

People mobility and its model

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Abstract Influence of the human factor to development of economy becomes stronger. However people is not homogeneous body. Therefore number of people transitions between residences, branches of economy, trades, social groups and so on grows. Empirically noticed laws of movement, for example, Ravenstain's laws, generate some the demanding resolution paradoxes. The solving of paradoxes leads to an extension of the pull-push model containing some parameters. The parameters map i) demand of human resources reflecting influence of employers; ii) supply including influence of employees; iii) resemblance and iv) difference of arrival and departure groups' factors containing people choice. The aim of communication is to demonstrate a solution of identification problem and capacity to work of the extensional model.

People mobility and its properties. Influence of the human factor to development of economy becomes stronger. However people is not homogeneous body. Therefore number of people transitions between residences, branches of economy, trades, social groups and so on grows. Empirically noticed laws of movement, for example, Ravenstain's laws, generate some the demanding resolution paradoxes.

It is easy to explain people transitions from groups with a bad life conditions to groups with good. But why is there a return flow always? This is the first paradox of Ravenstain's laws. If an incomes difference for a couple of groups grows the flow to one direction increases, but the return flow decreases (skew-symmetry). Let distance between two groups falls then both flows decrease (symmetry). Why do flows sometimes increase, and sometimes decrease, if resemblance of conditions decreases? This is the second paradox of Ravenstain's laws.

People mobility is connected with a labour market. The labour market is controlled by supply and demand, as any market. Property of the labour market is that the workers have purposes. They can move them self to reach these purposes. Thus, the labour market consists of three subjects. Employers are the first subjects. They creating or reducing workplaces control the supply and demand. Employees are the second one. They changing groups carry out their choice. The best ecology, say, pools people, and the worst one push away. The third subject is administration. It specifies restrictions of arbitrariness both, accepting laws, say, terms of dismissal, duration of work and so forth

The purpose of the worker is to improve the working and life's conditions. His or her transition shows person's preferences and choice. So, if we are able "to clear" flows from influence of a supply and demand then the rest is the choice of people. This choice shows preferences of conditions in-group for their any pair. People, "voting by feet" for the best

conditions reveal influence of conditions. Thus, transitions contain the full information about group properties. We need only to discover it.

2. How does the general model reflect people mobility? Any people mobility model should have the characteristics (parameters) reflecting all already noted properties. Let's mention a question, how we can change, say, demand. Clearly, for this purpose we need investments, which can increase demand, if employers create new manufacture, and reduce it, replacing old technologies to job saving one. We need find parameters before entering movement factors into the model. If parameters and factors are known, it is possible to define, what of the second and how they influence to the first. However all parameters are to be found without knowledge of factors. We need the model just for this purpose.

We considering all models existing now note, that the "pull-push" model is the most suitable for general model creation. It contains already parameters reflecting attraction, pushing out and resemblance of conditions (inverse distance value). It is necessary to add only distinction (skew-symmetry) to the model. Thus, *the general model of population flows*, suitable for the description of migration, interbranch, social and other types of people mobility looks like:

$$\lambda_{ij} = B a_j b_{ij} c_i, \quad (1)$$

where $\lambda_{ij} n_i$ is a flow from the group i to the group j ($i, j = \overline{1, k}$), n_i is population number of initial group i . c_i is people capacity to leave initial group i , connected with supply of human resources. a_j is availability of group j , it reflects demand and is controllable by employers. b_{ij} is choice of initial group (i) people an other group j . Two groups i and j comparison b_{ij} splits up two factors q_{ij} and r_{ij} . The first q_{ij} defines distinction of conditions and is skew-symmetric. The second r_{ij} is connected with conditions resemblance and is symmetric. The constant B is a measurement unit (for example, thousand person per year), all others parameters are dimensionless. Thus, λ_{ij} is *people transitions intensity* from i to j . The total number of groups (regions of residence, employees at branches of economy, social statuses, etc.) is k .

The equalities connecting a population structure $\mathbf{n}(0)$ at starting time point $t=0$ with any another $\mathbf{n}(t)$ form system of the differential equations or the *general model of movement of the population*:

$$d\mathbf{n}(t)/dt = \mathbf{C}\mathbf{n}(t), \quad (1')$$

where elements $c_{ji} = \lambda_{ji} - \delta_{ij} \sum_j \lambda_{ij}$ form matrix \mathbf{C} , δ_{ij} is the Kronecker's symbol, and elements n_i at the moment t are the components of k -dimensional column-vector $\mathbf{n}(t)$.

Let's explain, how the model includes symmetry and skew-symmetry. The choice parameter r_{ij} satisfies the symmetry condition $r_{ij} = r_{ji}$ for all i, j . Parameter q_{ij} is skew-symmetric, and it satisfies, for example, equality $q_{ij} + q_{ji} = 1$. Any positive function $b_{ij} = b(\mathbf{x}_i, \mathbf{x}_j)$ of two vector

arguments x_i and x_j is known to be presented as product symmetric r_{ij} and skew-symmetric q_{ij} functions. The vector argument is a set of any mobility factors for groups of departure i and arrival one j . Their values are not necessary for us yet.

The general model of the population movement is known to describe all Monrovia models, including models of demography, migration, social mobility and some others. We know statistical data about transitions number between groups too. If for the observed period we know transitions number between each couple of groups and initial groups numbers it is possible to estimate transitions intensity. Now the problem consists of model identification, i.e. by knowing transitions intensities we need to find all parameters of general model.

3. Parameters identification and their properties. The decision of model identification problem, i.e. definition of its parameters over observations, is simpler if we add some restrictions to already described and obligatory:

$$q_{ij}+q_{ji}=1, q_{ij}\geq 0, r_{ij}=r_{ji}, r_{ij}>0 \quad \forall i,j=\overline{1,k}. \quad (2)$$

Let's take advantage of complement, for example,

$$r_{ii}=\text{const}, \quad \forall i = \overline{1,k} \quad \prod_{j=1}^k a_j = \prod_{i=1}^k c_i = 1. \quad (3)$$

Thus, all resemblances r_{ii} are not obligatory identical, they can depend on group. Obviously, conditions resemblances of the Krasnoyarsk region and the Oryol area cannot be compared. In the models of interbranch mobility, for example, internal resemblance of conditions for the agriculture can differ from branch of mechanical engineering.

Except for such restrictions let's allocate quite natural assumption.

Hypothesis. *The basic role of the human resources market plays supply and demand. In model (1) supply and demand are defined first of all by availability of groups and capacity to leave initial for people. Thus, transition intensities variability depends on parameters c_i and a_j .*

The theorem. *Model (1) is identifiable then and only then, when the previous hypothesis and restrictions (2,3) satisfy, or more strong:*

Sufficiency. If

$$q_{ij} = \frac{\lambda_{ij} a_i c_j}{\lambda_{ij} a_i c_j + \lambda_{ji} a_j c_i} \quad r_{ij} = \frac{\lambda_{ij} a_i c_j + \lambda_{ji} c_i a_j}{B a_i c_j a_j c_i}, \quad (4)$$

$$\text{where } a_j = \frac{\sqrt[k]{\prod_{i=1}^k \lambda_{ij}}}{B}, \quad c_i = \frac{\sqrt[k]{\prod_{j=1}^k \lambda_{ij}}}{B}, \quad \text{and } B = \sqrt[k^2]{\prod_{i=1}^k \prod_{j=1}^k \lambda_{ij}} \quad (5)$$

than equalities (1) are satisfied and the hypothesis is true.

Necessity. If the hypothesis, the equalities (1) and last of (3) are true, estimations (5) are the least squares approximation $\ln \lambda_{ij}$ by sums of $\ln B + \ln c_i + \ln a_j$ after potentiation, parameters (4) follow from division (1) by estimations (5) a_j and c_i and from restrictions (2).

4. Results of experiment. To include factors to the model we need now to find four more certain functions of factors for any pair of groups. Availability /demand/ of group depends, probably, only on no every its properties, but, for example, only on investments. Capacity to leave group /supply/ can be defined, for example, by its environment. Resemblance and distinction are defined by conditions of two groups. This dependence is symmetric function of conditions for resemblance. It is skew-symmetric for distinction. The first depends on a geographical position, network of roads and traditions, the second does on number of workplaces and unemployed, on earnings, available housing, etc. Except these absolutely important restrictions to functions form, a method of their form finding becomes clearer. We know now in fact not only factors values but values of each function.

Capacity to work of the model was checked on data about migration and interbranch movement in the USSR, Russia and some other countries and regions. I.V. Rogovina using flows has calculated all parameters of the model.

Shares (in %) the intensity, explained by factors on the countries and kinds of movement

| The countries and regions | Factors of mobility | | | The countries and regions | Factors of mobility | | |
|---------------------------|---------------------|--------|--------|---------------------------|---------------------|--------|--------|
| | supply | demand | choice | | supply | demand | choice |
| USSR 67 | 12,0 | 38,0 | 50,0 | Latvia* | 28,9 | 22,8 | 48,3 |
| USSR 73 | 3,4 | 39,7 | 56,9 | Estonia* | 5,2 | 47,5 | 47,3 |
| USSR 89 | 2,2 | 41,2 | 56,6 | Krasnodar* | 8,6 | 53,1 | 38,3 |
| Russia 96 | 8,7 | 25,2 | 66,1 | Hungary | 2,4 | 17,5 | 80,1 |
| Russia 97 | 5,5 | 27,2 | 67,3 | Bulgaria | 38,6 | 29,2 | 32,2 |
| Russia 98 | 8,2 | 24,0 | 67,8 | Finland | 4,6 | 45,4 | 50,0 |
| Russia 99 | 7,9 | 27,6 | 64,5 | Israel 86 | 3,1 | 45,1 | 51,8 |
| Israel 85 | 3,0 | 55,1 | 41,9 | Israel 87 | 3,4 | 47,6 | 49,0 |

*) interbranch movement

Parameters of resemblance have shown, that conditions of the Baltic republics, Ukraine and Moldova are closest for people. Republics of Central Asia had also similar conditions. Other republics USSR were in the middle of the list, Russia occupies one of last places. Calculation of flows in Russia has shown similar results. Distinctions of areas conditions, both for the USSR, and for Russia, have presented quite clear conclusions. A. Ivanova for distinctions has checked up concordance of people preferences.

5. Conclusion It is clear theoretically and results of calculations show that a model of population movement are not present without taking into account resemblance and distinctions. Therefore the model of type (1) is necessary.

It is premature to make practical conclusions because using only people transitions, i.e. people reaction to group's life qualities, we studied the problem of opportunity to select separately resemblances, distinctions, availability and capacity to leave. Because in fact the statistical data were less then the model parameters we spent the calculations to understand only, whether it is possible to extract all parameters from transition numbers.

1. All parameters of general model (1) can be obtained by the basis of flows between groups in which people reflect the understanding of availability of groups, their capacities to leave, and also resemblances and distinctions of life quality for any pair.

2. Often resemblance in pull-push models is defined by inverse value of distance. Distances are proportional to transport prices. Therefore human resources market in Russia falls because prices of transfer of any kind of transport increase more quickly than incomes.

3. Usual conclusion reliability about applicability for economic-demographic model what we can make after an estimation of all parameters is in the best case 0,99, and more often it is 0,95. Here the conclusion about necessity to account both resemblance and distinction is done much more confidently, i.e. necessity of the general model is proved experimentally.

4. Transitions of people allow us to receive the information even about political conditions that was showed by movement between republics USSR in 1989. During this period the attitude between Armenia and Azerbaijan were very far from comprehensible to people what had reflected their preferences. These republics were in the end of last places of life quality list.

Models of population mobility are created for the different purposes. One of the cores happens forecasting structure of the population in the future. If the structure of the population does not answer our representations about quality then other problem appears: the problem of people transitions regulation. The decision of such problem demands knowledge how parameters of transitions depend on mobility factors. It is clear, the knowledge of factors influence helps to improve quality of the forecast. We need mobility factors to forecast and regulate the structure.

However not any factors can be used for regulation, but only what we can control. Natural cataclysms strongly influence mobility, but to consider them is impossible. This circumstance is known if we forecast agriculture productivity. Here the forecast of a crop leads to weather but weather forecast is not easier at all. Therefore factors should be divided on controllable and uncontrollable. Change of economic strategy or tactics of administration influences transitions, but to predict the moment of this change is not simply. And it is even more difficult to predict, when innovation will be realized. Thus, before to include factors to the forecast and regulation we need to understand, how much we can influence people mobility.

So, forecasts share to passive and active. The forecast using scenarios concerns to passive. For example, we believe, that group i demand will raise 5 %, and others are the constant. However we cannot show, how this result can achieve because the display concerns already the result to active forecasts. People mobility is usual depends on such factors, to predict which (for example, earthquake) is more difficult than to guess mobility people behaviour. Therefore accuracy of active forecasts is far from desirable.