l}(t_0+k,t_0+k+1)$ (21). Hence, the vector $N_{\text{frc}}(t_0+k,t_0+k+1)$ can be defined as the weighted average of the values $N_{\text{frc}_l}(t_0+k,t_0+k+1)$ with weights ω_l, $l=\overline{1,L}$. Each weight ω_l can be interpreted either as the probability of scenario l, $l=\overline{1,L}$, or as the share of the effect corresponding to this scenario in the resulting impact of the control action.

3.3. The Impact of Control Actions on the Employment Forecast in the Agricultural and Industrial Sectors of the Labor Market of the Russian Federation in 2022

As an example of control actions, we consider public investment in the agricultural and industrial sectors of the Russian Federation (the financing of higher education programs to train highly specialized employees and direct budget allocations to support sectoral enterprises) [32–34]. They are included in the first five sectors in the OKVED-2 classifier.

For this control action, we define five scenarios differentiated by the sectors of the Russian labor market with the effect of control during 2022: a twofold increase in the intensity of the inter-sectoral resource flow from the state $S_2^{(0)}$ to the state $S_1^{(j)}$ (an increase in the number of employees in sector j from the unemployed persons) and a twofold decrease in the intensity of the labor resource flow from the state $S_1^{(j)}$ to the state $S_2^{(j)}$ (a decrease of employees leaving the labor market), $l=\overline{1,5}$.

The results of these control actions are the changes in the sectoral employment forecasts at the end of 2022 based on the specified balance mathematical model (see subsection 2.3). For each scenario, they are determined by formula (21), where $t_0+k=2021$ and $P_{\text{frc}}^{(1)}(2021)$, $P_{\text{frc}}^{(2)}(2021)$ and $P_{\text{frc}}^{(3)}(2021)$ are the forecasting vectors obtained by the constant, linear, and nonlinear trends, respectively. For a particular scenario l, $l=\overline{1,5}$, and a particular trend i, $i=\overline{1,3}$, the linear operators $R_{l,i}$ (20) are given by

$$R_{l,i}=R\left(0, M_{l,1}, P_{\text{frc}}^{(i)}(2021)\right)$$
$$\times R\left(n+l, M_{l,2}, P_{\text{frc}}^{(i)}(2021)\right), l=\overline{1,5}, \quad i=\overline{1,3},$$

where $M_{l,1}=\left\{\left(l,\tilde{k}\right)\right\}$, $M_{l,2}=\left\{\left(n+2,1/\tilde{k}\right)\right\}$, $\tilde{k}=2$, and n = 20 is the number of market sectors.

For the given operators $R_{l,i}$, $i=\overline{1,3}$, we calculate $N_{\text{frc}_l}(2021, 2022)$, $l=\overline{1,5}$. Each of these values is the forecasting vector of labor market indicators for 2022 with the effect of control actions in scenario l. Table 3 presents the sectoral employment forecasts in different scenarios l, calculated by formula (14) using the values $N_{\text{frc}_l}(2021, 2022)$, $l=\overline{1,5}$.

According to Table 3, for scenario l, the forecasted number of employed persons changes significantly only in sector l, $l=\overline{1,5}$. The weights of the geometric mean (the resulting impact of control actions; see subsection 3.2) of the sectoral employment forecasts in each scenario may differ. For the agrarian sector (included in sector 1), the impact of public investment on sectoral employment dynamics is ambiguous [34]: an increase in the number of highly qualified specialists attracted to the sector is compensated by a decrease in the total number of employees due to digital transformation and changes in technological structures [35]. The same digital transformation processes can contribute to a smoother development of sectors in the industrial sector [36]. In accordance with these studies, for test calculations, let scenario 1 be considered impossible and the weights of the other scenarios be equal to each other. Then the analysis of the resulting

Table 3

Sectoral employment forecasts for the Russian labor market at the end of 2022 (thousand people), based on the specified balance mathematical model in different scenarios (the effects of control actions)

Sector no.	Scenario l				
	1	2	3	4	5
1	4 666.44	4 519.90	4 516.47	4 520.14	4 523.12
2	1 138.90	1 226.71	1 136.18	1 138.31	1 140.15
3	10 051.24	10 039.97	10 543.40	10 041.78	10 058.18
4	1 575.46	1 574.99	1 573.76	1 672.87	1 577.56
5	693.63	694.14	693.00	694.16	733.93
6	6 516.41	6 512.62	6 508.91	6 513.49	6 519.01
7	13 161.80	13 148.77	13 143.83	13 151.78	13 166.03
8	5 780.17	5 773.82	5 766.45	5 774.85	5 783.99
9	1 832.88	1 832.56	1 830.03	1 832.64	1 834.44
10	1 615.62	1 615.19	1 611.62	1 615.11	1 617.03
11	1 246.00	1 245.13	1 241.79	1 245.16	1 247.40
12	1 863.43	1 862.64	1 860.15	1 862.82	1 865.01
13	1 936.15	1 935.61	1 933.06	1 935.74	1 937.75
14	755.91	756.33	755.13	756.41	757.25
15	2 081.83	2 081.23	2 079.79	2 081.84	2 084.33
16	3 647.07	3 644.00	3 643.66	3 645.53	3 650.08
17	5 287.04	5 279.88	5 271.08	5 281.02	5 291.53
18	4 440.84	4 434.70	4 426.83	4 435.66	4 444.80
19	1 136.00	1 135.70	1 133.69	1 135.77	1 137.25
20	1 559.94	1 560.62	1 557.57	1 560.33	1 560.97
Σ	**70 986.76**	**70 874.49**	**71 226.40**	**70 895.40**	**70 929.81**

forecasted impact of the control action under consideration leads to the following conclusions. Compared to the sectoral employment forecast (see subsection 2.3), it is expected to obtain:

• a significant increase in the number of employees in sector 2 (by 18.5 thousand people), sector 3 (by 163 thousand people, to the level of 2017), sector 4 (by 28 thousand people, to the level of 2019), sector 8 (by 19 thousand people, to the level of 2019) and sector 17 (by 21.5 thousand people, including employment forecasts in other sectors not directly affected in the scenarios), and sector 17 (by 21.5 thousand people);

• a decrease in the number of employees in sector 1 (by 6 thousand people), sector 6 (by 10 thousand people), sector 7 (by 24 thousand people), and sector 12 (by 4.5 thousand people).

CONCLUSIONS

This paper has presented and validated an approach to considering control actions on the labor market when forecasting sectoral employment indicators. This approach is efficient due to the reliability of its components: the balance mathematical model of the sectoral structure dynamics of a labor market and the forecasting scheme of labor market indicators based on this model.

For the labor market of the Russian Federation in 2011–2016, the dynamics of sectoral employment indicators have been forecasted with a better quality in the case of independent trends of inter-sectoral movement indicators compared to the case when the types of trends of inter-sectoral movement indicators specifying the same labor market indicator are considered to be identical (general intra-sectoral trends). Nevertheless, general intra-sectoral trends can be used in the forecasting scheme of labor market indicators to test the hypothesis that several factors segmenting a particular market indicator have the same trend.

The forecasting scheme based on general intra-sectoral trends has shown the same reliability as the forecasting approach directly by labor market indicators; for several observations (2011 and 2016), the proposed scheme provides significantly higher reliability of forecasting. Hence, in a group of cases, application of the forecasting approach considered above seems preferable. Formalizing this group, as well as assessing the efficiency of the proposed forecasting scheme in this group, is the objective of further research.

The forecasting scheme-based approach to determining the results of control actions on the sectoral structure dynamics of a labor market has been validated in the case where the effect of control actions is the expected variation of inter-sectoral movement indicators. An example of the labor market of the Russian Federation in 2017–2022 has been provided to demonstrate the impact of given control actions in agricultural and industrial sectors on the overall sectoral employment forecast at the end of 2022.

Thus, the forecasting scheme based on the balance mathematical model and the approach to considering control actions (with a given expected impact on the inter-sectoral mobility of labor resources during the forecasting period) form a forecasting methodology for the results of managerial decisions on the sectoral structure dynamics of a labor market. This methodology can be applied to assess the efficiency and risks of management at a preliminary phase. Moreover, this methodology can be generalized for arbitrary multi-sectoral economic systems with control actions in the form of changes in the intensities of inter-sectoral flows.

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