THE GRAVITY MODEL OF RUSSIA’S INTERNATIONAL TRADE: THE CASE OF A LARGE COUNTRY WITH A LONG BORDER

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Abstract

The paper contains the results of theoretical development and empirical verification of spatial gravity model of Russian trade. The authors conclude that the spatial variables and especially the location of the state border checkpoints have a significant effect on the volume and routes of Russian imports.

Keywords: international trade, gravity model, border checkpoints.

JEL classification: F1, F2,

Introduction

The globalisation of economic processes has continued in recent decades and the volumes of international trade have grown continuously, greatly outpacing growth in output. The creation of the General Agreement on Tariffs and Trade (GATT) and the World Trade Organization (WTO), the conclusion of various forms of preferential trade agreement and establishment of international institutes to provide support and promotion of trade in one way or another have reduced total production costs of the world output and increased the variety of commodities. The global production model, in which different intermediate components are manufactured in different countries or even on different continents, has become more common. Many large manufacturing companies became transnational a long time ago. Over the past 20 years world trade has seen considerable change in the location of manufacturing facilities. Virtually all countries, with few exceptions, participate actively in world trade. The recent economic crisis showed that despite such a model of the global economy implying that, on the one hand, there has been a great diversification of trade relations, on the other, the key players in the field of trade have faced serious problems, resulting in the transfer of risks via the trade chain to substantially all the world economies.

In this situation an understanding of the mechanisms and restrictions of the factors in world trade that influence the volumes and routes of trade flow is quite important for conducting of economic policy. One of the most popular econometric models is the ‘gravity model’ of international trade which can be explained by many of the classical theories of trade. It attempts to identify the above factors. However, most of its modifications have two major faults: they do not take into account either the geographical sizes of countries or the routes of the trade flows. In addition, these models automatically imply that goods may be imported into a country at almost any point along the state border; or, more precisely, these classic academic works, as a rule, do not even discuss this issue due to the lack of available data. For many countries such simplifying assumptions do not result in significant distortions when assessing the parameters of the gravity model of trade. However, for a country such as Russia, which has a large area and a long state border, these simplifications are hardly applicable.

This paper is devoted to the specification of a theoretical spatial gravity model of international trade for Russia, which takes into account the above peculiarities. Its empirical verification is performed using data on the import to different Russian regions, from various countries of the world, through particular border crossing points.

The first section describes key approaches used in the development of the specifications for the usual gravity models of international trade. The second section describes the specification of the model for Russian trade in particular and demonstrates its key results. The final part contains our main conclusions and proposals relating to economic policy.

Key approaches to the development of gravity specifications for models of international trade

Gravity models of trade were originally developed as convenient econometric tools for the analysis of trade flows between countries and they have gained quite widespread acceptance due to their "good" (consistent with intuitive) empirical results[1]. Until quite recently (20 years ago) these models have not been subjected to full theoretical justification or rigorous analytical deduction of their hypotheses. However, today many papers with certain reservations derive gravity models of trade specifications from the prerequisites of each of the most applicable basic theories of economics research in international trade: David Ricardo's theory of comparative advantage[2], the Heckscher-Ohlin model (formalised in [Samuelson, 1948]), Krugman's theory[3] ('New theory of international trade').

One of the first works in which the gravity model of international trade was used was [Tinbergen, 1962]. As the author notes, the model used was quite simple. It proposed an equation relating the export volume from one country into another using the following explaining variables: the GDP of the exporting country, the GDP of the importing country and the geographic distance between the two countries.

It should be noted that the author simply introduced the econometric specification of the model without deriving it from strict theoretical assumptions. The author reasoned the choice of these variables for explaining export volume using the following intuitive considerations: (a) the volume of export goods which a country may present for international exchange

[1] The empirical works which used a gravity equation deal, as a rule, with aggregated trade flows. International trade models for certain types of goods are considered, for example, in [Kadochnikov, Sinelnikov-Murylev, Chetverikov, 2003]

[2] See, for example [Deardorff, 2007]

[3] See [Krugman, 1984]; [Krugman, 1986], etc.

depends on the size of its economy (i.e. on GDP); (b) the quantity of goods which can be sold in a country depends on the size of its market (i.e. on GDP); (c) trade volumes will also depend on the cost of transportation of the goods, which, in the author assumption, should be proportional to the distance between the countries in question. In addition, the author included dummy variables for the participation of partner countries in various trade agreements.

The simplest multiplicative form of the expression which relates the above factors with the volume of exports from one country into another, and which the author used, is as follows:

$$E_{ij} = \alpha_0 Y_i^{\alpha_1} Y_j^{\alpha_2} D_{ij}^{\alpha_3}, \qquad 1)$$

where E_{ij} — export from country i to country j, Y_i — GDP of country i, Y_j — GDP of country j, D_{ij} — distance between country i and country j, α_i — estimated coefficients of export elasticity which include relevant variables.

An empirical estimation showed that the coefficients of the key variables were significant and had correct signs consistent with the propositions which had been made in the formulation of the model.

These results laid the foundation for further wide application and duplication of this form of the gravity equation. However, Tinbergen's work did not present a rigorous and comprehensive theoretical justification of this specification of the trade equation.

Among the examples of works in which this model was applied (in various forms but without strict theoretical justification) are [Poyhonen, 1963a, 1963b], [Pulliainen, 1963], [Geraci, Prewo, 1977], [Prewo, 1978], [Abrams, 1980], etc.

Attempts to develop a theoretical foundation for the gravity equation of trade were made at different times and with different degrees of intensity. In most cases it was a search with a predetermined result, which researchers were willing to justify econometrically. Among such works the following may be noted: [Leamer, Stern, 1970] with a probability model, [Leamer, 1974], in which variables from the gravity equation and the Heckscher-Ohlin theorem were used simultaneously, [Anderson, 1979] relied on micro-justifications and on the Armington hypothesis[4], [Bergstrand, 1990], in which the author modelled monopolistic competition, etc.

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[4] The Armington assumption is a special form of aggregating the volumes of consumption of one commodity which components are manufactured in different countries.

One of the most popular works on this subject is [McCallum, 1995], in which an empirical result known as the ‘border puzzle’was obtained.

In this work the following relation was evaluated:

$$\ln x_{ij} = \alpha_1 + \alpha_2 \ln y_i + \alpha_3 \ln y_j + \alpha_4 \ln d_{ij} + \alpha_5 \delta_{ij}, \qquad 2)$$

where x_{ij} is export from region i to region j, y — GDP of the regions, d_{ij} — distance between the regions, δ — dummy variable, equal to 1 if the regions are within the same country and 0 otherwise.

This equation was estimated based on 1988 data for trade between 10 Canadian provinces and 30 American states, which covered about 80% of American-Canadian trade at that time. It was paradoxical that trade between the Canadian provinces (controlling all other variables) was found to be 22 times larger than trade between Canadian provinces and the US states. The authors questioned why the virtually erased border between Canada and the USA actually reduced mutual trade so considerably. For several years no reasonable explanation for this outcome was found.

The results obtained in this work created a whole series of studies devoted to the ‘border puzzle’. Some of them used the results obtained, as for example in [Engel, Rogers, 1998], others obtained similar results although based on different statistical data. For example, in [Paas, Tiiu, 2002] the gravity model was applied to analyse trade in the USSR, Yugoslavia and Czechoslovakia; [Djankov, Freund, 1998] studied the effects of trade barriers for the USSR; [Hejazi, 2005] tested whether data on the regional concentration of exports in OECD countries were consistent with the gravity model; [Winchester, 2009] was devoted to studying trade in New Zealand, [Wolf, 2008] — to interregional and international trade in Germany in 1885-1933 and [Mayer, Combes, Lafourcade, 2004] studied the same patterns as McCallum for the French regions, attempting to answer the question whether business and social networks were the key to the ‘border puzzle’.

In addition, a substantial amount of further research has been devoted to attempting to find a solution to the problem[5]. A comprehensive theoretical model which predicted the appearance of the ‘border puzzle’ was proposed in [Anderson, Wincoop, 2003]. In this paper

[5] See, for example, [Head, Ries, 2001], [Evans, 2001], etc.

an attempt was made to develop a theoretical justification for the gravity model of international trade which could obtain consistent and effective estimates in the the empirical research[6].

With reference to [Anderson, 1979] the authors note that the volume of bilateral trade between two countries or regions (other conditions being equal: GDP, individual characteristics of trade partners, etc.) is negatively related to the barriers to trade between these regions compared with the average size of the barriers to trade with all other trade partners of the regions in question. The intuitive explanation proposed by the authors may be formulated as follows: the more difficult trade is between either of the two regions and other regions, the greater is the motivation for mutual trade between these two regions. The size of the average barrier to trade with other countries was named the ‘multilateral resistance’.

Anderson and Wincoop suggest that the lack of clear theoretical justification in earlier econometric works and, hence, incorrect specification of the gravity equation, results in two major problems. The first problem is bias in the coefficient estimates, resulting from omitted variables in the regression equation. The other problem is partly a consequence of the first, and resides in the incorrect results of research in comparative statics (comparison of equilibrium conditions when changing the exogenous variables or model prerequisites), which is often the main goal of empirical studies on this subject.

The first assumption used by Anderson and Wincoop in their theoretical model is that there exists one differentiated product, and that each region or country specialises in manufacturing only one type of this product. The supply volume of each type of this product is fixed. The second assumption is for equal homothetic preferences as defined by the CES utility function[7]. Prices of the products differ between the regions due to different trading costs (each country manufactures only one form of the product). After maximisation of the consumer’s utility function the authors obtain the following form of the gravity equation:

$$x_{ij} = \frac{y_i y_j}{y^W} \left(\frac{t_{ij}}{P_i P_j} \right)^{1-\sigma}, \qquad 3)$$

[6] As the authors show inconsistency and inefficiency of the estimates result from an incorrect model specification, in particular from incorrect construction of the distance variable.

[7] This utility function determines the volume of aggregated import. The approaches to description of demand for certain types of imported goods are described, for example, in [Knobel, 2011]

where x_{ij} — value of export from region i to region j; $y_i = \sum_j x_{ij}$ — total income of region i; $y^w \equiv \Sigma_j y_j$ — nominal income of the world economy; $\theta_j \equiv y_j / y^W$; σ — elasticity of substitution between commodities; t_{ij} — cost of transportation from i to j; $P_j^{1-\sigma} = \sum_i P_i^{1-\sigma} \theta_i t_{ij}^{1-\sigma}, \quad \forall j$ — recursive relation for price index introduced in the transformation process (reflects the 'multilateral resistance' because it includes expenses relating to trade with all countries).

Equation (3) is the expression for the volume of international trade at the equilibrium point and is used in the paper as the main equation of the model. Conceptually, it implies that the volumes of trade between any pair of countries, all other conditions being equal, will be larger than those between another pair of countries with smaller GDPs. Similarly, the volumes of trade between any pair of countries, all other conditions being equal, will be larger than those between another pair of countries the distance between which is greater. The authors use the indices P_i, included in the final ratios as numeric equivalents of the 'multilateral resistance' because they are dependent on the size of the bilateral barriers t_{ij}. Therefore, in accordance with the equation, the greater is the 'multilateral resistance' (i.e. the greater the distance to other large trade partners), the larger is the volume of trade between the two countries in question.

Anderson and Wincoop emphasize that the most meaningful component of the international trade model they have developed is the dependency of trade volumes between regions on the multilateral resistance (the size of the relative barriers). Based on microeconomic assumptions the authors have obtained a form of the gravity equation which is distinguished from the simplest standard form by the presence of the 'multilateral resistance' which reflects the dependency of trade volumes on the size of the relative trade barriers. This modification of the gravity model has enabled the authors to find a solution to the 'border puzzle' using empirical data. Repeating the calculations of [McCallum, 1995] with the inclusion in the model of 'multilateral resistance' shows that the presence of the border reduces trade volume by only 20-50%, i.e. 'multilateral resistance' explains the major part of the 'border puzzle'.

The gravity model which had been developed in [Anderson, Wincoop, 2003] was widely used in scientific research studies later. Moreover, some of further works proposed certain modifications to this model. For example, in [Akerman, Forslid, 2009] per capita GDP was introduced in the gravity equation as an additional variable, [Chen, Novy, 2009] introduced multilateral resistance which varied with time, and [Novy, 2013] proposed a modification of the model for panel data.

[Baier, Bergstrand, 2009] proposed a method which simplified econometric estimation of the theoretical model presented in [Anderson, Wincoop, 2003]. Authors' idea was very simple and quite productive: to expand the expressions for the price indices P_i, characterising the 'multilateral resistance', into a Taylor series: $\boldsymbol{f}(\boldsymbol{\xi_i}) = \boldsymbol{f}(\boldsymbol{\xi}) + \boldsymbol{f}'(\boldsymbol{\xi})(\boldsymbol{\xi_i} - \boldsymbol{\xi})^2 + \boldsymbol{o}((\boldsymbol{\xi_i} - \boldsymbol{\xi})^2)$ in ξ.

Then the gravity equation takes the following form:

$$\ln x_{ij} = \beta_0 + \ln y_i + \ln y_j - \beta_1 \ln d_{ij} - \beta_2 Border_{ij} +$$
$$+\beta_1 \ln MRDist_{ij} + \beta_3 MRBorder_{ij} + \varepsilon_{ij} \qquad 4)$$

where d_{ij} is the distance between regions i and j (proxy for the value of trading costs); $Border_{ij}$ — dummy variable representing the existence of the state border, equal to 1 if the regions belong to different countries or equal to zero otherwise;

$$MRDist_{ij} = \sum_{k=1}^{N} \theta_k \ln d_{ik} + \sum_{m=1}^{N} \theta_m \ln d_{mj} - \sum_{k=1}^{N} \sum_{m=1}^{N} \theta_k \theta_m \ln d_{km} ,$$

$$MRBorder_{ij} = \sum_{k=1}^{N} \theta_k Border_{ik} + \sum_{m=1}^{N} \theta_m Border_{mj} - \sum_{k=1}^{N} \sum_{m=1}^{N} \theta_k \theta_m Border_{km}$$

The $MRDist_{ij}$ variable is an index constituting the sum of the GDP-weighted distances from the regions in question to all other regions. In other words, this variable characterises the average distance of regions i and j from the other regions in relation to the world average of this distance. Hence, it is a measure of the 'multilateral resistance'. The equivalent interpretation is true for the $MRBorder_{ij}$ variable, which relates to the existence of the border between the pair of countries in question and other world countries.

The results of empirical evaluation of Baier-Bergstrand model are fairly consistent with those obtained in [Anderson, Wincoop, 2003]. In particular, the distance coefficients in these two models, estimated using the same data, are almost equal.

Specific features of Russia's international trade modelling

When considering trade involving geographically extensive countries (such as Russia) the necessity arises for a more accurate and detailed account of the transportation costs. As a rule, goods are imported to a country through specially equipped crossing points only. In the case of countries where the crossing points are closely spaced this is not really important, as the distance over which the goods are transported is unlikely to differ greatly from the shortest possible distance. However, when considering trade in large countries the differences between the shortest and the actual distances involved are too significant to be ignored. Moreover, for small countries it can be assumed that all consumption and production are concentrated within quite a narrow geographical area; however, for large countries this assumption would be wrong. In this case it is necessary to consider the actual production and consumption regions within the country and, hence, their export and import.

Figure 1 below presents a diagram of the possible movement of goods from foreign countries across the state border of Russia and into the internal regions of the country. The distance which the goods pass from the shipping country to the receiving region is the sum of two components: $d_{i\mu}$ (from the manufacturer to the crossing point) and $d_{\mu j}$ (from the crossing point to the place of consumption).

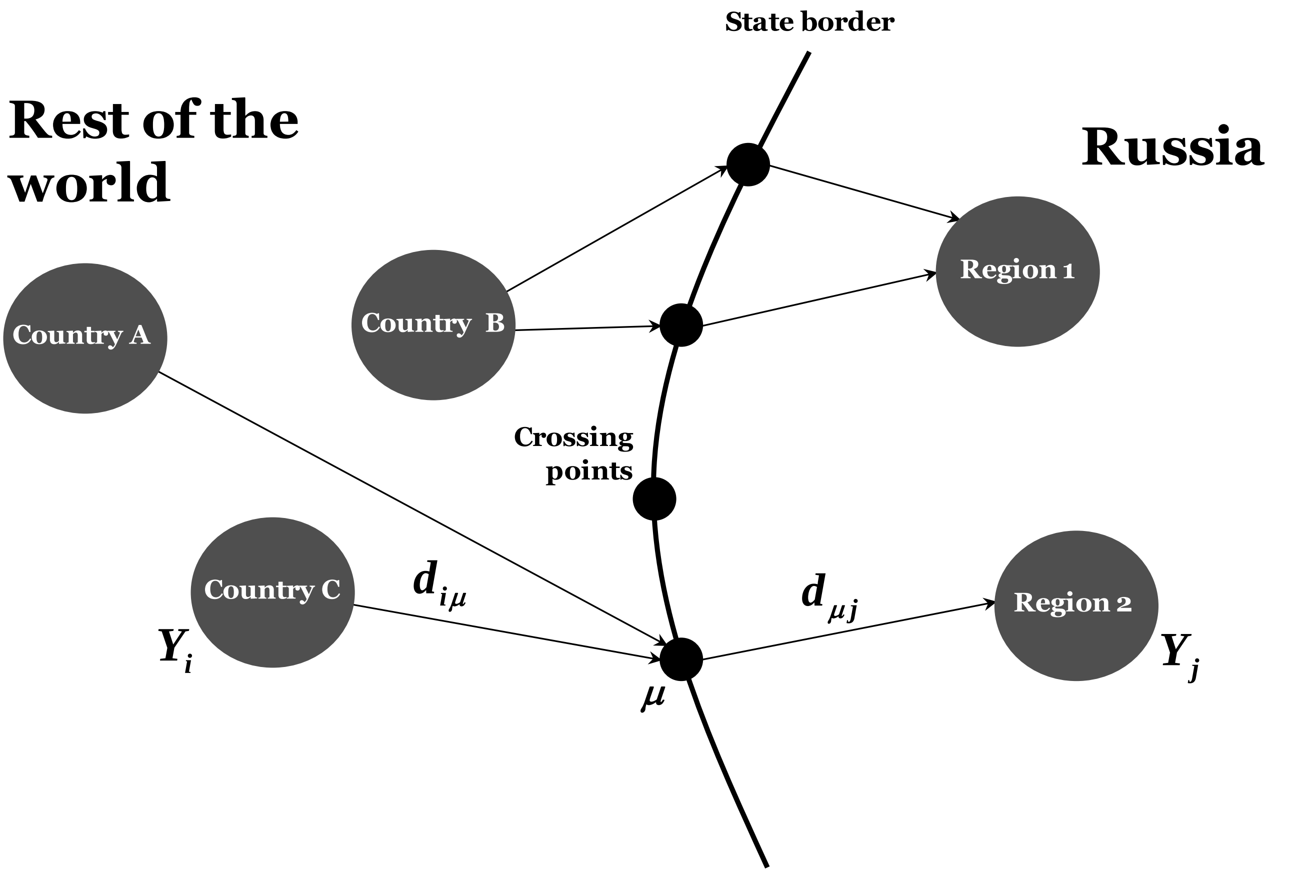

Figure 1. Diagram of trade flows through crossing points on the state border

Import of goods into the internal regions of a large country with an extensive external border is possible only through crossing points on the external border μ (in certain cases the crossing points may be located within the internal territory, at airports for example). Thus, the distances actually passed by any goods, imported from country i to internal region j, will be the sums of two components: the distances along the trade routes from country i to crossing point μ and the distances along the trade routes from crossing point μ to internal region j.

Based on the theoretical model [Anderson, Wincoop, 2003] and [Baier, Bergstrand, 2009] we have developed a modification of the gravity equation for trade which takes into account all of the above features[8]. The augmented model contains an equivalent for the ‘multilateral resistance’ for crossing points on the state border and takes into account the fact that the trade volume of region j with country i is limited by the existing structure and location of the crossing points.

Evaluation of the spatial gravity model for Russia trade

The econometric specification of the gravity equation with notation/interpretation for each component is presented below.

$$\underbrace{\ln x_{i\mu j}}_{\text{Import}} = \beta_0 + \beta_1 \underbrace{\ln y_i}_{\text{GDP of country i}} + \beta_2 \underbrace{\ln y_j}_{\text{GRP of country j}} - \beta_3 \underbrace{\ln d_{i\mu j}}_{\text{Distance between i and j via the crossing point μ}} +$$

$$+\beta_3 \underbrace{\ln MRDist_{ij}}_{\text{Weighted sum of distances from i and j to other regions and countries (‘multilateral resistance’)}} + \underbrace{\ln \sum_{\mu} \frac{1}{(d_{i\mu} + d_{\mu j})^{\beta_4}}}_{\text{Border transparency coefficient}} + \underbrace{\ln \frac{1}{\sum_{\mu} \frac{1}{(d_{i\mu} + d_{\mu j})^{\beta_5}}}}_{\text{Sum of distances between regions i and j through all crossing points (equivalent of ‘multilateral resistance’ for crossing points)}}$$

[8] See. [Kaukin, 2013]

The first summand is a constant. The second and third summands are the GDP of the exporting country and the GRP of the importing region respectively, which serve as proxies for the sizes of their economies.

It is assumed that the size of the exporting economy is positively correlated with its production capacity and, therefore, has a positive effect on the trade flow that may be potentially exported to the destination region. Hence, we expect a significant positive sign for the coefficient of the GDP of the exporting country variable.

The size of the importer's economy is, in turn, a characteristic of the internal market and, hence, reflects the demand for imported goods. Thus, it is expected that the larger the size of the economy of the importing party, the greater will be the volume of flow of the import trade, all other conditions being equal. Therefore, we expect a significant positive sign for the coefficient of the GRP variable of the importing region.

In accordance with common practice, the distance between the countries is a proxy variable for the transportation costs. It is assumed that the greater is the distance between the two countries or regions in question, the larger the transport costs will be. Hence, when costs of transportation between two countries are large not all exporting companies of the first country will be able to trade with the second country. For example, the profit from export activities, in this case may be less than the profit they could gain from sales of these products on the domestic market, or even be negative if the production and transport costs exceed the potential revenues. Hence, we expect a significant negative sign for the coefficient of the variable of distance between the exporter and importer.

The fifth term in the gravity equation is the sum of the weighted distances from the exporter and importer to other countries (in essence, it is an equivalent to the 'multilateral resistance'). In this case the main hypothesis is that if, besides the 'exporter-importer' pair, we consider that there are other countries or regions in close proximity, the volume of trade flow between the pair will be less, all other conditions equal, than in the case where other countries are at a considerable distance from the pair in question.

The seventh term is the sum of the weighted distances from the crossing points (in essence, it is an equivalent of the 'multilateral resistance' in the case of the existence of crossing points). The main hypothesis is similar to that formulated in the description of the fifth term, but in this case we consider not the alternative exporters and importers and the relevant distances to them, but the alternative crossing points on the state border. In particular, we expect that if there are other crossing points in close proximity to the crossing point through which the exporter transports its goods to the importer, the volume of trade flow through the crossing point in question will be less than it would be if the other crossing points were on more distant sections of the border.

The sixth term in the gravity equation is the indicator of border transparency. The effect of this term on the trade volume is opposite to that considered above in interpreting the sum of the weighted distances to the crossing points. The main hypothesis here is that, all other conditions being equal, the existence of just a few crossing points on any section of the state border may reduce the trade flow passing through each of them compared to the situation where the density of crossing points on the border is higher. The small number of crossing points on the border limits the possibilities for importers and exporters, so, if the transport costs for some of them are too high, this might make it more profitable to sell the products on the domestic market or in the markets of other countries. This can happen in the situation where the existing crossing points are located too far from the optimal (shortest) transportation route. Thus, increasing the density of the crossing points on a certain section of the state border or, in other words, reducing the sum of the weighted distances to alternative crossing points, should result, all other conditions being equal, in the growth of trade flow between the exporter and importer in question. If this hypothesis is true, we will obtain significant positive signs for the coefficient included in the border transparency indicator.

In carrying out the econometric evaluation we will first evaluate the classic form of the gravity equation proposed in [Anderson, Wincoop, 2003] and [Baier, Bergstrand, 2009] without the specific variables reflecting the impact of the existing configuration of the crossing points (specification (1)). Then we will estimate the specification proposed in this paper, with the border transparency coefficient and the sum of the distances between the trade partners through other crossing points (specification (2)).

The major problem in the empirical estimation of the gravity equation is the possibility of omitted variables existence. The theoretical gravity equation, as constructed, may not take into account certain features of the regions or crossing points which may have a considerable effect on the trade volume. For example, these could be: a bad state of transportation routes in the region, a low capacity of the crossing point, an agricultural specialisation of the region, etc. These omitted variables may also be non-observable. In order to avoid bias in our estimates as a result of mis-specification we will estimate specifications of gravity equation with various individual effects.

We will test two assumptions: that the regions or crossing points have certain characteristics which are not specified in the theoretical model and that these may be taken into account only by the introduction of individual effects. For this purpose we will modify specification (2) by introducing dummy variables for the Russian regions (specification (3)) and crossing points (specification (4)).

As an illustrative example, Figure 3 presents the possible data distribution and estimates of the model with individual effects for the crossing points. The figure specifies import volumes from various countries to different regions of Russia through three crossing points: Naushki, Belgorod and Big Port Saint-Petersburg.

In the case of absence of individual effects (dummy variables) for the crossing points, we would either fail to observe the dependency between the distance and the import volumes or, in some cases even obtain a positive coefficient in the regression. However, taking into account the individual effects enables us to obtain a clear negative dependency between the import volumes and the distance. Here each subsample for the individual crossing points has a slightly different in magnitude angular coefficient.

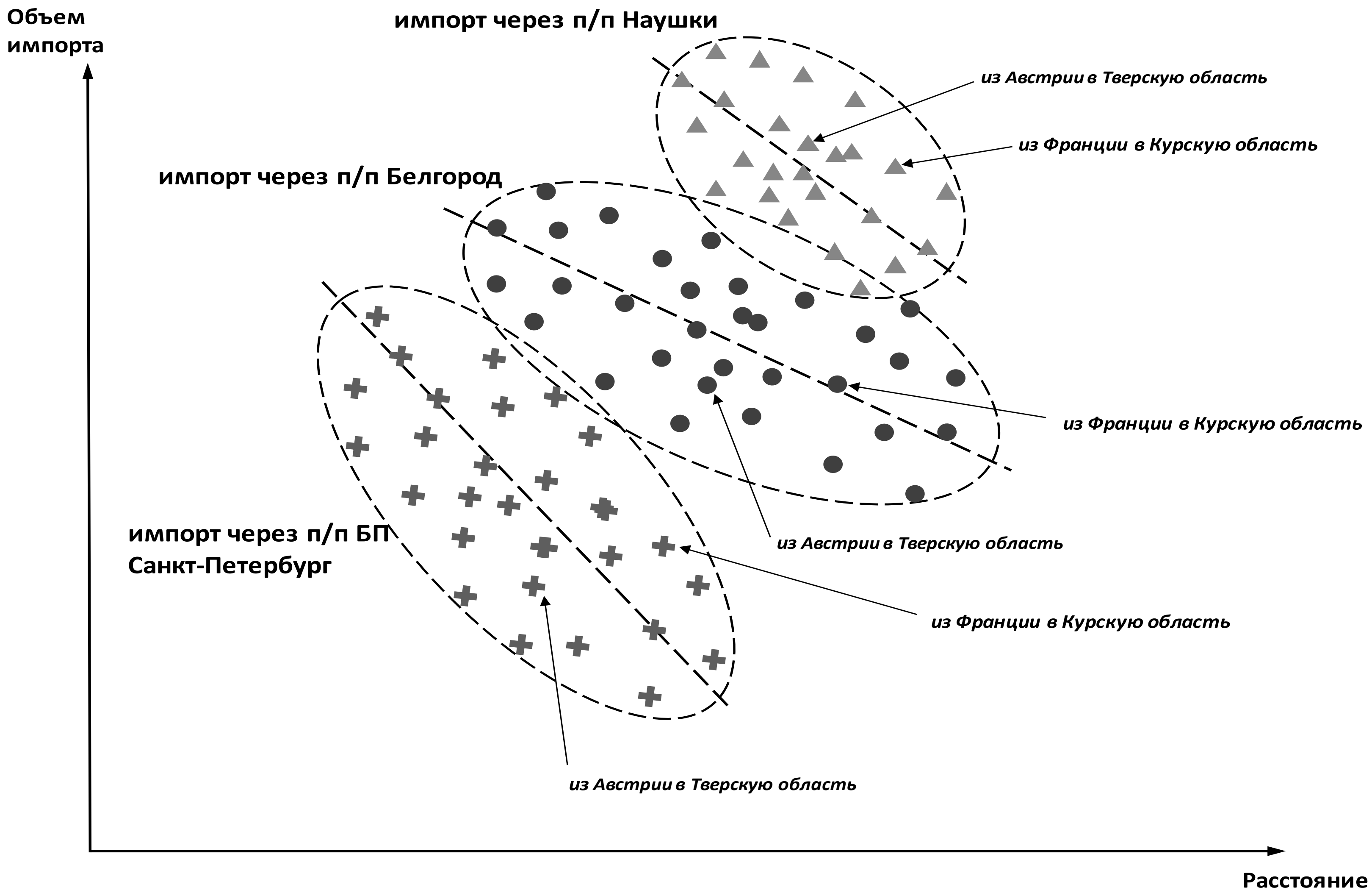
Объем
импорта
импорт через п/п Наушки
из Австрии в Тверскую область
из Франции в Курскую область
импорт через п/п Белгород
из Франции в Курскую область
из Австрии в Тверскую область
импорт через п/п БП
Санкт-Петербург
из Франции в Курскую область
из Австрии в Тверскую область
Расстояние

Figure 2. Model example of dependency between import volumes and distance between the trading partners. Assuming crossing points cause individual effects

Объем импорта	Import volume
Импорт через п/п Наушки	Import through the Naushki crossing point
Из Австрии в Тверскую область	From Austria to the Tver oblast
Из Франции в Курскую область	From France to the Kursk oblast
Импорт через п/п Белгород	Import through the Belgorod crossing point
Из Австрии в Тверскую область	From Austria to the Tver oblast
Из Франции в Курскую область	From France to the Kursk oblast
Импорт через п/п БП Санкт-Петербург	Import through the BP Saint-Petersburg crossing point
Из Австрии в Тверскую область	From Austria to the Tver oblast
Из Франции в Курскую область	From France to the Kursk oblast
Расстояние	Distance

The coefficient value in this case indicates how the import volume will change when, for example, the import to the Belgorod oblast of French goods is switched to the import of Brazilian goods, or when there is a re-orientation of French exporters from the Belgorod market to the Chelyabinsk market (provided that all shipments are carried out through a particular crossing point). In this specification these two switches are absolutely identical, the magnitude of the effect being determined solely by the change in distance. Thus, the values of the coefficients in this specification illustrate the degree of variability of trade flows through a single crossing point in relation to the trade between different countries and different regions.

It is not difficult to build a similar interpretation explaining the economic implications of the coefficients in the regression for an individual effect for an internal region. The results of estimates of all the proposed specifications are laid out in table 1[9].

Table 1. Results of estimation of different specifications of the gravity equation for international trade

Dependent variable — volume of imports from a certain country through a particular crossing point to a particular Russian region				
Specification	**(1)**	**(2)**	**(3)**	**(4)**
Estimation method	Least-square	Non-linear least-square	Non-linear least-square	Non-linear least-square
Constant	1.59	-19.04**		
Dummy variables for regions			yes	
Dummy variables for crossing points				yes
GDP of partner countries	-0.09**	-0.11**	-0.07*	0.50**
GRP of Russian regions	0.27**	0.32**		0.86**
Relative distance between trade partners	-0.60**	-2.45**	-3.03**	-3.45**
Border transparency coefficient (power in the denominator)		0.22**	0.08**	0.19**
Sum of distances through other crossing points (power in the denominator)		2.45**	3.27**	1.91**
R^2	0.0016	0.0023	0.0148	0.8958
Adj. R^2	0.0016	0.0022	0.0138	0.8954
Year	2011	2011	2011	2011
Number of observations	88,510	88,510	88,510	88,510

[9] For additional information on econometric estimation method see [Kaukin, 2013]

Note: * — significance at 5%, ** — significance at 1%.

The results demonstrate that for the first and second regressions the dependency of the import volumes on the relative distance of transportation of goods is significant and negative, while their dependency on the size of the importing region is significant and positive. The coefficient of the variable of the GDP of the exporting country is significant and negative.

The coefficients in the second regression, being a part of the coefficient of the border transparency and the weighted sum of the distances to the alternative crossing points, are significant and positive, as was suggested in the theoretical model. This can be viewed as evidence that the assumptions which we formulated about the influence of spatial effects on trade volumes does not conflict with the statistical data.

Firstly, the coefficient in the border transparency index is found to be significant and positive. This may be interpreted in full accordance with the assumptions formulated earlier: when the number of crossing points on a particular section of the state border increases, one of the observed effects will be an increase in the volume of goods transported through this section. This effect is associated with the restrictions on potential trade previously caused by the long distance via other crossing points which had meant high transport costs.

Secondly, the coefficient in the sum of the distances to other crossing points is also found to be significant and positive. This is an illustration of the second effect which will be observed in the case of an increased number of crossing points on a particular section of the border: in this situation the exporter and importer have a choice between almost identical routes passing through neighbouring crossing points, and hence, the trade flow through any individual crossing point is likely to decrease to a certain degree.

Moreover, a comparison of the results of the first and second regressions estimations shows that the addition of spatial effects to the gravity equation results in a significant increase in the coefficient of relative distance: if we suggest the presence of spatial effects, the influence of the relative distance on trade volumes is more significant than if we assume that no spatial effects exist.

It should also be noted that the specification of the model which takes into account spatial effects in accordance with the estimate results, better corresponds to the statistical data: R^2 in the second regression is a little higher than in the first one. However, the value of R^2 in these regressions is very low, which (together with the negative sign of the GDP variable) may be the evidence of the existence of variables not included in the gravity equation, yet which influence the import volumes.

The results of estimations of specification (3) of the gravity equation show that the introduction of dummy variables for the Russian regions into the model does not result in qualitative changes to results which had been obtained earlier.

The coefficients of the relative distances, and those included in the 'border transparency coefficient' and in the weighted sum of distances to other crossing points, remain significant and have correct (intuitive) signs which correspond to the hypotheses formulated earlier. However, as seen from the table, the introduction of dummies for the regions had no effect on the negative sign of the exporting country GDP variable, and this can not be explained by the theoretical model, although it did slightly increase the value of R^2. In this case the hypothesis of the equality of all the introduced dummies is rejected.

The results of the estimations of specification (4) show that the introduction of dummy variables for the crossing points had a substantial effect. The values of all the coefficients, without exception, have signs which count in favour of the hypotheses formulated earlier; all coefficients are significant. Examining the obtained regressions, we determined that the actual data distribution is very similar to the situation presented in figure 3 above. For each variable the sample consists of individual data clouds (for each crossing point), separated from each other. Thus, the introduction of individual dummy variables[10] for the crossing points allows for a more accurate description of the underlying data generation process. Regression (4) is the key empirical result of this work.

Table 2 contains the results of model estimations for the subsamples of trade volumes which were transported by different means of transport.

Table 2. Results of estimations related to different means of transport

Variable	Coefficient			
	Marine	Rail transport	Road transport	Air transport

[10] The 'physical meaning' of dummy variables is described in the conclusion section of this article.

	transport			
Dummies for crossing points	yes	yes	yes	yes
GDP of partner countries	0.34**	0.39**	0.52**	0.67**
GRP of Russian regions	0.60**	0.51**	0.93**	1.18**
Relative distance between trading partners	-2.07**	-1.88**	-4.25**	-0.31**
Border transparency coefficient (power in the denominator)	-0.08**	0.88	0.19**	1.37**
Sum of distances through other crossing points (power in the denominator)	1.71**	1.29**	2.31**	0.93**
R^2	0.9126	0.8587	0.8358	0.9757
Number of observations	7,863	6,581	60,544	12,710

Note: * — significance at 5%, ** — significance at 1%.

In order to be able to conclude with certainty that the introduction of dummy variables for the crossing points was justified and that the results obtained (including the increased value of R^2) reflect the real economic dependencies, rather than the effect of the introduction of a large number of dummy variables into the regression, we performed separate estimations of the gravity equation in specification (2) for each crossing point.

As an illustration of the results obtained, Figure **Ошибка! Источник ссылки не найден.** presents distribution of coefficients of the relative distances estimates in the regressions for crossing points in the case of road transport (for other modes of transport similar results were obtained, with the only difference being the average value of the coefficients of the relative distances).

The results of the estimations show that the coefficients in the regressions estimated for individual crossing points, as a rule, have the sign predicted in the theory so a hypothesis of their equality to zero is rejected. In the case of road transport crossing points, as seen from the picture, the values of most coefficients lie in the range from 0 to -10; whereas the average is -4.8 (previously, in the regression for the entire sample for road transport, an average value of the relevant coefficient of -4.25 had been obtained) [11].

Moreover, Figure **Ошибка! Источник ссылки не найден.** depicts the values of R^2 in the regressions for road transport crossing points. It is obvious that most values

[11] As seen from the diagram, just a few coefficient values are above zero; it should be noted that these coefficients are found to be insignificant.

exceed the values of R^2 obtained in the regressions of specifications (1) and (2), being about 0.001[12]. This can be regarded as evidence that the proposed specification of the gravity equation corresponds well to the data at the level of individual crossing points, and that the major part of the unexplained variance may be the result of individual characteristics of the crossing points (see the ‘Conclusion’ section for their interpretation). In this situation the introduction of dummy variables for the crossing points is expedient.

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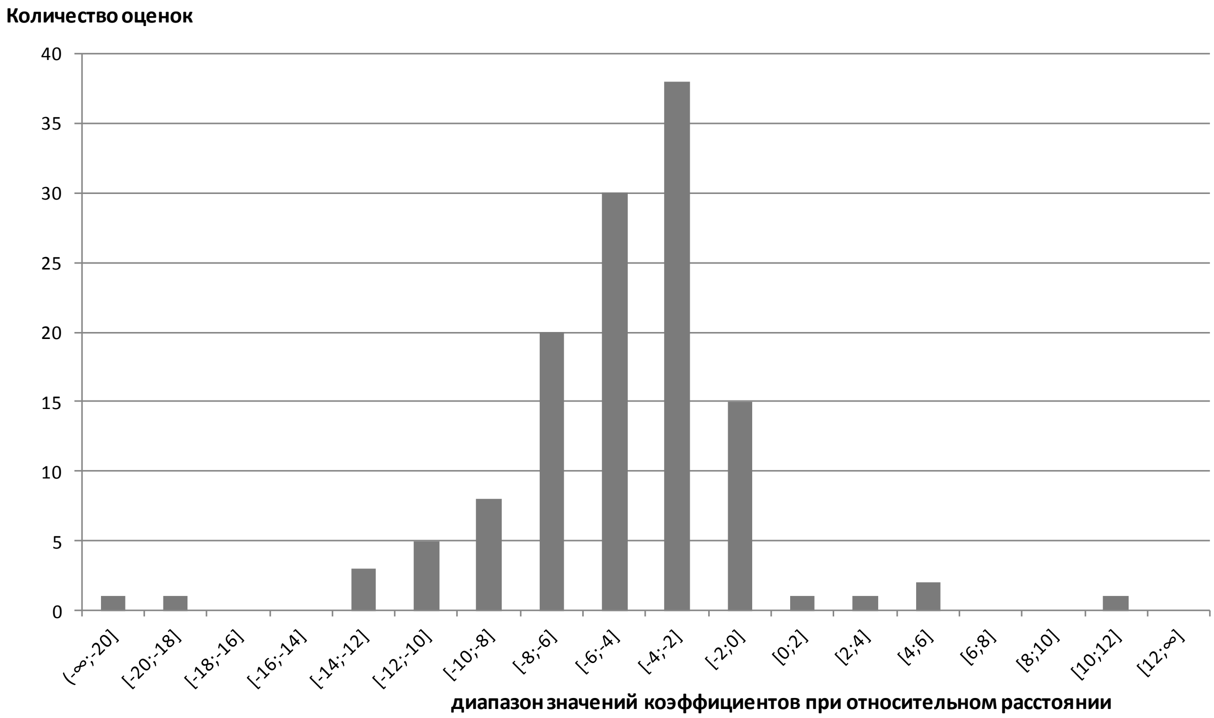
[12] We should note that the values of R^2 in the individual regressions are, on average, lower than the value of R^2 for the regression on the entire sample, using dummy variables (specification (4)). This is associated with peculiarities of the calculation of the R^2 coefficient which, by definition, is calculated using the following formula: $\boldsymbol{R}^2 = 1 - \frac{\boldsymbol{ESS}}{\boldsymbol{TSS}} = 1 - \frac{\sum (y - \hat{y})^2}{\sum (y - \bar{y})^2}$. In switching from the estimation of individual regressions for checkpoints to the estimation of the regression for the entire sample, when using dummy variables, the ESS contribution for each point changes slightly due to the modeling of the total inclination angle of the estimated dependency for all the checkpoints, however, this change will be relatively small. On the other hand, the TSS changes quite significantly upwards, because, for the regression on the entire sample, the value of $\bar{y}$ will be the same across the entire sample (although not for any individual checkpoint). Thus, in the regression on the entire sample the value of TSS will increase considerably in relation to ESS compared to the case of regressions on the individual checkpoint subsamples. This means that, in comparison to the individual regressions on the subsamples, the value of R^2 on the entire subsample should be greater, and this is observed in practice. Conceptually, this means that when estimating the regression with dummy variables we are technically “ascribing” to them additional explanatory power, which, in reality, they do not have.

We should also note that, when estimating the spatial regression using special within-transformation, we obtained R^2 as equal to 0.14.



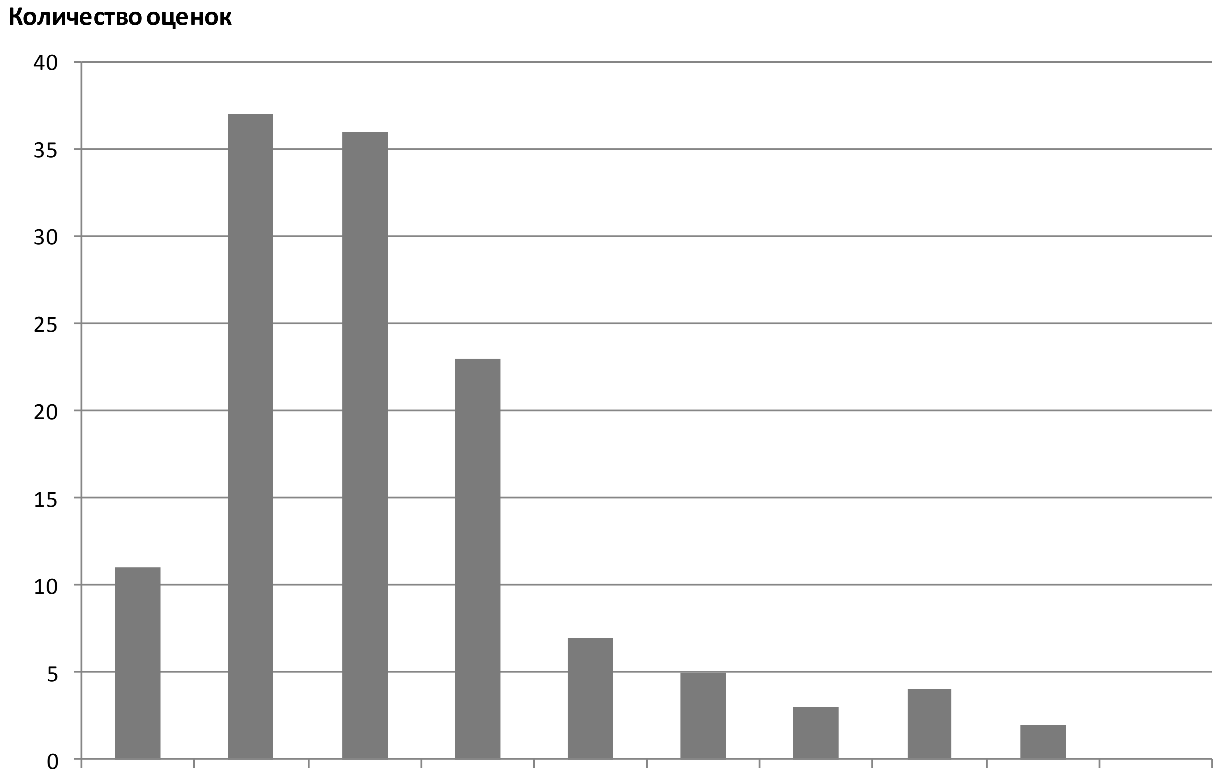


Figure 4. Values of the coefficients of the at relative distance and R^2 obtained by evaluation of the gravity equation in specification (2) separately for each vehicular crossing point

Количество оценок	Number of estimates

Диапазон значений коэффициентов при относительном расстоянии	Range of values of coefficients for the different relative distances
Диапазон значений R^2	Range of values of R^2

Summing up, it can be said that the results of estimation of the gravity equation developed in the theoretical part of this paper have shown that:

- the coefficient of the relative distance is significant, negative and equal to -3.45 (depending on the mode of transport, the values range between -0.31 and -4.25);
- the parameter of the border transparency coefficient (the coefficient in the denominator) is significant, positive and equal to 0.19 (depending on the mode of transport, the values range between -0.08 and 1.37);
- the coefficient of the sum of the distances through other crossing points is significant, positive and equal to 1.91 (depending on the mode of transport, the values range between 0.93 and 2.31);
- the coefficients of the GDP of the exporting country and the GRP of the importing region are significant, positive and equal to 0.50 and 0.86, respectively (depending on the mode of transport, the values range between 0.34 and 0.66 and between 0.51 and 1.18).

Conclusion

This paper presents the results of a theoretical development and verification of the spatial gravity model of international trade for the Russian Federation. It describes the key approaches to the creation and application of gravity models of trade and proposes the specification and methodology of estimation of an extended gravity model to take spatial effects into account.

The first part of the paper modifies the theoretical fundamentals of the gravity models of trade by describing the real processes of international trade relations. In particular, the developed spatial gravity model takes into account the fact that international trade by the Russian Federation is carried out through border crossing points, and is able to highlight the factors affecting the trade volumes passing through each of the different available routes.

Taking into account the type of theoretical model obtained, a non-linear least-squares method was applied for its estimation in the empirical part of the paper. The the model was also estimated taking into account different individual effects: both for the regions involved in trade and related to the crossing points. The aim here was to take into account different non-observable factors, which had not been included explicitly in the gravity equation. The coefficients of the model obtained were analysed for the cases of different modes of transport being used in the actual movement of goods.

The following conclusions may be drawn, based on the results of the study:

1) The spatial gravity model which has been developed in this paper may be used for description of the volumes and routes of Russia's international trade flow and for forecasting their response to changes in a range of factors. The values of the coefficients within the model, obtained by econometric estimation, do not conflict with the formulated theoretical hypotheses.
2) The distance between the importer and exporter, which is a proxy variable for trade barriers, has a negative impact on trade volumes; however we must take into account, not the distance itself, but its relative length, compared to the distances to other trade partners (i.e. taking into account the 'multilateral resistance'). This result is entirely consistent with the findings of international research on this subject.
3) In addition to the effects of the relative distances involved, trade volumes may also be affected by other spatial factors, in particular, the location of the crossing points. Here we observe the operation of two simultaneous and opposite effects: on the one hand, opening of an additional crossing point on a border section results in redistribution of the trade flows, and to some reduction in the flow through the pre-existing crossing points, whilst, on the other hand there is an increase the aggregate trade flow across the border section as a whole, due to the reduction in the hindrances to trade.
4) Due to the significance of the individual dummy variables for crossing points it can be concluded that the model presented in the paper is not adequate for explaining the dependencies of trade flows between

different crossing points, although it does provide quite a good explanation of the dependencies for any single crossing point. It appears that those factors which are not taken into account by the model are related to the individual characteristics of the crossing points themselves (their actual capacity, complexity of customs clearance, specialisation of the crossing point, condition of the infrastructure, ease of access) and have a significant effect on the differences in trade flows. The explanation of these may become the subject of further research.

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