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Searching for the Appropriate Measure of Multilateral Trade-Resistance Terms in the Gravity Model of Bilateral Trade Flows

A b s t r a c t. The aim of the paper is to compare different approximations of multilateral trade-resistance in the gravity model and the influence of their use on estimation results for models of EU-trade. Three synthetic variables: for bilateral trade costs, exporter's and importer's remoteness are used as an alternative for including time-varying country effects. Results indicate significant impact of those variables but not wholly compatible with the theory. Estimated coefficients of trade determinants, including Euro's effects, have expected values in both approaches only if the FE estimator is applied.

K e y w o r d s: international trade, panel data, gravity model, multilateral trade-resistance terms, bilateral trade costs, globalization in the XXI century, Euro's effect

J E L Classification: F10, F14, F15, C23, C24, C26.

Introduction

The gravity model is a common tool for analyzing the flows of international trade. The characteristics of panel data allow for taking into consideration unit specific effects with regard to territorial units covered by the study, as well as time effects referring to the years under analysis. Therefore,

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it assists in controlling for unobserved heterogeneity, which could not be accounted for by explanatory variables in the model, which is useful for such a macroeconomic study. An additional incentive for using the gravity model is that the necessary data is relatively easily available. Estimation results of a majority of studies described hereinafter are quite similar for the main variables in the model – differences come from the different test samples and different time periods, as well as from different estimation methods used in the research.

Focusing on theoretical assumptions of the model can easily explain the inaccuracy of some empirical trade analyses based on the gravity model. According to the theory of Anderson and van Wincoop (2003), decisions about international trade essentially depend on the relative trade costs, which are however not easy to measure. One of the aims of this study is to identify the best measure of these costs, which will cover the multilateral trade-resistance, both for exporter and importer. Estimated panel gravity models include typical explanatory variables: national income, measure of bilateral distance and the set of dummy variables for common border, common language and access to the sea. Additionally, considering the utility of the gravity model by the test of trade-agreement effect, in former analysis there were the dummy variables used to describe the participation in The Economic and Monetary Union (Micco et al., 2002, 2003; Maliszewska, 2004).

Another purpose is the analysis of the international trade between EU countries, which create an integrated, relatively homogenous area, where such variables like tariffs or rates of exchange that do not have to be included in the model. Globalization is often defined as the growing integration of economies and societies around the world[1] "mainly by free trade and free capital mobility, but also by easy or uncontrolled migration" (Daly, 1999), "leading to the notion of a borderless global or planetary economy" (Avinash, 2000), which makes the European Union a great example of the globalized economies.

Globalization in the XXI century is a specific time – there are deeper and broader changes in the global economy – spread of the "New Economy" as well as the new information and communication technology (ICT), what is pointed out in recent studies (Ramos and Ballell, 2009; Farhadi et al., 2012; García-Muñiz and Vicente, 2014). Friedman describes 1999 as the year of the Internet, when the globalization started a new era, opened for outsourcing, offshoring and other new activities changing the global trade structure

[1] Definition used by The World Bank Group, 2001.

(Friedman, 1999). That is the reason choosing 1999 the starting year of the analyzing time period.

Three research hypotheses were put forward within the framework of the carried out objective. The first assumes that the travel time between centroids of countries is a good base for approximation of bilateral trade costs. Following the second hypothesis, bilateral trade flows increase if exchange partners are members of the Eurozone. The third hypothesis assumes that synthetic variables of bilateral costs and remoteness are accurate approximation of multilateral trade-resistance terms for EU countries.

Two first parts of the paper discuss the theoretical assumptions of the gravity model for trade flows and the problems with its estimation. The third focuses on the description of the new measures for multilateral trade-resistance terms. The final part presents the results of conducted research.

1. Theory of the Gravity Model of Bilateral Trade Flows

The first gravity equation was based only on empirical research of Tinbergen (1962). Inspired by Newton's law of universal gravitation, author presented following "traditional" gravity equation for trade[2]:

$$Y_{od} = \alpha_0 X_o^{\alpha_1} X_d^{\alpha_2} D_{od}^{\alpha_3}, \tag{1}$$

where: Y_{od} – volume of trade flow from country *o* (origin) to country *d* (destination), X_o, X_d – national income of countries *o* and *d* (GNP volumes), D_{od} – physical distance between the two countries.

More generally, we can describe the gravity model by four forces: G – external (global) factors expressing "gravitational constant", although it is only held constant in the cross-section, S_o, M_d – specific factors of origin and destination factors expressing their "masses", and ϕ_{od} – negative factors expressing the trade costs, with the following form:

$$Y_{od} = G \cdot S_0 \cdot M_d \cdot \phi_{od}, \tag{2}$$

The gravity model with panel data structure can be written in following logarithmic form:

$$\mathbf{Y}_{od,t} = \alpha_0 + \alpha_1 \mathbf{X}_{o,t} + \alpha_2 \mathbf{X}_{d,t} + \alpha_3 \mathbf{D}_{od,t} + \boldsymbol{\varepsilon}_{od,t}, \tag{3}$$

[2] This equation implies that exports have a constant elasticity with respect to each of three explanatory variables – what means that a 1 per cent increase in the GNP of country *d* always results in an increase of α_2 per cent in the exports of the supplying country *o*.

where: $d \neq o, \in \{1,2,...,N\}$, $\mathbf{Y}_{od,t}$ – flow values (log) between regions *o,d* – object's number[3], *t=1,2,...,T* – number of time period, $\mathbf{X}_{o,t}$, $\mathbf{X}_{d,t}$ – explanatory variables values (log) respectively for origin and destination regions, $\mathbf{D}_{od,t}$ – bilateral trade costs, including distance between regions (log), $\alpha_0, \alpha_1, \alpha_2, \alpha_3$ – structural parameters of the model[4], $\boldsymbol{\varepsilon}_{od,t}$ – random component.

Tinbergen (1962) also extended his model for 18 developed countries by dummy variables of common border, Commonwealth preference and Benelux preference and, in the second case, by the Gini coefficient of export commodity concentration. Further research of econometricians was expanded by additional variables and effects, like time effects or country pair effects. Nevertheless, the gravity equation still needed the theoretical assumptions, which became a key issue in the following years. The theory of gravity model was proposed by Anderson (1979), Bergstrand (1989), Deardoff (1998), Eaton-Kortum (2002) and Anderson and van Wincoop (2003). The last one was named as "the final structural gravity equation" and it passes now for the most accurate description of reality. The most important part relates to the relative trade costs, which are included in the model as multilateral trade-resistance (MTR) terms. Namely, these two terms measure the exporter's and importer's joint average trade resistance (in terms of trade barriers), which each of them faces to all their other potential trading partners. For instance, if there is a rise in trade barriers between importing country *d* and all its other possible trading partners (inward MTR rises), the relative price of the exporting country *o*'s products will decrease and trade flows between *o* and *d* will increase. Likewise, if outward MTR rises, overall demand on *o*'s exported products will slow down, thus reducing the price P_o, which, under conditions of the constant trade barriers, will consequently increase trade flows between both countries. The new structural gravity equation takes the form of:

$$EXPORT_{od} = \frac{X_o X_d}{X^W} \left(\frac{t_{od}}{\pi_o P_d} \right)^{1-\sigma}, \tag{4}$$

[3] In case of panel gravity models, which analyze trade flows, a pair of regions represents an object (unit), namely $i = \{o,d\}$. For *N* analyzed regions $(N^2 - N)$ objects are included in the study, i.e. pairs of trading partners.

[4] Prediction that $\alpha_1 = 1$, $\alpha_2 = 1$ leads to the unit-income-elasticity model, what was often assumed by researchers in the studies.

with:
outward (exporter's) multilateral trade-resistance**:**

$$(\pi_o)^{1-\sigma} = \sum_o \left(\frac{t_{od}}{P_d} \right)^{1-\sigma} \frac{X_d}{X^W}, \qquad (5)$$

and inward (importer's) multilateral trade-resistance:

$$(P_d)^{1-\sigma} = \sum_o \left(\frac{t_{od}}{\pi_o} \right)^{1-\sigma} \frac{X_o}{X^W}. \qquad (6)$$

where: X_o, X_d – national income values of both trading countries, X^W – World's income, t_{od} – trade cost factor reflecting bilateral trade resistance between country *o* and *d*, σ – elasticity of substitution.

The conception of multilateral trade-resistance of trading countries is intuitively convincing since all the countries have a lot of potential alternative trading partners and relationships with them that influence the bilateral trade-resistance. Hence the trade impediments between countries should not be approximated only by the bilateral trade costs. Moreover, the import and export of more developed and wealthy countries should be easier, which is also expressed in the above form of gravity equation by implementing the income shares in the total World income. Omitting the theoretically motivated MTR terms in the gravity models leads to the systematic bias in coefficient estimates of bilateral trade-cost variables. This form of gravity model, acclaimed to be the most accurate one because of using relative differences between countries, was easily expanded to describe another foreign flows, namely migration flows (Anderson, 2011).

2. Difficulties with Empirical Research Based on the Gravity Model of Trade Flows Using Panel Data

The multiplicative nature of the gravity equation, quality of available database, characteristics of panel data or the big amount of missing data yield many potential problems with a solid empirical analysis. Among the biggest problems occurring by estimating the panel data gravity models are[5]:

- multitude of zero-observations (log-linearization is not feasible in these cases),

[5] More problems with trade data are presented in Feenstra et al. (2001). For essential reference on panel-data models see Hsiao (2003).

- error terms in the usual log-linear form of the gravity equation are heteroscedastic (which violates the assumption that error term should be statistically independent from the regressors, using OLS-method after the log-linearization leads to inconsistent estimates of the elasticity of interest, the NLS estimator is in turn very inefficient, as it ignores the heteroscedasticity),
- variance of the error term is not constant (NLS estimator is not optimal)
- trade data are suffering from rounding errors (that leads to the bias of estimates),
- MTR terms should be included in the gravity model of bilateral flows, but they are not directly observable.

There are many potential methods that can more or less overcome the foregoing problems. One way with the first problem is dropping the pairs with zero from the trade-data set, what allows for using OLS estimation method. Another way is to keep these observations by adding a constant to zero-observations, for instance ($Y_{ij}+1$) and use again OLS method, what can be found in Martinez-Zarzoso (2007), Westerlund and Wilhelmsson (2009), or use tobit model for panel data (Soloaga and Winters, 2001; Baldwin and DiNino, 2006; Tripathi and Leitão, 2013). However, all three of these methods lead to inconsistent estimates (especially by tobit models, where estimation results depend on the chosen constant). To avoid this problem, Santos Silva and Tenreyro (2006) proposed the use of PPML (Poisson pseudo maximum likelihood) estimator[6] in levels, which not only deals with zero-value observations, but also can be easily adapted in models with endogenous regressors, providing unbiased estimates in the presence of heteroske-dasticity, where all observations are weighted equally.

The choice of an accurate estimation method in face of all the problems connected with the gravity model is never infallible; hence the common way is to use several estimation methods, appropriate to considering case of study. Every estimator has pros and cons[7] and the inference based on the only one method is not advisable. Even using the Hausman test by pointing out the right version of model between RE and FE is not practiced since the form of both models is not the same (the lack of constant variables in FE-model) and the assumption about individual fixed effects between trading

[6] Previously authors used the gamma PML (GPML), which gave good results, but is very sensitive to measurement errors – as it gives an extra weight to the noiser observations. The PPML method was originally proposed by McCullagh and Nelder (1989).

[7] Details about majority of estimation methods of gravity model are presented by Gómez-Herrera (2013).

pairs in this case seems to always be the right one. However, the readiness of researchers to know the coefficients by constant variables leads to implementing more estimation methods. The comparison of the coefficients gives an answer to the questions asked in the hypotheses of the research. Interesting research of Gómez-Herrera (2013) includes a comparison of many estimation methods (truncated OLS, OLS ($Y_{ij}+1$), tobit, probit – with Heckman's approach[8], RE, FE and PPML), where gravity model, despite of physical distance and dummies (common border, common language, same country and participation in trade agreements)[9] among regressors, included also exporter and importer time varying effects. The results of comparison of several techniques with a dataset covering 80% of World trade induce to choose the Heckman sample selection model as the preferred estimation method within nonlinear techniques when data are heteroskedastic, but this approach is preferred when the data also contain a significant proportion of zero observations – what is natural by analyzing 80% of the World trade.

The need of using MTR terms is the result of new structural gravity equation proposed by Anderson and van Wincoop (2003), which logarithmic form is following:

$$\begin{aligned}\mathbf{EXPORT}_{od,t} &= \alpha_0 + \alpha_1\mathbf{X}_{o,t} + \alpha_2\mathbf{X}_{d,t} + \alpha_3\mathbf{t}_{od,t} + \alpha_4\boldsymbol{\pi}_{o,t} \\ &+ \alpha_4\mathbf{P}_{d,t} + \boldsymbol{\varepsilon}_{od,t},\end{aligned} \tag{7}$$

where: $\sigma = 1-\alpha_3$.

There are two ways to take MTR on board in the gravity model: 1) creating synthetic variables for both countries – remoteness[10] – or: 2) including time-varying individual effects for both countries in the gravity model (the dummy variables identifying the exporter and importer)[11].

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[8] See Bikker and de Vos (1992), Linders and de Groot (2006), Martin and Pham (2008).

[9] The formula to compute the effect of dummy-variables is following: $\left(e^{b_i}-1\right)\times 100\%$, where b_i is the estimated coefficient.

[10] Wei (1996) defined as the log of GDP-weighted average distance to all other countries.

[10] The use of simulation method allows to obtain MTR as well. However, because of the complex calculation problem, this method is rarely taken into consideration by researchers. Anderson and van Wincoop (2003) used non-linear programming to include MTR terms, assuming that elasticity of substitution equal to $\sigma = 8$. However, Feenstra (2002) showed that it is possible to apply importer and exporter fixed effects to obtain approximately similar results. Alternatively, Baier and Bergstrand (2009) introduced variables of MR approximations which produce consistent estimates, using Taylor approximation. This approach were used also by Behar and Nelson (2012).

The first method faces a problem with the choice of the right form of the variable. The implementing of physical distance is not enough to approximate bilateral costs, used then in the remoteness variable, since it doesn't cover the whole trade costs, is not time-varying and forces to take the assumption about symmetric bilateral trade costs. There also appeared to be another calculation problems, for instance the measure of inter-distance by the formula proposed by Head and Mayer (2002)[12]. The literature provides a lot of ways to calculate bilateral trade costs. The most common way, despite using only physical distance, is to create bilateral costs-equation by implementing dummy variables, such as common border, common language, landlocked and others, namely[13]:

$$t_{od} = d_{od}^{\beta_1} \cdot \exp\left[\beta_2 border_{od} + \beta_3 language_{od} + \ldots (other\_dummies)\right]. \tag{8}$$

However, the equation above is still difficult to calculate and provides still constant and symmetric variable for both countries of the trading pair. The calculation of time-varying bilateral trade costs is possible through using the time-varying specific variables in the equation with some specific weights, like:

$$t_{od,t} = \ln\left(w_1 x^s_{1od,t} + w_2 x^s_{2od,t} + w_3 x^s_{3od,t} + \ldots + w_n x^s_{nod,t}\right), \tag{9}$$

where: w_n – weights, $x^s_{nod,t}$ – standardized values of regressors[14].

Substantial weakness of this approach is the problem of appropriate weights. Taking the arbitrary weights does not seem to be correct in face of the differences between countries and non-theoretical or empirically-based assumptions.

The use of the second method – time-varying individual effects – seems to be easier, however, it increased the dimension of the estimated matrix causing calculating problems and does not allow for incorporating specific variables for countries into the model due to collinearity, what leads to a bias[15].

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[12] In this study, the author proposed the approximation of the inter-distance based on literature, namely ≈ square root of land surface*0,4.

[13] See Baier and Bergstrand (2009); Baldwin and Taglioni (2006).

[14] For more details about the method, see Drzewoszewska et al. (2013).

[15] Likewise, the inclusion of the exporter and importer dummies in the model means that inclusion of time invariant exporter and importer characteristics is not possible in this case. See Ruiz and Vilarrubia (2007).

Facing the problems above, there is no standard way to incorporate MTR in the gravity model so far. In the literature, there is a lot of research with exporter and importer effects in gravity model of bilateral trade flows, e.g. Rose and Wincoop (2001), Baltagi (2003), Ruiz and Vilarrubia (2007). The popular practise is to include country-pair effects as well, eg. Glick and Rose (2002), Baltagi (2003), Micco et al. (2003), Fratianni and Hoon-Oh (2007), Fidrmuc (2008), Bussière and Schnatz (2009). Furthermore, using time effects in the gravity model is a common issue now, as it replaces global circumstances, shocks, ect. Another way could be spatial modeling – in the research of FDI Fernández-Avilésa et al. (2012) proposed a simple FDI-based measure of financial distance with the use of spatial techniques.

The remoteness variables for exporting and importing countries used in foregoing studies have different formulas, are both time-varying (Baldwin and Taglioni, 2006) and fixed (Fidrmuc, 2001; Ruiz and Vilarrubia, 2007). For instance, Head (2003) calculates remoteness as a country's average weighted distance from its trading partners, where weights are the partner countries' shares of world GDP.

The physical distance between trading countries approximates bilateral trade costs since the first application of gravity model. The coefficient of this variable in estimated models is always negative in all the empirical analysis, what makes it a common measure used by researchers. However, the trade costs are created primarily by transport costs, which are depended on the quality of transport infrastructure, tariffs, prices, as well as on the distance. An alternative measure of bilateral trade costs for UE countries is prosed in the empirical part of this study.

3. A New Measure of Remoteness

The new formula of remoteness variables, proposed in this study, allows for using time-varying bilateral costs, which according to the strong assumption in Anderson and van Wincoop (2003) theory are symmetric. Besides, using the distance between countries to describe their bilateral costs leads to the constant remoteness, which is another unreal assumption. The formulas of three synthetic variables – bilateral costs $t_{od,t}$, exporter's remoteness $REM_{od,t}$ and importer's remoteness $REM_{do,t}$ – are following:

$$t_{od,t} = \frac{DISTANCE_{od}}{IMPORTER'S\_OPENNESS_{od,t}}, \tag{10}$$

where:

$$IMPORTER'S\_OPENNESS_{od,t} = \frac{EXPORT_{od,t} + EXPORT_{do,t}}{TOTAL\_IMPORT_{d,t}}. \quad (11)$$

Bilateral trade costs (10) became time-varying in this approach, which suits better to reality – trading costs are not constant over time and the psychical distance, especially in the era of globalization XXI century, does not lower the trade flows as much as 50 years ago. Here the distance between countries, measured by travel time between the centroids of trading countries, is divided by share of bilateral trade exchange in the total import of importing country. Moreover, this method reflects the theoretical significance of importer's demand in the final amount of bilateral trade flows.

Importer's demand is also underlined by the following form of exporter's remoteness variable:

$$REMOTENESS_{od,t} = \sum_{k \neq o,d} \frac{t_{ok,t}}{INCOME_{k,t} / WORLD\_INCOME_t}, \quad (12)$$

which is the sum of bilateral costs divided by importer's income share in the World's total income. It is expected that a relatively richer importing country will have a larger overall demand, hence the export to this country will be relatively easy (exporter's remoteness is smaller then).

In this approach, importer's remoteness variable includes analogously the exporter's income share in the World's total income as a weight in the weighted average:

$$REMOTENESS_{do,t} = \sum_{k \neq o,d} \frac{t_{kd,t}}{INCOME_{k,t} / WORLD\_INCOME_t}. \quad (13)$$

However, the denominator of importer's remoteness variable above underlines exporter's condition, what (being still potential good weight) does not play substantial role in the demand of importing country[16]. Potentially better weight would be a share of bilateral export from the importer in his total export, since it better expresses importer's condition and also reflects the interrelation with his trading partner. Hence, an alternative measure for importer's remoteness is the following:

[16] In macroeconomic theory, import is defined as a function of the domestic absorption A (total demand for all final marketed goods and services) and the real exchange rate σ, taking the form of: $I = f(A,\sigma)$. See Burda and Wyplosz (2005).

$$REMOTENESS_{do,t} = \sum_{k \neq o,d} \frac{t_{kd,t}}{EXPORT_{dk,t} / TOTAL\_EXPORT_{d,t}}. \quad (14)$$

Comparison of the estimated coefficient's sign of both above importer's remoteness synthetic variables would give an answer if the second form, more economically justifiable, contains a better approximation of inward multilateral resistance. According to the theoretical assumptions of Anderson and van Wincoop (2003), the MTR terms should have a positive impact on bilateral trade flows.

According to the theory, estimation results of models with remoteness synthetic terms and models with countries time-varying specific effects should have similar estimates of the rest of the variables. This could confirm that the created synthetic variables are a good approximation of MTR, which allows for estimation of their exact influence, also giving an opportunity to use more estimators, like PPML or HT. The model to compare has the following form:

$$\begin{aligned} \mathbf{EXPORT}_{od,t} &= \alpha_0 + \alpha_1 \mathbf{I}_{o,t} + \alpha_2 \mathbf{I}_{d,t} + \alpha_3 \mathbf{I}_t + \alpha_4 \mathbf{t}_{od,t} \\ &\quad + \alpha_5 \mathbf{X}_{od,t} + \boldsymbol{\varepsilon}_{od,t}, \end{aligned} \quad (15)$$

where: $\mathbf{I}_{o,t}, \mathbf{I}_{d,t}$ – time-varying individual effects, $\mathbf{I}_t$ – time effects, $\mathbf{t}_{od,t}$ – bilateral trade costs, $\mathbf{X}_{od,t}$ – set of dummies for the trading pair.

An easier way to estimate MTR can be the assumption that MTR is constant over time, what allows for using only fixed individual effects for both countries, with lower dimension of the estimating matrix. However, this assumption is advisable in the case of relatively short time period, so it is not considered in this study.

4. Gravity Model of Bilateral Trade Flows for EU Countries in the Period of 1999–2011 – Empirical Results

The data used in this study consists of a sample of 25 EU countries, with the following database-sources: Comtrade/OECD, WDI and Google Maps application. In order to analyze the trade in the era of globalization XXI century, the chosen time period of research is opened by "the year of the Internet" and includes the last year of available data. Variables included in the analysis are presented in Table 1.

The first step of research was to look for an alternative variable that could replace the physical distance in the traditional gravity model. As a matter of fact, the physical distance is considered as a good approximation of bilateral trade costs, however it does not take into account the quality of transport infrastructure, which varies over the countries and influence on the time and costs of transportation. The use of the time travel between centroids of countries became possible owing to free Google Map application, which time-data was downloaded on 14.03.2014[17].

Table 1. Variables included in the analysis of international trade flows

Variable	Definition	Measure unit	Source
EXPORT	Export flows in current prices from origin country to destination country	USD	Comtrade/OECD
GNI	Gross National Income in current prices[18]	USD	WDI
DIST	Great circle distance between the national centroids	km	Author's calculation
TRAVEL	Travel time by road between the national centroids[19]	hour	Google Maps
border	1 if two trading countries share a common border and 0 otherwise	dummy variable	
language	1 if two trading countries share a common language and 0 otherwise	dummy variable	
sea	1 if at least one from both trading countries is not landlocked and 0 otherwise	dummy variable	
OneEMU	1 if the importer belongs to The Economic and Monetary Union but the exporter does not and 0 otherwise	dummy variable	
BothEMU	1 if both of the trading countries in the pair are members of The Economic and Monetary Union and 0 otherwise	dummy variable	

[17] Generally, Google Maps application offers a route planner for traveling by foot, car, bicycle (beta test), or with public transportation. It does not include the information about current traffic in its calculation (this is a property of another application - the Google Traffic). Reproducing the calculation in a short time period gives equal results of the travel time by car between two chosen locations. Google created the application in 2005, hence it is impossible to find a data with the measurement of travel time across last 13 years. However, the regular collecting of the data generated by Google Maps could be successfully used in the future research.

[18] The use in the study GNI instead of GDP variable is intentional, as it measures income received by a country both domestically and from overseas. In fact, there is considered the output from the citizens and companies of a particular nation, regardless of whether they are located within its boundaries or overseas. The first empirical research provided by the author of the gravity equation – Tinbergen (1962) included similar measure, namely GNP.

[19] Great circle distance algorithm was used in the calculation.

Table 2. Traditional gravity model of trade flows for EU-25 countries[20] in 1999–2011 with physical distance between centroids as approximation of bilateral trade costs – results for alternative estimation methods

Model A	OLS ($Y_{ij}+1$)	RE	FE	HT	Tobit ($Y_{ij}+1$)	PPML
lnGNI_o	–0.13	1.30***	1.30***	1.30***	1.97***	0.76***
lnGNI_d	0.52***	1.05***	1.05***	1.05***	0.58***	0.74***
lnDIST	–1.23***	–1.50***		–1.50***	–1.51***	–0.98***
OneEMU	–0.24	0.08	0.08	0.08***	–0.16*	–0.15***
BothEMU	0.25**	0.14***	0.14***	0.14***	0.15*	–0.02
border	0.21	0.13		0.13	0.05	0.21***
language	–0.38	–0.07		–0.06	–0.34	0.47***
sea	0.21	0.33***		0.33***	0.33*	0.08**
TE	Yes	Yes	Yes	Yes	Yes	Yes
CE	Yes	Yes	No	Yes	Yes	No
Constant	20.70***	–30.40***	–40.40***	–32.50***	–35.40***	–11.60***
Number of state	600	504	504	504	600	504
Observations	7800	6533	6533	6533	7800	7800
R^2			0.777			

Note: TE – time effects, CE – country effects (separately for exporter and importer); *** p<0.01, ** p<0.05, * p<0.1.

Table 3. Traditional gravity model of trade flows for EU-25 countries in 1999–2011 with travel time between centroids as approximation of bilateral trade costs – results for alternative estimation methods

Model B	OLS ($Y_{ij}+1$)	RE	FE	HT	Tobit ($Y_{ij}+1$)	PPML
lnGNI_o	–0.13	1.30***	1.30***	1.30***	1.96***	0.75***
lnGNI_d	0.52***	1.05***	1.05***	1.05***	0.59***	0.73***
lnTRAVEL	–1.39***	–1.76***		–1.76***	–1.77***	–1.03***
OneEMU	–0.26*	0.07	0.08	0.07***	–0.19**	–0.19***
BothEMU	0.27**	0.15***	0.14***	0.15***	0.17*	–0.09***
border	0.21	0.09		0.09	0.01	0.19***
language	–0.40	–0.13		–0.13	–0.42*	0.38***
sea	0.25	0.35***		0.35***	0.35**	0.09***
TE	Yes	Yes	Yes	Yes	Yes	Yes
CE	Yes	Yes	No	Yes	Yes	No
Constant	16.30***	–35.40***	–40.40***	–38.30***	–40.40***	–15.00***
Number of state	600	504	504	504	600	504
Observations	7800	6533	6533	6533	7800	7800
R^2			0.777			

Note: TE – time effects, CE – country effects (separately for exporter and importer); *** p<0.01, ** p<0.05, * p<0.1.

[20] The sample includes all EU countries without Malta and Cyprus.

Validity of replacing physical distance by travel time in the gravity model was checked by comparison of estimation results of two models: with distance as approximation of bilateral trade costs (Model A) and with travel time respectively (Model B).

Tables 2 and 3 show that the gravity model with travel time estimated with several estimation methods – OLS ($Y_{ij}+1$), RE, FE, HT, tobit ($Y_{ij}+1$) and PPML – gives similar estimates of other variables as the model including physical distance. The influence of travel time is significant and still negative in all cases, as expected. Hence, the travel time between centroids of trading countries is replacing the physical distance in the gravity model in this study.

Different results for the dummy variable describing the participation of only the importing country in EMU have different estimates, however negative signs occur only by the most naïve methods – namely OLS and tobit model, where zero-export flows are replaced by the value of 1. Unexpected signs occur by PPML method, however, the estimated models do not include country effects, which can lead to the bias in estimates.

Despite improving the gravity equation by introducing the variable which covers the influence of physical distance and the quality of road infrastructure, the variable of travel time remains still constant, what does not represent the whole reality. Then the second step of the research is to create a time-varying synthetic variable describing bilateral trade cost according to the formula (10) and afterwards use it in the next synthetic variables: exporter's and importer's remoteness, according to (12), (13) – Model 1 – and according to (12), (14) – which reflects Model 2[21]. All synthetic variables were used in the gravity model (7), with and without fixed country effects for exporter and importer. The most similar estimates, with higher R^2 coefficients as well, were obtained in the models including time and country effects, whose estimation results are shown in Table 4.

[21] The share in World income in remoteness variable was counted in two ways: through dividing by the total income of UE-25 countries as well as by the total World income. As expected, the estimation results in both cases were almost identical estimates, including the R^2 coefficient of estimated FE-model (90%), where the only differences were exposed by the constant.

Table 4. The structural gravity models of trade flows for EU-25 countries in 1999–2011 with remoteness as an approximation of MTR – results of approaches 1 and 2 for alternative estimation methods

Model 1	RE	FE	HT	Tobit	PPML
lnGNI_o	0.424***	0.468***	0.428***	0.425***	0.286***
lnGNI_d	2.259***	2.215***	2.256***	2.258***	1.449***
lnBTC_od	–0.690***	–0.659***	–0.687***	–0.689***	–0.587***
lnREM_od	1.103***	1.068***	1.100***	1.102***	0.642***
lnREM_1_do	–0.523***	–0.515***	–0.523***	–0.523***	–0.326***
OneEMU	0.244***	0.238***	0.243***	0.243***	0.040*
BothEMU	0.257***	0.245***	0.256***	0.257***	–0.015
border	–0.085**		–0.078***	–0.083***	0.038*
language	–0.078		–0.075	–0.078	0.181***
sea	0.072*		0.076*	0.073**	–0.054**
Constant	–53.030***	–51.680***	–53.550***	–53.040***	–25.180***
Observations	6533	6533	6533	6533	6533
Number of state	504	504	504	504	
R^2		0.918			
Model 2					
lnGNI_o	0.484***	0.546***	0.494***	0.486***	0.256***
lnGNI_d	1.845***	1.797***	1.838***	1.844***	1.735***
lnBTC_od	–0.638***	–0.596***	–0.632***	–0.637***	–0.622***
lnREM_od	0.757***	0.710***	0.750***	0.756***	0.960***
lnREM_2_do	–0.260***	–0.248***	–0.259***	–0.260***	–0.457***
OneEMU	0.256***	0.248***	0.255***	0.256***	0.018
BothEMU	0.292***	0.275***	0.290***	0.292***	–0.031**
border	–0.005		0.008	–0.002	–0.066***
language	–0.036		–0.029	–0.034	0.145***
sea	0.159***		0.169***	0.161***	0.087***
Constant	–42.910***	–42.350***	–41.310***	–42.910***	–33.890***
Observations	5441	5441	5441	5441	5441
Number of state	420	420	420	420	420
R^2		0.900			
TE	Yes	Yes	Yes	Yes	Yes
CE	Yes	No	Yes	Yes	No

Note: TE – time effects, CE – country effects (separately for exporter and importer); *** p<0.01, ** p<0.05, * p<0.1.

Table 4 does not show the fully expected results. Mainly, the coefficient of importer's remoteness variable remains negative in all cases, although, due to the Anderson and van Wincoop's theory, it covers trade barriers between importing country and all its other potential trading partners, so it is expected to have a positive influence on bilateral import flows from the one considering importer's partner. The construction of synthetic remoteness variable as weighted average of bilateral costs of trade with other partners is, however specific – not such strongly connected with relative prices as in the theoretical approach. In the case of the importer this remoteness could be interpreted more as the importer's ability to import from other countries, which is not so opposite to the ability to bilateral import, seeing that trading goods are differentiated not only by their place of origin[22] and the bilateral trade costs are not symmetric.

According to Table 4, none of border coefficients are positive, despite the PPML approach, which results in negative influence of sea access instead. Model 2 with importer's remoteness variable calculated with the formula (14), gives more similar estimates for the most of coefficients by using different estimation methods, including PPML. However the weakness of Model 2 is a smaller number of state, caused by the importer's remoteness synthetic formula, which dropped the observations with zero export values. Due to calculation problems in Stata software, the estimation of PPML model was possible only without the country effects, so the results remain biased, which can be the reason of the negative influence of *BothEMU* and *border* dummy variables. The different estimates of national incomes (comparing with empirical models of the traditional gravity equation) are the result of synthetic variables formulas, they remain however significantly positive.

Table 5. The structural gravity model of trade flows for EU-25 countries in 1999–2011 with time-varying country effects as an approximation of MTR terms (Model 3)

Model 3	RE	FE	HT
lnBTC_od	–1.000***	–1.000***	–1.000***
OneEMU	–0.030***	0.177***	–0.260***
BothEMU	–0.030***	0.177***	–0.260***
border	–0.845***		–0.839***
language	–0.843**		–0.489
sea	1.008***		1.070***
TE	Yes	Yes	Yes
CE (time-varying)	Yes	Yes	Yes
Constant	27.10***	26.25***	25.78***
Observations	6533	6533	6533
Number of state	504	504	504
R^2		0.999	

Note: TE – time effects, CE – country effects (separately for exporter and importer); *** p<0.01, ** p<0.05, * p<0.1.

[22] Anderson and van Wincoop (2003) assume that each country specializes in the production of one good in the derivation to follow. As a matter of fact, in reality good specific trade resistance varies depending on the product class under consideration, what by estimation of model with aggregated data, like this used in the study, causes a large bias. See Anderson and van Wincoop (2004), Anderson and Yotow (2011).

In order to check if the created remoteness synthetic variables can be a good approximation of multilateral trade-resistance, the estimates of the models should be in phase with the estimates of models including time-varying countries effects, which is the next step of study. The estimation results are presented below in Table 5.

The complexity of calculation (using Stata software) of the model with time-varying countries effects (Model 3) does allow only for the use of RE, FE and HT estimators. The FE-model gives the estimates only for time-varying and non-specific country variables, however it seems to be the most accurate method since its extremely high coefficient of determination and the additional use of time-invariant pair effects, which absorb all time-invariant determinants of bilateral trade costs, leading to relative small bias in the estimates. Furthermore, as the only one estimator, FE results with the same coefficients' signs in all considering cases. According to these results, bilateral trade costs synthetic variable has a negative influence on the bilateral and the EMU-effects are positive.

Table 6. Results of Hausman test, Sargan-Hansen test of overidentifying restrictions and the test for time effects

Hausman test	Chi-square	p-value	TE (time effects)	CE (const)	CE (time-varying)*	result
Model 1	746.92	0.00	+	–	–	FE
Model 2	475.79	0.00	+	–	–	FE
Model 3	–16165.56	–	+	–	+	FE
Model 3	760.99	0.00	+	–	–	No answer**
Test of overidentifying restrictions	S-H statistic					
Model 1	2308.25	0.00	+	–	–	FE
Model 1	588.20	0.00	+	+	–	
Model 2	5195.58	0.00	+	–	–	FE
Model 2	4791.49	0.00	+	+	–	
Model 3	2597.88	0.00	+	+	–	FE
Model 3	2134.06	0.00	+	–	–	FE
Test for time effects	F statistic					
Model 1	286.85	0.00	+	–	–	TE
Model 2	158.96	0.00	+	–	–	TE
Model 3	2.6e+13	0.00	+	–	+	TE

Note: * Test of overidentifying restrictions (fixed vs random effects) for model with time effects (TE) and time-varying country effects (CE) is not feasible due to permanent presence of collinearity; ** "No answer" occurs when the matrix was not positive definite.

The results of Hausman test (Table 6), conducted for all three models, show that FE estimators is more preferred than RE. However, including time-varying country effects results in negative chi-square statistic. Due to the investigation of Schreiber (2008), this result can happen only if H_1 of the test is true – FE is consistent and preferred. Moreover, the results of Sargan-Hansen test of overidentifying restrictions confirm the choice of FE estimator.

Conclusions

The purpose of this paper was to analyze the structural gravity model of trade flows with alternative approximations of multilateral trade-resistance terms. The empirical results of two synthetic variables – bilateral trade costs and exporter's remoteness give significant and expected signs of coefficients. The sign of third created synthetic variable – importer's remoteness – remains a problematic issue, since the estimates of importer's remoteness do not respond to the theory of gravity model in any case. The theory of structural gravity equation assumes however symmetric trade barriers and lower differentiation of trade than is observed in the researching sample of EU countries, especially under conditions of globalization in the XXI century. Based on the estimation results for statistically preferred FE-model only, it can be concluded that the proposed synthetic remoteness variables are good measures of MTR since including them in the model gives similar results as the model with time-varying country effects. However, it did not allow for unequivocal verification of the third hypothesis.

All the results with alternative estimation methods provided grounds for the first research hypothesis verification, confirming the accuracy of using the bilateral trade costs synthetic variable, based on the travel time between country centroids and importer's openness.

The conducted analysis did not allow for verification of the second research hypothesis, according to which bilateral trade flows increase if exchange partners are members of Eurozone. Different signs of estimated dummies describing the membership in EMU, especially in models including time-varying country effects, do not establish the accurate euro effect on the export flows between UE countries in the last 15 years.

The specificity of researched sample and time period has definitely influence the deviation from the theoretical suspicions. Among the problems still left open for consideration, the following should be mentioned: the extension of the research sample by other global-leading countries, the use of spatial effects and the use of synthetic trade costs and remoteness variables in the model with disaggregated data.

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Problem właściwego pomiaru multilateralnego oporu wobec handlu w panelowym modelu grawitacji

Zarys treści. Celem artykułu jest porównanie różnych metod aproksymacji multilateralnego oporu wobec wymiany międzynarodowej w modelu grawitacyjnym. Analizie poddany jest także ich wpływ na wyniki różnych metod estymacji modelu bilateralnych przepływów handlowych w Unii Europejskiej w latach 1999-2011. Jako alternatywę dla zastosowania w modelu zmiennych w czasie indywidualnych efektów dla kraju importera i eksportera, proponowane są trzy zmienne syntetyczne opisujące bilateralne koszty handlu, opór eksportera oraz opór importera. Tradycyjna miara odległości w modelu grawitacji, jaką jest dystans fizyczny, zastąpiony został czasem trwania podróży pomiędzy centroidami państw. Wyniki estymacji wskazują na istotny statystycznie wpływ proponowanych zmiennych, jednakże znak oceny parametru oporu importera nie odpowiada założeniom teoretycznym modelu grawitacji. Wpływ pozostałych zmiennych, w tym efekt strefy euro, jest w pełni zgodny z oczekiwaniami jedynie w przypadku zastosowania estymatora FE.

Słowa kluczowe: wymiana międzynarodowa, dane panelowe, model grawitacji, multilateralny opór wobec handlu, koszty handlu bilateralnego, globalizacja XXI wieku, strefa euro.