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ONE MODEL OF MIGRATION FLOWS CONTROL*

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The paper presents a discrete optimal control problem with constraints on which a method for calculation of migration flows, where qualified and unskilled workers are distinguished, is discussed. At the same time, the optimality criterion in the problem is associated with the achievement of the maximum output with the minimization of the total number of migrants. Numerical calculations are provided that illustrate the sustainable growth scenario over a 10 year period. The work objectives included the development of an approach for calculating the necessary size of working-age population migration and its components to achieve optimal output growth. A macromodel is proposed, which is a discrete optimal control problem. An algorithm for the control synthesis is pro-posed. Numerical modeling is carried out. The obtained results can be used in migration flows planning and management processes.

Keywords: mathematical modeling, migration, economic growth, numerical experiment, skilled and un-skilled labor.

Introduction. In almost all countries of the world a variety of migration processes can be observed under the influence of which the economic and social characteristics of the host countries change. The pace of change does not always correspond to the necessary and coordinated adaptation of both the migrants to the life in a new society and the indigenous people to the changing characteristics of the society, which naturally leads to the emergence of social tension. Therefore, today the issues related to the quotas development for the labor migration inflows and the forecasting of both the population size and the corresponding national economies development are relevant today.

Due to the need to take into account numerous factors affecting the migration and a close connection with economic processes, it is necessary to conduct research simultaneously or right before the decision-making process in this area, taking into account the basic laws and carry out the appropriate simulation calculations based on economic and mathematical models using information technologies. Considering that the determination of quotas, measures for the organization of migration flows will effect economic behavior and will in fact be the control for subsequent economic development, it is natural to raise questions about the rational choice of these controls that are in some sense optimal from the selected criterion standpoint. Here, a convenient mathematical apparatus for such models studying and a basis for numerical algorithms construction are provided with the help of optimal control and nonlinear programming methods.

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In the literature there are works of this kind where optimal control models are used. Let us consider the results of some of these works [1]. In particular work [2] considers the problem of organizing a controlled migration flow that will replenish labor resources and support economic development, assuming that the birth rate in the region is low and life expectancy is increasing. In this work based on the data from Austria the specified optimization problem is considered and the corresponding simulation results are presented. The model is a problem of optimal control of the age density of the population with constraints, where the behavior of the control object is described by a first-order partial differential equation on an infinite time interval. The task is to find some rational selection of two controls (the intensity of the immigration flow and its age profile) that ensure the retention of a given population size, which makes it possible to determine specific optimal immigration strategies and quotas for the migration flow.

In [3], a variant of the dynamic model where regional migration is considered due to the redistribution of state capital investments between regions is proposed. The model is initiated by the Tiebout hypothesis [4], which states that the difference in the individual consumer preferences and the possibility of migration provide an effective spatial distribution of the population. Here, the problem of the optimal distribution of labor resources between regions is considered in order to maximize the total production efficiency of the whole state. As a result, the mathematical model is a discrete optimal control problem, where the volume of regional labor resources is considered as a control function, and the optimality criterion is the sum of regional output production functions.

Let us note the research results of Lukina and Prasolov, presented in [5]-[7], where similar issues were also considered, in particular, a nonlinear dynamic model of controlled labor migration is constructed and an algorithm for the optimal quota selection is given.

Recently, the models that take into account the heterogeneity of migration flows have appeared. Obviously, qualified migrants (if countries are oriented towards economic development) are more useful for the economy of the host countries and have a higher rate of an adaptation. Here we note the works [8]-[10], where the models take into account the grouping of migrants into two classes – qualified and unskilled.

Materials and methods. The goal of this paper is to formulate a discrete problem of optimal control of the migration flow with constraints on the basis of models [8]-[10], including both qualified and unskilled workers, and carry out the corresponding simulation calculations. For this let us consider a control problem for an economic growth model that takes into account migration flows in the economy labor force. At the same time, using a modification of the Cobb-Douglas function that takes into account the division of labor resources into two classes, a discrete dynamic model of output is considered. We will assume that the labor force is an aggregate that takes into account skilled and unskilled labor which make different contributions to the output, as well as the labor of indigenous people and migrants that have different dynamics. At the same time, for simplicity, we will assume that the size of the indigenous working-age population is unchanged. We take the number of inflows of skilled $v(t)$ and unskilled $u(t)$ migrant labor resources and assume that migrants do not leave the country if they have already arrived (there is no outflow).

It is required to construct a control in the form of feedback that takes into account the dependence on the indicators of the economy state and which in the period of 10 years allows to achieve the maximum GDP (gross domestic product) while minimizing migration with various restrictions on the number of migration flows at each moment of time.

We introduce the following equations of dynamics

$$K(t+1)=\lambda_1((1-\delta)K(t)+\rho(1-a)Y(t)),\ K(0)=K^0,\lambda_1>0 \quad (1)$$

$$U_m(t+1)=(1+\mu_U)U_m(t)+u(t),\ U_m(0)=0, \quad (2)$$

$$S_m(t+1)=(1+\mu_S)S_m(t)+v(t),\ S_m(0)=0, t=0,1,\ldots,T-1 \quad (3)$$

where

$$Y(t)=\lambda_2 AK^{\alpha}(t)\left(\gamma S^{\psi}(t)+(1-\gamma)U^{\psi}(t)\right)^{(1-\alpha)/\psi},\lambda_2>0 \quad (4)$$

$$U(t)=(1+\beta_U)^t U_b(0)+U_m(t), \quad (5)$$

$$S(t)=(1+\beta_S)^t S_b(0)+S_m(t), \quad (6)$$

$$u\le M_1e^{-\theta t},\ v\le M_2(t),\ M_1e^{-\theta t}+M_2(t)\le M(t), \quad (7)$$

$$\theta>0,\ u(t)>0, v(t)>0,\ t=0,1,\ldots T-1.$$

Here $Y(t)$ is the three-factor production function [11] based on the Cobb-Douglas function in which a CES-unit that includes skilled *S(t)* and unskilled *U(t)* labor is used as a labor component and at the same time in each of the qualification classes there is as the indigenous (index b) and the migration (index m) population, δ is the capital disposal coefficient, *a* is the direct cost ratio (share of the intermediate product in the output), ρ is the accumulation rate, β_S,β_U are the growth rate of the skilled and unskilled classes of the population, αis the capital elasticity in the production function, parameter ψ means that the used aggregated function is close to the standard Cobb-Douglas function obtained by passing to the limit $\psi\to 0$, γ is the contribution of the skilled worker to the output, *A* is the accumulative factor productivity, $S_m(t)$ is the dynamics of the number of skilled migrants, $U_m(t)$ is the dynamics of the number of unskilled migrants. Here the coefficients μ_S,μ_U denote the growth rate of the number of skilled and unskilled migrants. Here we will assume that the total annual number of migrants does not exceed a given value $M(t)$, the initial number of unskilled migrants is decreased by the following law $M_1e^{-\theta t}$, where $\theta>0$ is the given value, and $M_2(t)$ is the restriction on the dynamics of the number of skilled migrants, so that $M_1e^{-\theta t}+M_2(t)\le M(t)$, $t=0,1,\ldots T$.

We will seek the controls as a function of output (Y) and capital (K), namely, $u(Y,K)=\varepsilon_1Y+\varepsilon_2K$ и $v(Y,K)=\eta_1Y+\eta_2K$, to minimize the following functional

$$Y(T)-\omega\sum_{0}^{T-1}\left(u(t)+v(t)\right)^2\to\max, \quad (8)$$

where the parameter ω regulates the migration flow and the coefficients $\varepsilon_1,\varepsilon_2,\eta_1,\eta_2$ are found by solving the corresponding nonlinear programming problems.

Results. The presented macromodel reflects the main economic mechanisms but at the same time it does not fully take into account the dynamics of the number of working-age workers of the indigenous population and does not consider the possible migrantsoutflow, therefore, the use of this model is sufficient for a qualitative analysis on a limited time interval with some parameter fitting. As the adjustable parameters we consider the coefficients λ_1, λ_2 introduced in the right-hand sides of equations (1) and (4). These coefficients are chosen from the condition that the trajectories of the model are as close as possible to the trajectories that correspond to the scenario that the capital (K) increases in about 2.65 timesover a period of 10 years. The identification of the model coefficients is carried out on the basis of the international economic statistics data and numerical experiments in Matlab R2020a. The parameter values are:

$\rho = 0.2$, $\delta = 0{,}06, a = 0{,}42,\ \beta_s = \beta_u = 0{,}005,\ \mu_s = \ \mu_u = 0.02,\ S_b(0) = 0{,}4$,

$U_b(0) = 0{,}6,\ \alpha = 0{,}6,\ \psi = 0{,}01,\ \gamma = 0{,}8, K(0) = 1{,}18, A(t) = (1+0.005)^t$,

$M_1 = 0.022,\ M = 0.04, \theta = 1, \lambda_1 = 0.18,\ \lambda_2 = 0.7, \omega = 0.01.$

The initial conditions for the parameters are $\varepsilon_1 = 1,\ \varepsilon_2 = 1,\ \eta_1 = 1,\ \eta_2 = 1$.

The results are presented in Figure 1.

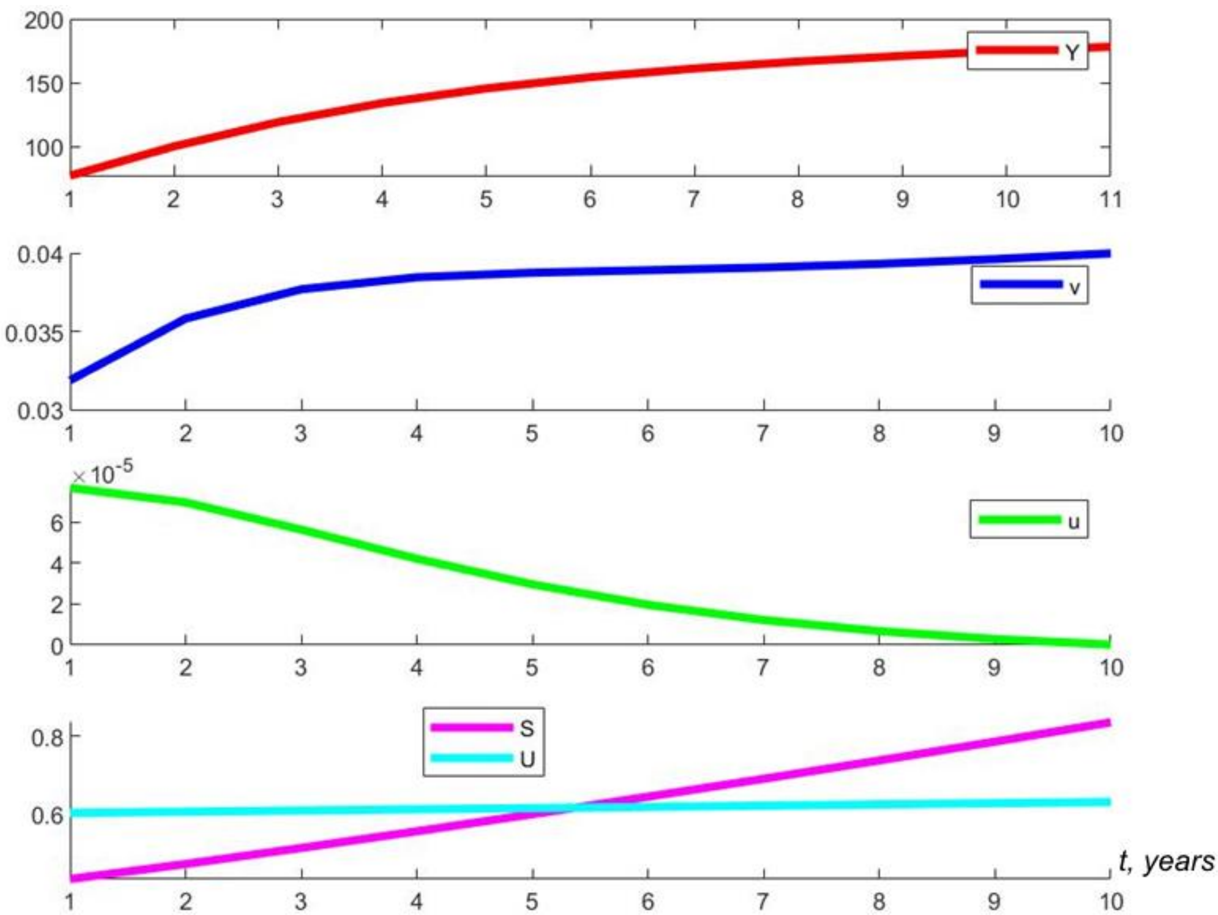

Figure 1. Curves of the output (Y), controls u, v, skilled and unskilled labor S, U for 10-years period

The criterion value is 178.1943.The found coefficients values are $\varepsilon = 10^{-3}$ [0.0162-0.6460], η =[0.0032-0.1199].

Discussion and Conclusions. Here a mathematical model for the problem of optimal control of economic growth taking into account the contribution of the migration flow to the labor force and the division into skilled and unskilled labor is built. Computational experiments have shown that the model makes it possible to obtain a plausible growth rate of output and allows to make a suggestion that the predominance of unskilled workers in the migration flow leads to the decrease in the growth rate of output and to the increase in economic inequality.

Calculations show that over an interval of 10 years the structure of the inflow of migrants is as follows: the demand for skilled workers at the beginning of the period clearly increases and approaches a constant value while the share of unskilled workers in the total inflow of migrants decreases which ensures a noticeable increase in output at the beginning of the period and a decline in the rate of output in the last third of the period. The same is observed for the capital growthdynamics: at the beginning of the period the growth of output clearly increases and approaches a constant level. Due to the fact that the inflow of qualified migrants is higher than that of unskilled from some point of time the total number of skilled workers begins to exceed the number of unskilled workers.

Note, however, that during migration crises the imbalance between inflows of skilled and unskilled labor shifts towards the latter which aggravates inequality and social tension. This increases the importance of control measures to regulate themigration.

One of the directions of this model development is associated with the development of behavioral hypotheses [12] regarding the actions of potential and actual migrants in response to the control decisions that limit the migration. Due to the fact that these processes cause a wide public resonance it is also relevant to study information confrontations [13] that arise around the migration topic.

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ОБ ОДНОЙ МОДЕЛИ УПРАВЛЕНИЯ МИГРАЦИОННЫМИ ПОТОКАМИ *

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В работе приводится модель дискретной задачи оптимального управления с ограничениями, на которой обсуждается способ расчета миграционных потоков, где различаются квалифицированные и неквалифицированные работники. При этом критерий оптимальности связывается с достижением максимального выпуска при минимизации общей численности мигрантов. На одном сценарии приводятся численные расчеты, иллюстрирующие сценарий устойчивого роста в течение 10 летнего периода. Целями работы являлись разработка подхода к расчету необходимой численности миграции трудоспособного населения и ее составляющих для достижения оптимального роста выпуска. Предложена макромодель, представляющая собой задачу дискретного оптимального управления. Предложен алгоритм нахождения синтеза управлений. Проведено численное моделирование. Полученные результаты могут быть использованы в процессе планирования и управления миграционными потоками

Ключевые слова: математическое моделирование, миграция, экономи-ческий рост, численные расчеты, квалифицированный и неквалифицированный труд.

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