Trans-Siberian railway and interrelation of economic development of regions

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Abstract. The extending of Trans-Siberian railway is considered as homotopic parameter, i.e. a factor of a geographical location and connectivity of economic space, forming a line of functional order along which the economy of Siberia and the Russian Far East is transformed. It is possible to pass judgment on a similarity of economies by correlating the regional investments on industry and agriculture VRP. For this purpose the economic connectivity (similarity) of regional economies along the railway is calculated with using a Jacobi determinant for vectors of coefficients of investment acceleration. The comparisons are carried out concerning parameters of Irkutsk region economy. The indexes reflecting advantages of the regional environment of economic activity or regional investment climate are calculated. The main spatial and temporary trends of formation of geoeconomic relations of regions are revealed. It is possible to consider Baykal region with intracontinental position and unique natural features as peculiar "reference point" for the comparative quantitative geographical analysis of economic activity conditions.

1. Introduction
Presence of the alternate transport paths of movement of people and goods from the East on the West and in the opposite direction was important geohistorical advantage of the Euroasian continent at all times. The movement was on sea and river water ways and numerous roads in the course of migration of Asian people and Russian development of the territory. Construction and exploitation of the Trans-Siberian railway (TSR) had allowed to establish uninterrupted year-round transport connection of regions of Siberia and the Far East with the European part of Russia since beginning of the 20th century. It affected both positive and negative on traditional economic activity of the population and further was important in the history of the whole country and for economic development of its east lands. As a result the economic belt was created as an economic complex of open resource economies of regions arranged in geographical order along TSR and developed in the conditions of the market relations with special place of any region in all-Russian and international division of labor.

Due to the occurrence of fundamental problems of scheduling new transcontinental railways and the related economic belts [1], it makes sense to reveal the created regularities of interregional relations along TSR and feature of the geographical environment of economic activity with use of the modern models of the analysis of territorial development opportunities.
2. Models and Methods

The quantitative methods are widely and efficiently used at the solution of transport and economic problems [2]. As a first approximation, the nature of interregional connections can be estimated by means of formulas of intensity of movement on different sites of the railway, taking in account of various factors of influence [3]. Integrated approach in the analysis of space data from various sources [4] is used at a research of regional economy penetrated with TSR on the example of development of the cities.

The Trans-Siberian railway (TSR) is a network of the railways connecting Moscow during more 100 years with east regions of Russia and the countries of the Far East [5]. It is an infrastructure factor of a connectivity of economic space, a homotopic path of the functional order along which the economy of Siberia and the Russian Far East sequentially is transformed.

Homotopy is called the continuous map \( F(t,x):[0,1] \times X \rightarrow Y \) which is continuously depended on parameter \( t \in [0,1] \). Time or the space position of an object can be accepted as parameter \( t \). This parameter has initial value (location) \( t=0 \) and terminal maximal value corresponding to \( t=1 \). For example, it is possible to take as \( t=0 \) a starting point of TSR, i.e. the station Moscow-Yaroslavskaya, and as \( t=1 \) a terminal point Vladivostok which railway station is located apart \( L_m = 9289 \) km from Moscow. Parameter \( t \) for any location \( L \) on this way is calculated by a simple formula \( t = L/L_m \in [0,1] \), where \( L \) is distance from Moscow by railway.

The space \( X \) is interpreted as a set of values of various \( (i-\)th) economic and ecological reasons, i.e. factors and potentials \( x=\{x_i\} \in X \) of territorial development. The space \( Y \) corresponds to a set of \( k \)-th results \( f(x) = \{f(x)\} \in Y \) of economic activity. The reasons \( x(t) \) and results \( f(t,x) \) are parametrized with time moments or geographical coordinates of a location \( t \). There are \( x(0) \) and \( f(0,x) \) for Moscow location and \( x(1) \) and \( f(1,x) \) for Vladivostok position. We will coordinate regions \( j \) with values \( t_j \), that correspond to their administrative center locations \( L_j \) on railway track. In this case the correlation of economies is reflected in comparison of economic assessment functions \( z_j=f(t_j,x) \) for different regions. For this purpose the Jacobi determinant [6] is used. For two variables \( x_1 \) and \( x_2 \) and two estimations \( z_1=f(t_1,x) \) and \( z_2=f(t_2,x) \) of different regions \( j=1 \) and \( j=2 \) the determinant is equal to

\[
J = \begin{vmatrix} \frac{\partial z_1}{\partial x_1} & \frac{\partial z_1}{\partial x_2} \\ \frac{\partial z_2}{\partial x_1} & \frac{\partial z_2}{\partial x_2} \end{vmatrix} = \begin{vmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{vmatrix} = a_{11}a_{22} - a_{12}a_{21} \tag{1} \]

Here \( a_{ij} = \frac{\partial^2 z}{\partial x_i \partial x_j} \) is the partial derivative expressing sensitivity of change of the function \( z_j \) on factor \( x_i \); \( a_{1j} = \{a_{ij}\} \) is dual vector (covector) of a vector of factors \( x=\{x_i\} \).

If the module is \( |J|=|J|=0 \) in some range of variables \( x_1 \) and \( x_2 \), then functions \( z_1 \) and \( z_2 \) in this range are interdependent. These functions are independent at case \( |J| \neq 0 \) [7]. It is supposed, the more deviation the value \( J \) from zero, the connection of \( z_1 \) and \( z_2 \) is worse. The last statement theoretically is proved by linking \( J \) with a gramian \( \Gamma \) which value is a degree of independence of vectors and functions in indexes of a deviation of positive value \( \Gamma \) from zero [8].

It is possible to pass of judgment on a similarity of economies by correlation of investment processes in which the dependence of the investment \( z_j \) on sectorial VRP \( x_i \) is considered. In this case coefficient \( a_{ij} \) has economic meaning of investment process acceleration. The bilinear connection of \( z_j \) with variables \( x_i \) is proved by theoretical and statistical methods [6]:

\[
z_j(x_j) - z_{0ij} = \sum_{i=1}^{n} a_{ij} (x_j - x_{0ij}), \quad H(a_i) = z_{0ij} - \sum_{i=1}^{n} a_{ij} x_{0ij} \tag{2} \]

where values \( z_{0ij}, x_{0ij} \) characterize geographical conditions of economic activity (environmental shift) or investment climate of regions. The value \( H(a_i) \) characterizes this environment in a complex. Coefficients \( a_{ij} \) are calculated by method of the rolling linear regression on time-series data. In this
In the case the value $H(a_i)$ has meaning of the intercept term in the linear equation. In according to equation (2), we find values $z_{0j}$, $x_{0i}$ with comparing $H(a_i)$ and $a_i = \{a_{ij}\}$.

### 3. Results and Discussion

The explained algorithm is implemented on the example of the research of dependence (2) of gross domestic investments $z(x)$ (million rubles/year) on volumes of production in the industrial $x_{1j}$ and agricultural $x_{2j}$ enterprises (million rubles/year) in regions. Calculations are based on indexes (in actual prices) of a social and economic condition and development of territories from the available database of Goskomstat (State committee of statistics) of Russia for period 1999-2013. Calculation of regional coefficients $a_i = \{a_{ij}\}$ is carried out with rolling regression on three points of the corresponding time-series data. On this basis with the equation (1) the indicator $J_{ij}$ of a connectivity of any region economy (along TSR) with Irkutsk region economy by years and root-mean-square value $J_{0j}$ for the entire period are estimated. Hereafter these values are compared with the homotopic parameter $t_i$ of each region for identification of the hidden regularities.

The Irkutsk region is situated almost in the center of the Asian continent on the main railway thoroughfares connecting Europe to the Russian Far East districts and the countries of the Southeast Asia. The Irkutsk city is situated on 5042 km of TSR from Moscow in 126 km from the coast of Lake Baikal (Slyudyanka railway station). Possessing a large volume of unique natural resources the Irkutsk region is industrially developed territory and the industrial center of the Baikal region where also there are the Republic of Buryatia and Zabaykalsky Krai (Trans-Baikal territory, Chita region). The leading industries of Irkutsk region are power and fuel industries, ferrous and nonferrous metallurgy, chemical and petrochemical production, mechanical engineering and metal working, forest, woodworking, pulp and paper industries.

The index of economic similarity $J_{mj}$ in time and regions changes in a different way that indicates an originality of the regional investment process (figure 1). However there are historical periods of high similarity of dependence of the investment volumes on sectorial VRP. There is the period before world financial and economic crisis of 2008. The crisis in the investment sphere in 2008 similarly influenced on economy of Russian regions ($J_{mj}$<2).

![Figure 1. Comparison by years of function of dependence of regional investment on the industry and agriculture VRP with function for the Irkutsk region by indicator $J_{ij}$ calculated with using Jacobi determinant and acceleration coefficients of investment process. Points are the calculated indexes. Regions: 1 – Vladimir region; 2 – Omsk region; 3 – Altai Krai (Barnaul); 4 – Primorsky Krai (Vladivostok).](image)

The dependence of mean values $J_{0j}$ on a difference of homotopic indexes $\Delta t_j = |t_j - t_0|$ (figure 2) is ambiguous. Value $\Delta t_j$ corresponds to the conditional distance by railway between each region and the region of comparison with the index $t_0$ (Irkutsk). Within boundaries of the Baikal region the connectivity index of investments $J_{0j}$ decreases at increasing a distance from the Irkutsk region in the
direction to the Republic of Buryatia and Zabaykalsky Krai. The connections \( J_{0j} \) < 20, which is weakly dependent on distance for industrial developed regions, are widespread. However the main trend expected is expressed in a positive linear dependence of the connectivity on distance and accordingly the homotopic index \( \Delta t_j \). This trend is unidirectional, but link lines are shifted for different regions. The dependence is described by the equation

\[
J_{mj} = a(\Delta t_j - n_j \Delta t_0)
\]

where \( a, \Delta t_0 \) are constants; \( n_j \) is the quantitative characteristic of the geographical investment environment. There are \( a=205.7, \Delta t_0 = 0.164 \) per calculation. The characteristic of the geographical environment is evaluated by an equation \( n_j = (a \Delta t_j - J_{mj})/a \Delta t_0 \). The value \( n_j \) increases both to the East and the West and depends on distances to the Baikal region, especially the Republics of Buryatia (figure 3).

\[\text{Figure 2. Dependence of mean values of connectivity index } J_{0j} \text{ of economies on the relative geographical location } \Delta t_j. \text{ Straight lines are the main trend of interconnection of indexes.}\]

\[\text{Figure 3. Dependence of the calculated characteristics of the geographical environment } n_j \text{ in regions on index of space situation } t_j. \text{ Curve line is the space trend of index } n_j \text{ changing.}\]

This regularity is appeared in compliance with the equation (3) as result of low space variability of the connectivity index of economies. Developing economy of Transbaikalia performs in Russia important transit function, connecting east and western regions and neighboring states, first of all with Mongolia and China. High freight density of traffic flows by the railroads in comparison with other regions of Siberia and the Far East is characteristic of this territory. Both midland and peripheral position and a lack of energy resources constrain growth rate of the economy. It is expressed in low negative values of the investment environment. The factor of a proximity to the political, administrative and economic center of Russia (to Moscow) and to seaports defines higher rates \( n_j \) of the geographical environment of regions.

Using the equation (3) the linear dependence of connectivity indexes of economies of two any regions \( s \) and \( j \) is established:

\[
J_{ms} - J_{0ms} = \frac{n_s}{n_j} (J_{mj} - J_{0mj}), J_{0mj} = a \Delta t_j
\]

where \( J_{0mj} = a \Delta t_j \) is the spatial and environmental shift of an connectivity index. The ratio \( K_{js} = n_s/n_j \) is a refractivity of geographical environments at transition from one region to another one. This is simple analogy of refraction of a light ray on borders of physical mediums in the geometrical optics.
Refraction coefficient $K_{js}$ between the neighboring regions of Siberia and the Far East does not increase with value $\Delta t$, i.e. the spatially close regions are uniform in characteristics of the economical and geographical environment.

4. Conclusion
For the identification of the hidden regularities of the space organization of territories of Siberia and the Russian Far East the economic connectivity (similarity) of regional economies in the line of TSR is estimated using the mathematical models and methods. The extending of TSR is considered as an infrastructure factor of a connectivity of economic space, a homotopic pathway of the functional regularity along which the economy of east regions of Russia sequentially is transformed and the international transport corridor between the countries of the southeasteast Asia and Europe is created. In geohistorical aspect from the TSR line in the directions to the North and the South were constructed and now is formed the parallels and meridians of the railroads for economic development of the countries of the Asian continent.

The analysis of similarity is based on comparison of economic functions of dependence of internal investments in the region on industry and agriculture VRP. Statistically coefficients of acceleration of investments in each group of economic branches are evaluated. On the basis of these coefficients using Jacobi determinant the indicator of interregional connectivity of investment functions is calculated.

The economy of regions with these functional indexes was compared to economy of the Irkutsk region (part of the Baikal region) possessing unique natural resources and the developed industry. In the temporary and spatial relation the connectivity indicator is very changeable. In order to identify the quantitative regularities the indicator of the geographical environment is evaluated. The indicator increases to the West and the East from the Baikal region. It makes sense to consider this region possessing intracontinental position and unique natural features as peculiar "reference point" for the comparative quantitative geographical analysis of economic activity conditions.

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References
[1] Bazarov B V 2017 "A new silk road": to statement of problems of strategic interaction of Russia and China Power 25(11) 7–12 (in Russian)
Nobis A 2017 The New Silk Road, old concepts of globalization, and new questions Open Cultural Studies 1 203–13
[2] Golts G A and Kartavenko G G 2008 Macroeconomy and transport: intercountry comparisons and regularities Bulletin of Transport Information 11 25–35 (in Russian)
Golts G A 2009 Turnpike freight transportation and gross internal product: an historiometric research for the purposes of prediction Problems of Prediction 113(2) 151–7 (in Russian)
[3] Mekhedov M I and Muginstein L A 2015 On problems of the organization of driving and effectiveness of use of traffic capacities of the station Railway Transport 7 20–7 (in Russian)
[4] Uchida S, Takeuchi W, Hatoyama K and Mazurov Yu 2016 Socio economic impact of Trans Siberian railway after the collapse of Soviet Union by integrated spatial data analysis IOP Conference Series: Earth and Environmental Science 37 1–6
[5] Mikhailoff M 1900 The Great Siberian railway The North American Review 522(170) Income accessed online on 18th July 2018 via https://enwikisource.org/wiki/The_North_American_Review/Volume_170/Issue_522/The_Great_Siberian_Railway
Westwood J N 1964 History of Russian Railways (London: George Allen and Unwin Ltd) 326 p
Westwood J N 2002 Soviet Railways to Russian Railways Studies in Russian and East European History and Society (London: Palgrave Macmillan) p 262
