ATLANTIS PRESS
Advances in Economics, Business and Management Research, volume 47
International Scientific Conference "Far East Con" (ISCFEC 2018)

Optimal Management of The Economic System of The Region Taking into Account The Dynamics of Human Capital

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***Abstract*— The article presents the numerical algorithm of solving the optimal management problem for a regional economic system adjusted for demographic dynamics in the conditions of scientific and technical and socio-educational progress. Based on the model of a regional economic system, the optimal management problem is considered.**

The transfer equation is used to model the amount of human capital, which takes into account budgetary and private investments made in human capital compo-nents: education, healthcare and culture

To solve the problem numerically, a software system has been developed, which includes a database of demographic and economic parameters of the Udmurt Re-public and implements a mathematical model of human capital dynamics, a fore-cast of demographic characteristics and an algorithm for solving the optimal man-agement problem for a regional economic system. As a result of solving the op-timal management problem, the optimal investment rates in human and production capital have been found, allowing the economic system to reach the trajectory of sustainable growth by 2022.

Keywords*— *optimal management, human capital, production capital, demographic dynamics, scientific and technical progress, socio-educational progress.

I. Introduction

This study discusses the solving of a dynamic optimal management problem for a regional economic system. The model of a regional economic system is taken as the basic model [1]. Based on this model we examine the optimal management problem for an economic system adjusted for human capital in the conditions of innovative social development which is characterized by scientific and technological progress (STP) and socio-educational progress (SEP) [2].

The relevance of the study of human capital based on its mathematical-economic modeling is related in particular to its significant impact on economic system devel-opment providing the competitiveness and rapid transition of the economy towards innovative growth. The modern theory of human capital was established in the early 1950s in the works of G. Becker [3] and T. Schultz [4]. Also, this topic was extensive-ly studied by H. R. Bowen, B. Weisbrod, J. Mincer, M. Fisher, Y. Ben-Porath and oth-er economists [5-7]. Complex evaluation of human capital has been made in the works by [8-14].

The solution of optimal regional economic system's management adjusted for overall demographic dynamics and workforce, presented in this paper, enables us to determine the optimal investment rates for social and production spheres that would facilitate sustainable economic growth in the conditions of STP and SEP. Pontryagin's maximum principle [15] and Bellman's principle of optimality [16] are used for this purpose.

II. Optimal Management Problem for a Regional Economic System Adjusted for Human Capital

A mathematical model of a regional economic system has the following parameters: a volume of goods manufactured, i.e. gross regional product (GRP) Y, volumes of production capital K and human capital H, a volume of investment in production capital I and human capital J, consumption rate C, and regional budget revenue D. Let us introduce the following notations: $N_F, N_R -$ tax payments to the federal and regional budgets respectively ($\rho_F = N_F/N$, $\rho_R = N_R/N$, $N = N_F + N_R$, $\rho_F + \rho_R = 1$); $T_t -$ grants, dotations and transfers; $s_0 = C/E -$ consumption rate in an economic system; $s_{k_i} = I_i/E -$ the rate of investment in production capital of i type; $s_{h_i} = J_i/E -$ the rate of investment in human capital of i type.

Two possible scenarios for a regional economic system development are studied: inertial and innovative ways of development. In the case of inertial development, it is assumed that the STP rate $\beta = \beta_1 = 0$ and the SEP rate $\kappa = \kappa_1 = 0$. The innovative scenario assumes that, since the moment t_0, a new, innovative way of an economic system's development begins. Taking this into account, two types of production capital must be distinguished: the funds in the inertial scenario $K_1(t)$ formed at the STP rate $\beta_1 = 0$ and the funds in the innovative scenario $K_2(t)$ formed at the STP rate $\beta_2 > 0$. Also, two types of human capital must be distinguished: the human capital $H_1(t)$ developed at the SEP rate κ_1 and the human capital $H_2(t)$ developed at the SEP rate $\kappa_2 > \kappa_1$.

The mathematical model of macroeconomic dynamics adjusted for human capital in the conditions of STP and SEP can be written as follows:

$$E = Y + T - N_F = I_1 + I_2 + J_1 + J_2 + C, \forall t \in \left[t_0, t_T\right]; \quad (1)$$

$$s_0 + s_{k1} + s_{k2} + s_{h1} + s_{h2} = 1, \; s_0 = \text{const}; \quad (2)$$

$$Y = F\left(K, H\right) = AK^{\alpha}H^{1-\alpha}; \quad (3)$$

$$E = \omega F(K,H), \omega = 1 + \upsilon\rho_F\left[\nu\left(\rho_R/\rho_F\right) - 1\right]; \quad (4)$$

$$D = \left(1+\nu\right)\rho_R\upsilon Y, \; T = \nu\rho_R\upsilon Y, \; N_F = \rho_F\upsilon Y; \quad (5)$$

$$C = s_0 E, \; I_i = s_{ki}E, \; J_i = s_{hi}E, \; i = 1,2; \quad (6)$$

$$\dot{K}_i = e^{\beta_i(t-t_0)}s_{ki}E - \eta_i K_i, \; i = 1,2; \; K = K_1 + K_2; \quad (7)$$

$$K_{10} = K\left(t_0\right), \; K_{20} = 0, \; K_{iT} = K_i\left(t_T\right); \quad (8)$$

$$\dot{H}_i = e^{\kappa_i(t-t_0)}\bar{\varepsilon}s_{hi}E - \chi_i H_i, \; i = 1,2, \; H = H_1 + H_2; \quad (9)$$

$$H_{i0} = H_i\left(t_0\right), \; i = 1,2, \; H_{iT} = H_i\left(t_T\right), \quad (10)$$

where υ is the percent of the GRP Y; ν is the percent of regional tax rates for the return of funds in the form of grants, dotations and transfers; T is the planning horizon.

Let $\lambda(t) = L(t)/P(t)$ [17-19] be the ratio of the economically active population L to the total population P; t_0, t_T is the planning interval; δ is the discount factor. The Cobb-Douglas production function (3) adjusted for linear homogeneity will be written as follows: $F\left(K,H\right) = LF\left(K/L, H/L\right) = LF\left(k,h\right)$.

The criterion functional is considered as a specific discounted consumption and is written as follows:

$$Cr = \int_{t_0}^{t_T} s_0\lambda\omega F\left(k,h\right)e^{-\delta\left(t-t_0\right)}dt \to \max_{s\in\Omega}, \quad (11)$$

$$\Omega = \left\{s = \left(s_l\right) = \left(s_{k1}, s_{k2}, s_{h1}, s_{h2}\right) : s_l \in \left[0,1\right], \sum_l s_l = 1 - s_0\right\} \quad (12)$$

The process of providing the optimal management consists of two steps. Firstly, a quasi-stationary optimal path that the economic system must move to is designed. Then the economic system's optimal management during the transition period is constructed, moving the system on to the quasi-path and keeping it thereafter.

The quasi-stationary path is found from the following condition:

$$q_{ki}e^{\beta_i\left(t-t_0\right)} = q_{hi}\bar{\varepsilon}e^{\kappa_i\left(t-t_0\right)} = \lambda(t), \; i = 1,2. \quad (13)$$

Human capital consists of demographic and quality components. The demographic component of human capital includes a quantitative reproduction of population [20], the quality of human capital consists of the investment in healthcare, education, science and culture [21]. The dynamics of human capital components are described by the following equation:

$$\frac{\partial h_i\left(t,\tau\right)}{\partial t} + \frac{\partial h_i\left(t,\tau\right)}{\partial \tau} = -\nu_i h_i\left(t,\tau\right) + g_i\left(t,\tau\right) + i_i\left(t,\tau\right) \quad (14)$$

Here, $g_i = g_i\left(t,\tau\right)$, $i_i = i_i\left(t,\tau\right)$ are specific budget spendings and specific private investments in the i-component of human capital respectively; $\nu_i = \nu_i\left(t,\tau\right)$ is the "withdrawal" coefficient of the i-component.

The initial and boundary conditions are written as follows:

$$h_i\left(t_0,\tau\right) = h_{i0}\left(\tau\right), \; h_i\left(t,0\right) = 0, \quad i = 1,2,3;$$
$$h_i\left(t,\infty\right) \approx h_i\left(t,\tau_m\right) = 0, i = 1,2 \quad (15)$$

where $h_{i0}\left(\tau\right)$ is the distribution of human capital by age at zero time and is a solution of the Cauchy problem; $\tau_m = \tau_m\left(t\right)$ the age till which only 5% of the population live.

The total amount of human capital for the economically active population is calculated by the following formula:

$$H\left(t\right) = \int_0^{120}\sum_{i=1}^{3}\alpha_i h_i\left(t,\tau\right)\varepsilon\left(t,\tau\right)\rho\left(t,\tau\right)d\tau, \quad (16)$$

where $\varepsilon\left(t,\tau\right)$ is the percent of the population at the age of τ that was economically active in the year t, $\alpha_1 = \alpha_2 = \alpha_3 = 1/3$.

III. Results of solving the optimal management problem for a regional economic system adjusted for human capital

The algorithm for finding a numerical solution of the optimal management problem is implemented as a software system [22]. Let us look at the results of solving the optimal management problem for the statistical data on the Udmurt Republic during the period of 1996-2017 [23-24]. The solution to the problem of identifying the un-known parameters of the model (1)-(10) based on the statistical data for the period of 1996-2017 generated the following values: ; ; ; ; the Cobb-Douglas production function is written as .

The period from 2017 to 2022 ( ) is considered as the target period. The dynamics of some of the key macroeconomic parameters is presented further. The discount factor is taken to be 0,05.

Let us consider how the STP and SEP rates influence the economic development:

I. The forecast of the economic system dynamics ( ): 595,82 thousand rubles per capita;

II. Solving the optimal management problem for the inertial scenarios of an econom-ic system development ( ): time needed to move to the path of sustainable growth – 6,38 years, 669,13 thousand rubles per capita;

III. Conducting the parametric studies:

a) when the STP and SEP rates are equal (scenario 1): time needed to move to the path of sustainable growth – 4,22 years, 798,01 thousand rubles per capita;

b) when only the STP is present (scenario 2):): time needed to move to the path of sustainable growth – 5,06 years, 744,18 thousand rubles per capi-ta;

c) when only the SEP is present (scenario 3): time needed to move to the path of sustainable growth – 5,21 years, 720,04 thousand rubles per capita.

IV. Conclusion

The mathematical model and its numerical algorithm presented in this paper enable us to solve the optimal management problem for an economic system taking into account demographic dynamics in the conditions of scientific and technological and socio-educational progress.

As a result of solving this problem, the optimal management strategy for the re-gional economic system which can move to the path of sustainable growth is found. This would enable us to increase the consumption by 13% comparing to the predicted value. The parametrical studies that assume active involvement of STP and SEP are conducted. For example, in scenario 2 the value of criterion functional by 2022 in-creases by 3,4% more than when only the SEP rates are increased (scenario 3). Ap-parently, the combined increase (scenario 1) results in an even higher increase in eco-nomic characteristics: e.g., by 2022 the population's consumption will be 798 thou-sand rubles per capita which is 7% and 11% higher than in scenarios 2 and 3 respec-tively, and 19% higher than in the optimal management scenario.

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