Regional socio-economic parameters modeling and system analysis by means of programming and computing suite

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Abstract. This paper presents a programming and computing suite which comprises regional socio-economic parameters database (gross regional product, physical capital, human capital and their investment volume), an analytical subsystem which renders mathematical models of parameters’ analysis and forecasting, as well as visual representation unit of modeling and forecasting results. In view of the results, a system research report is built, providing information on socio-economic condition of the region. The calculations are performed by the example of the Udmurt Republic.

1. Introduction

Ensuring regional socio-economic system development stability is a focal area of Russia’s policy. An operational research and regional economic condition estimation are necessary for the implementation of such a policy. Thereby, a need for socio-economic parameters forecasting arises. Socio-economic processes are quite difficult to model and estimate due to an element of uncertainty, whose presence is constant in the economy. For that reason, application of mathematical modeling methods and their parameters forecast is rather relevant nowadays. Implementation of these methods is set to be made current by using state-of-the-art IT solutions [1, 2]. In this vein, a programming and computing suite (PCS) was developed, which comprises the Udmurt Republic (UR) regional socio-economic parameters database and analytical subsystem, which provides a mathematical model analysis and socio-economic parameters forecast. PCS enables one to render an analytical report on current regional economic development condition, which is supplemented by visualization of modeling and forecasting results.

2. Materials and research methods

PCS implements a method for modeling and forecasting the dynamics of regional socio-economic parameters:

1) Physical capital (key assets which are supplemented via capital investments – investments in physical capital [3]):

\[ \frac{dK(t)}{dt} = I(t) - \eta K(t), K(t = t_0) = K_0, \]  

(1)
where \( K(t) \) represents physical capital at time \( t \); \( I(t) \) represents an investment in physical capital at time \( t \); \( \eta \) represents physical capital retirement rate; \( t_0 \) represents an initial instant of time.

2) Human capital (comprises education capital expressed in monetary value, health capital and culture capital, all of which are supplemented via investments in human capital [4]):

\[
\frac{dH(t)}{dt} = \bar{\varepsilon} J(t) - \chi H(t), \quad H(t = t_0) = H_0,
\]

where \( H(t) \) represents human capital at time \( t \); \( J(t) \) represents investments in human capital at time \( t \); \( \chi \) represents human capital depreciation rate; \( \bar{\varepsilon} \) represents average proportion of the population engaged into production.

3) Gross regional product [5]:

\[
Y(t) = A[K(t)]^\alpha [H(t)]^\beta,
\]

where \( Y(t) \) represents gross regional product at time \( t \); \( A, \alpha, \beta = const \) are the parameters being estimated.

Figure 1 represents the structure of «Regional socio-economic system parameters forecasting and modeling» PCS, which comprises three main units: database, analytical subsystem and output visualization unit. Database was built via «MS SQL Server» software program. It contains statistical data on economical parameters available at the Russian Federal Treasury official website and Russian statistics official websites. The database is integrated into PCS, providing an ability to add and change data and access statistical data necessary for calculations by means of SQL.

Subsequent PCS unit demonstrates an analytical subsystem which was developed by means of Microsoft Visual Studio IDE.

![Figure 1. «Regional socio-economic system parameters forecasting and modeling» PCS structure.](image-url)

Figure 1. «Regional socio-economic system parameters forecasting and modeling» PCS structure.

These are some main PCS-implemented socio-economic system parameters analysis and forecasting mathematical models:
- regression models;
- autoregressive models and moving-average models;
- models built by means of principal component analysis;
neural network models.

Statistical source database is split into training set $\Omega^{\text{learn}}$ and testing set $\Omega^{\text{test}}$ (retroprognosis plot) with a purpose of choosing an appropriate forecasting model.

The following indicators are used to estimate retroprognosis quality and choose the most suitable model for a short-term forecasting [6]:

- mean squared error:
  \[
  \sigma = \sqrt{\frac{\sum_{t=1}^{N^{\text{test}}}(y_t - \bar{y}_t^{\text{mod}})^2}{N^{\text{test}} - 1}}, \quad t \in \Omega^{\text{test}}; 
  \]  
  (4)

- correlation ratio of modeled parameter statistical and calculated value:
  \[
  r = \frac{\sum_{t=1}^{N^{\text{test}}}(y_t - \bar{y})(\bar{y}^{\text{mod}} - \bar{y}^{\text{mod}})}{N^{\text{test}} S_y S_{\bar{y}^{\text{mod}}}}, 
  \]  
  (5)

  where $S_y = \sqrt{\frac{\sum_{t=1}^{N^{\text{test}}}(y_t - \bar{y})^2}{N^{\text{test}} - 1}}$, $S_{\bar{y}^{\text{mod}}} = \sqrt{\frac{\sum_{t=1}^{N^{\text{test}}}(\bar{y}^{\text{mod}} - \bar{y}^{\text{mod}})^2}{N^{\text{test}} - 1}}$; $t \in \Omega^{\text{test}}$;

- average relative error:
  \[
  \bar{\delta} = \frac{1}{N^{\text{test}}} \sum_{t=1}^{N^{\text{test}}} \left| \frac{y_t - \bar{y}_t^{\text{mod}}}{y_t} \right| \cdot 100\%, \quad t \in \Omega^{\text{test}}. 
  \]  
  (6)

Here, $N^{\text{test}}$ represents $\Omega^{\text{test}}$ cardinality; $N^{\text{learn}}$ represents $\Omega^{\text{learn}}$ cardinality; $y_t^{\text{mod}}$ – series level value at time $t$, computed using the model; $\bar{y}^{\text{mod}}$ – series level average value, computed using the model.

PCS-implemented regression models, autoregressive models and moving-average models, as well as models built by means of principal component, are registered in [7]. Neural network modeling and forecasting methods are presented in [8].

3. Research results

Here are some regional socio-economic system parameter modeling and forecasting results as exemplified by the Udmurt Republic. Figures 2-4 represent results of modeling and forecasting physical capital dynamics, human capital and gross regional product respectively.

An analysis suggests that the Udmurt Republic physical capital declines. For its socio-economic system, assets’ retirement rate $\eta$ is 0.116.

An inverse trend prevails for the Udmurt Republic human capital, since a steady growth takes place. Human capital deprecation rate $\chi$ and average proportion of the population engaged into production $\bar{\varepsilon}$, which are estimated by means of statistical data, in the case of the Udmurt Republic economic system are 0.032 and 0.739 respectively.

The tendency towards physical capital decline (4.5% per year) concurrently with a human capital growth (5.0% per year) until year 2025 is expected.

Resource-production ratio of the Udmurt Republic is given by (see figure 5):
\[
Y(t) = 0.84[K(t)^{1.35}H(t)^{0.65}],
\]  
(7)
Herewith, a determination coefficient $R^2 = 0.84$, and a Fisher statistic $F = 67.3$.

**Figure 2.** Physical capital forecasting unit visualization.

**Figure 3.** Human capital forecasting unit visualization.
Figure 4. Gross regional product forecasting unit visualization.

Pravolzhsky Federal District gross regional product as of 2018

Figure 5. Resource-production ratio and statistical data \((k_H, y_H)\) UR.

\[ y_H(t) = \frac{Y(t)}{H(t)}, \quad k_H(t) = \frac{K(t)}{H(t)} \]

Coefficient \(A = 0.84\) is indicative of a regional economic system low technological advance. Physical capital \((\alpha = 0.35)\) and human capital \((\beta = 0.65)\) elasticity coefficient values suggest that increasing productive assets costs by 1% corresponds with an increase in output by 0.35%; and increasing human capital costs by 1% leads to an increase in output by 0.65%. Elasticity coefficients relation is \(\alpha/\beta = 0.54\), therefore, the Udmurt Republic economic system runs under a second input (human capital) deficit, while an extensional (fund-saving) growth takes place.
4. Conclusion
Therefore, a few regional socio-economic system parameters analysis and forecast methods were implemented by means of up-to-date information technologies. A «Regional socio-economic system parameters forecasting and modeling» programming and computing suite was developed, enabling us to estimate and forecast essential socio-economic parameters. PCS also enables us to render swift analytical report on regional economy condition and development, which is supplemented by visualizing modeling and forecasting results. PCS regional forecast result visualization is represented via tables, graphs, diagrams and cartograms.

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