Trajectories of Regions Economic Complexity Estimates

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Abstract: Analytical estimates of the impact of the development of a sector or type of economic activity to a strong level on the structures of regional economies have been obtained. The trajectories of assessments of the economic complexity of the regions are based on two approaches: 1) the choice of such a sector or type of economic activity for development to a strong level that ensures maximum growth of the economic complexity of the region; 2) the choice of such a sector or type of economic activity for development to a strong level, which has the maximum assessment of economic complexity. The analysis of the trajectories of assessments of the economic complexity of regions can be useful in solving management tasks aimed at increasing the economic complexity of the region, as it allows us to assess the mutual impact of changes in the structures of strong sectors of regional economies.

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1 INTRODUCTION

In the paper (Afanasiev, 2023) author used estimates of the economic complexity of regional economies obtained on the basis of data on production volumes by sector. In the further modification of the approach to assessing the economic complexity of regions, indicators of industrial production by types of economic activity (TEA) are used: the volume of shipped goods of own production, work performed and services performed for four enlarged types of economic activity, as well as the structure of the volume of shipped products for each enlarged TEA.

Description of the structure of the regional economy according to TEA. To describe the structure of the regional economy, data on the volume of shipped products by TEA were used. First, let's determine the indicator RCA_{cp} relative competitive advantage:

$$RCA_{kj} = (y_{kj}/\sum_j y_{kj}) \,/\, (\sum_k y_{kj}/\sum_{kj} y_{kj}), \quad (1)$$

where is y_{kj}— production volume by TEA j of the region's economy k; RCA_{kj}— the ratio of the share of TEA production j in the total production volume of the entire TEA economy of the region to the share of k TEA production j of all regions in the production volume of all TEA economies of all regions. In accordance with the work (Hausmann, Klinger, 2006), the indicator RCA_{kj} for which the condition of the constraint type from below is checked. Namely, if the value of RCA_{kj} exceeds one, then the region's economy is considered to have a relative comparative advantage in k TEA output j; otherwise — there is no relative competitive advantage:

$$a_{kj} = \begin{cases} 1, & if\ RCA_{kj} \geq 1; \\ 0, & if\ RCA_{kj} < 1. \end{cases}$$

Matrix $A = (a_{kj})$ contains data on TEAs, which are developed in different regions at the level of relative competitive advantages determined using the expression (1). The rows of this matrix correspond to regions, the columns — TEA. Vector $(a_{kj_1}, \cdots, a_{kj_m})$ we will call the *structure of the strong* TEA economy of the region. k

Economic complexity. The concept of "***economic complexity of a region***" is considered as a characteristic that reflects the level of its technological development, which is determined by strong TEAs in the structure of its economy. Similarly, the economic complexity of a TEA depends on the level of technological development of those regions in the structure of which this TEA is present as a strong one. Economic complexity assessments (ECAs) have the following properties (Hidalgo, Hausmann, 2009; Afanasiev, Kudrov, 2021). The economic complexity of a region is proportional to the average level of economic complexity of strong TEAs in the structure of its economy:

$$ECI_k = a_1 \sum_j r_{kj} ECI_j,$$
$$r_{kj} = a_{kj}/q_{k,0},$$
$$q_{k0} = \sum_j a_{kj}, \quad (2)$$

where is a_1 — positive constant.

The economic complexity of TEA is proportional to the average level of economic complexity of the regions in the structure of the economies of which this TEA is strong:

$$ECI_j = a_2 \sum_k r^*_{jk} ECI_k,$$
$$r^*_{jk} = a_{kj}/q_{j0},$$
$$q_{j0} = \sum_k a_{kj}, \quad (3)$$

where is a_2 — positive constant. Let $\boldsymbol{c} = (ECI_{k_1}, ECI_{k_2}, \cdots)^T$ is a vector-column of ECA values for regions; $\boldsymbol{p} = (ECI_j, ECI_{j_2}, \cdots)^T$ — vector-column of ECA complexity values for types of economic activity; $\boldsymbol{R}_1 = (r_{kj})$, $\boldsymbol{R}_2 = (r^*_{jk})$ — weight matrices. From the ratios (2) and (3) it follows that $c = a_1 a_2 \boldsymbol{R}_1 \boldsymbol{R}_2 \boldsymbol{c}$, $\boldsymbol{p} = a_1 a_2 \boldsymbol{R}_2 \boldsymbol{R}_1 \boldsymbol{p}$. Thus, the ECA of the region is defined as the eigenvector of the matrix $\boldsymbol{R}_1\boldsymbol{R}_2$, and the ECA of TEA as the eigenvector of the matrix $\boldsymbol{R}_2\boldsymbol{R}_1$. Matrix $\boldsymbol{R}_1\boldsymbol{R}_2$ and $\boldsymbol{R}_2\boldsymbol{R}_1$ are stochastic: their elements are non-negative, and their sum by lines is equal to 1. Due to stochasticity, the matrix $\boldsymbol{R}_1\boldsymbol{R}_2$ has an eigenvalue equal to 1 and a corresponding eigenvector that consists of the same coordinates. In works (Hausmann, Rodrik, 2003; Sciarra et al., 2020), it is proposed to use the value of the eigenvector of matrices $\boldsymbol{R}_1\boldsymbol{R}_2$ as the values of the ECA regions and TEA, which correspond to the second maximum eigenvalue.

According to the Federal State Statistics Service, the volumes of shipped goods, work performed and services for 2019 were received for 24 types of economic activities. The ECAs of the regions based on TEA data are presented in the paper (Afanasiev, Gusev, 2023). Further, the approach to assessing the economic complexity of the regions based on data on production volumes by sectors of the economy described in the paper (Afanasiev, Kudrov, 2021) is also used.

The Economic Complexity Index measures the complexity of a region's production structure by combining information on the ***diversity of*** regional economies (the number of strong sectors, or TEAs) and ***the prevalence of*** strong sectors, or TEAs (the number of regions in which the sector or TEA is strong, i.e., produces at the level of relative competitive advantage).

2 METHODOLOGY

2.1 Analysis of the impact of the development of the sector or TEA to a strong level on the structures of regional economies

The estimates of economic complexity obtained according to the approach described above are relative. If, for example, for each pair «region *k* - sector *j*» or «region *k* – TEA *j*» production volumes y_{kj} will change proportionally, then the values RCA_{kj} and matrix elements of A that describe the regional structures of strong sectors, or strong TEAs, will not change. The ECA of regions will not change either.

Let's consider a more general case. Suppose that in region *k*, the output of sector (TEA) *j* increases by $\alpha_{kj} y_{kj}$. At the same time, for any other pairs of indices, production volumes do not change. Let's determine at what value the value of the α_{kj} sector (TEA) *j*, which was not previously strong in region *k*, will become strong.

Let's enter the notations: $U_j = \sum_k y_{kj} / \sum_{kj} y_{kj}$; $\beta_{kj} = y_{kj} / \sum_j y_{kj}$; $\gamma_{kj} = y_{kj} / \sum_k y_{kj}$; $\mu_{kj} = y_{kj} / \sum_{kj} y_{kj}$. Here is U_j — the sector's share of manufacturing (TEA) in the total output of regional economies; β_{kj} — the sector's output (TEA) as a share of the region's total economic output; γ_{kj} — the share of the sector's output (TEA) in the region's total output in regional economies; μ_{kj} — the sector's share of manufacturing (TEA) in the region's total output of regional economies.

Note that before the sector's output (TEA) increased by $\alpha_{kj} y_{kj}$, value $RCA_{kj} < 1$. In order to increase the sector's output (TEA) *by* $\alpha_{kj} y_{kj}$ It has become strong in the region *k*, value RCA_{kj} must be at least one, i.e. the inequality must be met:

$$\frac{\left(y_{kj} + \alpha_{kj} y_{kj}\right)\left(\sum_{kj} y_{kj} + \alpha_{kj} y_{kj}\right)}{\left(\sum_j y_{kj} + \alpha_{kj} y_{kj}\right)\left(\sum_k y_{kj} + \alpha_{kj} y_{kj}\right)} \geq 1.$$

From here we get the condition

$$\alpha_{kj} \geq \left(1 - RCA_{kj}\right) / \left[\left(1 - \gamma_{kj}\right)\left(1 - \beta_{kj}\right) - \left(1 - RCA_{kj}\right)\right]. \quad (4)$$

From the condition $RCA_{kj} < 1$ It follows that the right-hand side of inequality (4) is a positive value. If condition (4) is met, then *as a result of an increase in the output of sector* (TEA) *j by* $\alpha_{kj} y_{kj}$*, it is becoming strong in the region k.*

Let us assess how the development of sector (TEA) *j* to the level of strong in region *k* can affect the structure of strong sectors (TEAs) of this region. Let’s consider the sector (TEA) i $(i \neq j)$. Let's assume that this sector (TEA) was not strong in region *k*. With any positive inequality α_{kj}, there is an inequality, where in the right side there is a value RCA_{ki} before, and on the left , after the output of sector (TEA) *j* in region *k* increases by an amount $\alpha_{kj} y_{kj}$:

$$\frac{y_{ki}\left(\sum_{kj} y_{kj} + \alpha_{kj} y_{kj}\right)}{\left(\sum_j y_{kj} + \alpha_{kj} y_{kj}\right)\sum_k y_{ki}} < \frac{y_{ki}\sum_{kj} y_{kj}}{\sum_j y_{kj} \sum_k y_{ki}}.$$

If the sector (TEA) i $(i \neq j)$ was not strong in the region *k*, then as a result of sector (TEA) *j* becoming strong in region *k*, sector (TEA) *i* in region *k* will not become strong.

Suppose now that sector (TEA) *i* was strong in region *k*. Then $RCA_{ki} \geq 1.$ In order for the output of sector j to cease to be strong in region *k* after increasing the output of sector $\alpha_{kj} y_{kj}$ j by the amount (TEA) *i*, inequality must be met:

$$y_{ki}\left(\sum_{kj} y_{kj} + \alpha_{kj} y_{kj}\right) / \left[\left(\sum_j y_{kj} + \alpha_{kj} y_{kj}\right)\sum_k y_{ki}\right] < 1.$$

From here we get the condition:

$$\alpha_{kj} > \left(RCA_{ki} - 1\right) / \left[\left(1 - \gamma_{ki}\right)\beta_{kj}\right]. \quad (5)$$

Case $\gamma_{ki} = 1$ means that sector (TEA) *i* has a positive output only in region *k*. In this case, it would remain a strong sector (TEA), regardless of the change in the *j* sector's output (TEA). But there are no such cases in our data. If $\gamma_{ki} < 1$, then the right side of inequality (5) is a positive value. If the right side of inequality (4) is greater than the right side of inequality (5), then *when sector* (TEA) *j becomes strong in region k* sector (TEA), *i will cease to be strong in region k*.

Let us now assess how the development of the sector (TEA) *j* to the level of strong in the region *k* can affect the value of the element of the matrix of A the structure of strong sectors (TEA), corresponding to the sector (TEA) *j* in the region $s\ \ (s \neq k)$. Suppose that sector (TEA) *j* was not strong in region *s*. For any positive one α_{kj}, there is inequality:

$$\frac{y_{sj}(\sum_{kj} y_{kj} + \alpha_{kj} y_{kj})}{\sum_j y_{sj}(\sum_k y_{kj} + \alpha_{kj} y_{kj})} < \frac{y_{sj}\sum_{kj} y_{kj}}{\sum_j y_{sj}\sum_k y_{kj}}.$$

Therefore, if sector (TEA) *j* was not strong in the region $s\ \ (s \neq k)$, , then *when sector (TEA) j becomes strong in region k, sector (TEA) j in region s will not be strong*.

Suppose that sector (TEA) *j* was strong in region *s*. Then $RCA_{sj} \geq 1.$ after increasing the output of sector (TEA) *j* in region *k* by the amount of sector $\alpha_{kj} y_{kj}$ (TEA) *j* would cease to be strong in region *s*, inequality must be met:

$$y_{sj}(\sum_{kj} y_{kj} + \alpha_{kj} y_{kj}) / \left[\sum_j y_{sj}(\sum_k y_{kj} + \alpha_{kj} y_{kj})\right] < 1.$$

From here we get the condition:

$$\alpha_{kj} > \left(RCA_{sj} - 1\right) / \left[\left(1 - \beta_{sj}\right)\gamma_{kj}\right]. \qquad (6)$$

Case β_{sj} =1 means that in region *s*, only sector (TEA) *j* has a positive output. In such a case, it would remain a strong sector in region *s*, regardless of the change in the output of sector (TEA) *j* in region *k*. But there are no such cases in our data. If $\beta_{sj} < 1$, then the right side of inequality (6) is a positive value. If the right side of inequality (4) is greater than the right side of inequality (6), then *when sector* (TEA) *j becomes strong in region k, sector* (TEA) *j will cease to be strong in region s*.

Let's estimate how the development of sector (TEA) *j* to the level of strong in region *k* can affect the value of the element of the matrix of A the structure of strong sectors (TEA) corresponding to the sector (TEA) $i\ \ (i \neq j)$ in the region $s\ \ (s \neq k)$. Assume that sector (TEA) *i* was strong in region *s*. With any positive value of α_{kj} there is inequality:

$$\frac{y_{si}(\sum_{kj} y_{kj} + \alpha_{kj} y_{kj})}{\sum_j y_{sj}\sum_k y_{ki}} > \frac{y_{si}\sum_{kj} y_{kj}}{\sum_j y_{sj}\sum_k y_{ki}}.$$

Therefore, if sector (TEA) *i* was strong in region *s*, then *when sector (TEA) j becomes strong in region k, sector (TEA) i in region s will remain strong*.

If sector (TEA) *i* was not strong in region *s*, then $RCA_{si} < 1$. In order for the output of sector (TEA) *j* in region *k to* become strong in region $\alpha_{kj} y_{kj}$ s after increasing the output of sector (TEA) *j* by the *amount of* sector *(TEA) i*:

$$y_{si}(\sum_{kj} y_{kj} + \alpha_{kj} y_{kj}) / \left[\sum_j y_{sj}\sum_k y_{ki}\right] \geq 1.$$

From here we get the condition:

$$\alpha_{kj} \geq \left(1 - RCA_{si}\right) / \left(RCA_{si}\mu_{kj}\right). \qquad (7)$$

If the value of the right side of inequality (4) is greater than the value of the right side of inequality (7), then *when the sector* (TEA) *j will become strong in region k, and sector* (TEA) *i will be strong in region s*.

2.2 Modeling trajectories of ECA of regions

Of interest is how the ECA of complexity of regions changes when a new strong sector emerges in one of them. This issue is considered in the paper (Afanasiev, Gusev 2022) on the assumption that the emergence of a new strong sector does not lead to other changes in the structure of strong sectors of regional economies. Based on the analysis of ratios (2), this paper shows that the change in the ECA of a region with the emergence of a new strong sector in it mainly depends on the difference between the ECA of this sector and the average ECA of all existing strong sectors of the region. the higher the economic complexity of a sector, the higher the ECA of the region in which the sector becomes strong. Changes to the ECAs of other regions are also possible, as the sector difficulty estimates or TEAs (3) change. Taking into account the ratios (4-7), an important clarification can be made. *An increase in the output of one sector (TEA) in the economy of one region to the level of a strong one region may be accompanied by changes in the structure of strong sectors (TEAs) of other regions.*

These changes can also have an impact on estimates of the economic complexity of regions and sectors.

In order for the ECA to be considered as a guide for choosing areas of diversification, it is necessary that the trajectories of change in these assessments correctly reflect the actions of the region aimed at developing new strong sectors or TEAs in it. To do this, the development of new strong sectors or TEAs in a region, focused on increasing its economic complexity, must be accompanied by a relative increase in its TEA compared to the ECA of regions not focused on the development of new strong sectors.

Let us construct the trajectories of ECA of regions on the basis of a situational model (Klykov, 1974; Pospelov, 1986) diversification of the structures of regional economies. For comparative analysis, we use data on both sectors of the economy and TEA. ECA we will calculate for all regions. For clarity, we will look at the figures, each of which shows the ECA trajectories of not all, but only a few regions.

A situation is simulated when one or more regions purposefully diversify the structure of strong sectors of their economy. Each of these regions, at the next stage of modeling, develops that new strong sector (TEA), the emergence of which leads to the maximum growth of the ECA of this region. At each step of computer modeling, such a sector is identified by enumerating all possible options. Other regions are not purposefully engaged in diversification. Their ECA trajectories are given for comparison. A point on the ECA trajectory of any region corresponds to the next step of diversification.

To simulate the trajectories of regional development, the authors developed a program in the Python programming language. The program allows you to obtain estimates of the economic complexity of regions in dynamics, going through various principles of choosing a sector (TEA) for development to a strong level. The standard time required to model one step of a region's development trajectory is approximately one minute. Thus, modeling the development of four regions in fifteen steps takes about an hour.

A Python program works roughly as follows. At the beginning and end of each step, there is a reassessment of the economic complexity of each region and sector (TEA). To make a decision on the best sector for development (TEA) in the region, each weak sector (TEA) is evaluated, if it becomes strong. Thus, for each region, a separate column of values for each sector (TEA) is obtained, reflecting how the economic complexity of the region will change with the development of the corresponding sector (TEA) to the level of strong. After that, there is a search for the highest value in this column and provided that this sector (TEA) is still weak, that is, it can be developed into a strong one, and it will maximize the economic complexity of its region. Then these sectors (TEAs) develop to strong ones.

3 RESULTS

Fig. 1 shows the trajectories of the ECA of 3 regions, estimated by sectors. The situation is considered when two regions - the Kursk region and the Vladimir region - purposefully diversify the economy. ***The emergence of a new strong sector in the region is modeled without taking into account the growth of output by the land value of 0 of the corresponding element of the matrix of the structure of strong sectors by 1 and does not affect the structure of strong sectors of other regional economies.*** At the initial stage of modeling, there are 22 strong sectors in the Kursk region. in the Vladimir region - 37, ECA of these regions are close. The Belgorod Region is not purposefully diversifying the economy. At the initial stage, estimates of its economic complexity are significantly higher than the estimates of the other two regions. At every step in the process of the emergence of new strong sectors, the ECA of the Kursk and Vladimir regions is growing. Estimates of the Belgorod Region change slightly as a result of changes in the ECA sectors. At the final stage, the assessment of the economic complexity of the Kursk region exceeds the assessment of the Belgorod region. The difference between the estimates of the Vladimir region and the Belgorod region is decreasing.

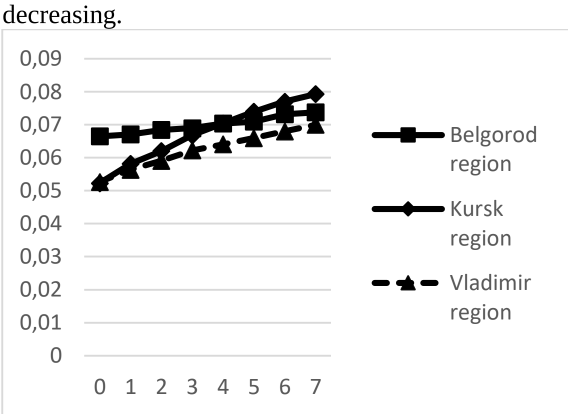

Figure 1: ECA trajectories based on sector data without taking into account output growth. Source: author's development of the program in Python.

Fig. 2 shows the trajectories of the ECA of 3 regions, also estimated based on sector data. The situation is considered when one of them, the Vladimir region, purposefully diversifies the economy. At the initial stage of modeling, there are 37 strong sectors in this region. At each stage of modeling, a new strong sector appears in the economy, which provides the maximum growth in the assessment of the economic complexity of the region. Economy. ***The emergence of a new strong sector in the Vladimir region is modeled taking into account the growth of the production volume of this sector to the level determined by condition (4).*** At the same time, at each step, RCA estimates for 79 regions are recalculated and the impact of each new strong sector in the Vladimir region on the structure of strong sectors of other regional economies is assessed. These changes, in turn, cause changes in the ECA of regions. The ECA of the Vladimir region increases significantly relative to the estimates of the economic complexity of the Belgorod and Kursk industries. The estimates of the Belgorod region change little as the complexity estimates of the sectors change. At step 4, the ECA of the Kursk region increases significantly due to the emergence of a new strong sector in its structure, caused by the diversification of the economy of the Vladimir region.

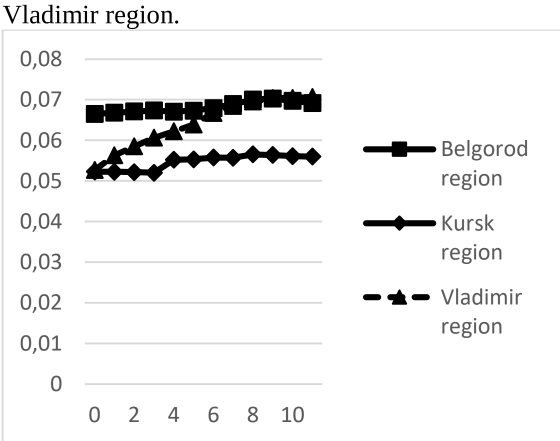

Figure 2: ECA trajectories from sector data given output growth.Source: author's development of the program in Python.

Fig. 3 shows the trajectories of ECA of complexity of 3 regions, estimated by sector. The situation is considered when two of them – the Kursk and Vladimir regions – purposefully diversify the economy. The emergence of a strong new sector in each of these regions is modelled on growth in output. At the initial stage, the ECA of these regions is lower than the ECA of the Belgorod region, which does not purposefully diversify the economy. The ECA of the Belgorod region changes slightly. At the final step, the ECA of the Belgorod Region is significantly lower than the ECA of the Kursk and Vladimir Regions. The trajectories of the ECA of each region are influenced by changes in the structures of strong sectors in other regions, occurring according to conditions (5-7).

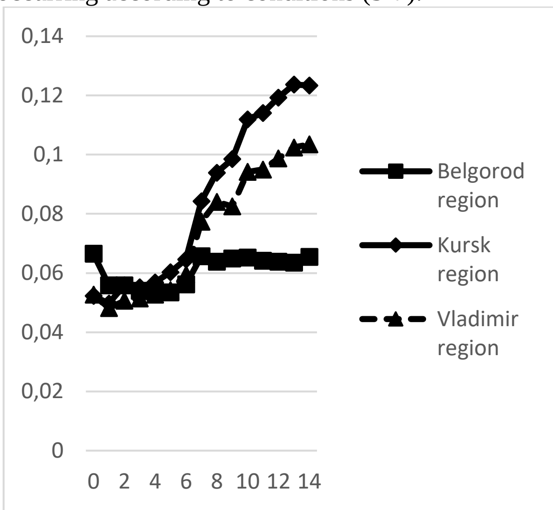

Figure 3: ECA trajectories based on sector data taking into account the growth of production Source: author's development of the program in Python.

Fig. 4 shows the trajectories of the ECA of 3 regions, estimated on the basis of TEA data. The situation is considered when one of them, the Kursk region, purposefully diversifies the economy. At the initial stage of modeling, there are 10 strong TEAs in this region. At each step in the economy, a new strong TEA appears, which provides the maximum growth in the assessment of the economic complexity of the region. The emergence of a new strong TEA in the Kursk region is modeled by the value of 0 of the corresponding element of the matrix of the structure of strong TEAs by 1 and does not affect the structure of strong TEAs in the regional economies of the Belgorod and Vladimir regions, which do not purposefully diversify the economy. The ECA of these two regions changes slightly due to changes in the ECA of TEAs caused by the diversification of the economy of the Kursk region. At the first steps, the ECA of the Kursk region increases significantly relative to the ECA of the Belgorod and Vladimir regions. After the 4th step, they decrease, as the new strong TEAs appearing in the structure of the economy of the Kursk region have relatively low ratings economic complexity. The ECA of the Belgorod region changes little compared to the ECA of the Vladimir region.

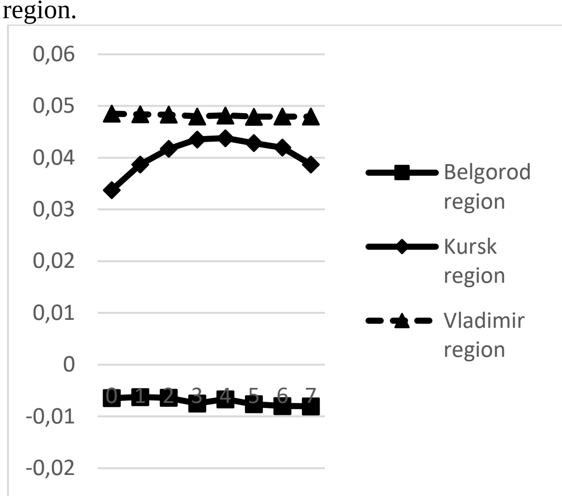

Figure 4: ECA trajectories of regions according to TEA data without taking into account the growth of production. Source: author's development of the program in Python.

In Fig. 5, the Kursk region and the Vladimir region purposefully diversify the economy, developing TEAs to the level of strong ones. At the initial stage of modeling, there are 10 strong TEAs in the Kursk Region, and 13 in the Vladimir region. The emergence of a new strong TEA is modeled based on the growth of the production volume of this TEA to the level determined by condition (4). The ECA of the Vladimir and Kursk regions is significantly increasing relative to the ECA of the Belgorod region. The ECA of the Belgorod region changes little as the ECA of types of economic activity changes. The trajectory of the ECA of each region is influenced by changes in the structures of strong TEAs of other regions, occurring according to conditions (5-7).

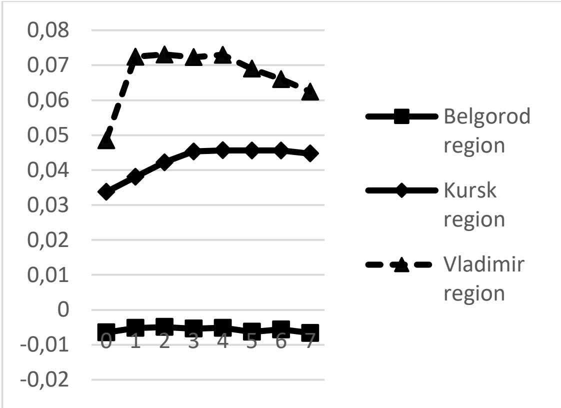

Figure 5: ECA trajectories of regions by TEA data given production growth. Source: author's development of the program in Python.

In the following example, the formation of the development trajectory of the structure of the regional economy is based on the choice of such a sector (TEA) in the region for development to the level of strength, which has the maximum assessment of economic complexity. Fig. 6 shows the trajectories of economic complexity of 3 regions, estimated by sectors. At every step in the economy, there is a new strong sector that has the highest ECA. In order for the sector to become strong, the growth of its production volume in the region is modeled in accordance with condition (4). The Vladimir and Voronezh regions are purposefully not diversifying the economy. However, at each step, the RCA and ECA scores for 79 regions are recalculated.

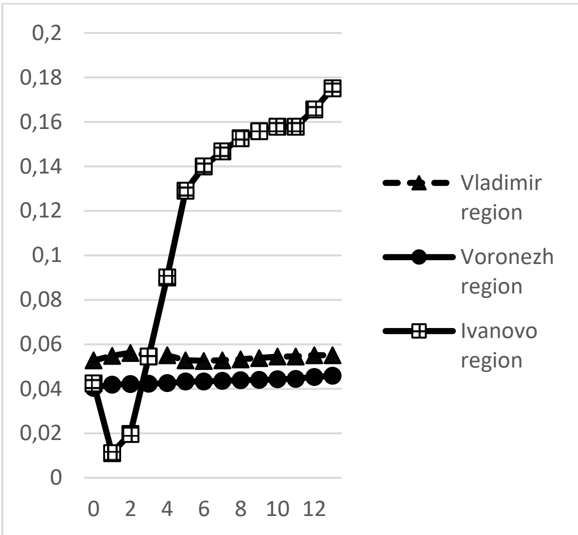

Figure 6: ECA trajectories from sector data given output growth. Source: author's development of the program in Python.

In Figure 6, the trajectory of the ECA of the Ivanovo region at step 1 does not increase, but decreases. This happens because when a new strong sector with the maximum ECA appears, two sectors cease to be strong in the economy of this region, since condition (5) is met for each of them. However, the next steps in the ECA trajectory are growing and significantly exceeds the ECA trajectories of regions that are not engaged in targeted diversification of their economies. ECAs of other regions change slightly.

4 DISCUSSIONS

Recommendations for diversifying the regional economy can be based on approaches that focus on increasing economic complexity. When forming the trajectories of development of the structure of the regional economy, two approaches are considered in this paper: 1) the choice of such a sector or TEA in the region for development to a strong level that ensures the maximum growth of the economic complexity of the region; 2) the selection of such a sector or TEA in the region for development to a level of strength that has the maximum assessment of economic complexity. The advantage of the first approach is that it forms a steady moderate growth of the ECA of a region. The advantage of the second approach is that it provides the possibility of achieving higher ECAs in the long run. The disadvantage of the approach is that in the short term, the ECA of a region can be significantly negatively affected by changes in the structure of its strong sectors or TEAs.

5 CONCLUSION

The analysis of the trajectories of ECA of regions, built on the basis of situational modeling, can be useful in solving management problems aimed at increasing the economic complexity of the region, as it allows you to assess the mutual impact of changes in the structures of strong sectors of regional economies. At the same time, the trajectories of the ECA of regions constructed by the two methods considered should be considered as an alternative for comparison with the trajectories obtained on the basis of expert selection of the sector or TEA for development to the strong level.

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