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The Gravity Model for Trade Theory

This article delivers a theoretical overview of the gravity model and some of its main applications. The goal is as well to provide some criticism and to discuss the effectiveness of this widely used model. The model, in fact, not only did not lose its appeal over time but, on the contrary, it continued to develop and to become more reliable and relevant. It becomes clear that, although it has some problems and limitations, the gravity model is still a widely used and compelling tool, especially in the trade flow area.

Jelen cikk a gravitációs modellról és annak fő alkalmazásairól nyújt áttekintést. A tanulmány további célja a széleskörben használt modell hatékonyságának megvitatása. A modell nem csak, hogy nem veszített népszerűségéből, hanem megbízhatóbbá és relevánsabbá vált. Világos, hogy a modell korlátai ellenére még mindig széleskörben bevett vizsgálati eszköz, különösen a kereskedelem terén.

Introduction

The gravity model, as an econometric tool, has been widely used by scholars working on trade flows, due to the relevant results it provides. The model aims to explain the volume of trade without focusing on its composition, and it uses an equation framework to predict the volume of trade on a bilateral basis and between any two countries. Thus, it is primarily interested in selecting economic variables that will be able to explain a substantial portion of the volume of trade at least in a statistical sense. However, this model also responds to several criticisms, both in terms of its theoretical basis and in its application.

Moreover, the gravity equation has become one of the most used empirical models when it comes to international trade. It can explain the determinants of trade flows between two countries and estimate future trade, measure the effects agreements on international trade flows, evaluate border effect, among others. In this context, this work wishes to conduct a theoretical discussion on the model and to present some empirical studies that used its design or its methodology. At the same time, it will discuss the reasons why the model resulted as compelling in the selected cases.

The article's structure is the following: in the next section, we elaborate on its theoretical background and econometric modelling. In the third section, we reflect on some criticisms that the model endures. In section four, we present a synthesis of empirical studies that used the model. Section five concludes.

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Theoretical background and econometric modelling

The basis of the gravity model is Newton's Law of Universal Gravitation. According to this law, the attraction between two bodies is directly related to its mass and inversely related to the square of the distance between them (1).

$$F = k\left(\frac{m_1 m_2}{d^2}\right) \tag{1}$$

Where F represents the gravitational force, m1 and m2 are the masses of the bodies, d is the distance and k is the gravitational constant.

In 1962 Jan Tinbergen transposed and applied this structure to trade flows. He was the first to introduce the gravity model in the field, and he did so by theorising that the trade between two countries is proportional to the GDP of those countries and inversely proportional to the distance between them. Thus, he modified the original equation of the model as follows:

$$X_{ij} = \left(\beta_0 \frac{Y_i^{\beta_1} Y_j^{\beta_2}}{D_{ij}^{\beta_3}}\right) \tag{2}$$

Where i and j are the countries and the volume of trade between them is represented by Xij. It is directly proportional to the incomes (Yi and Yj) and inversely proportional to the geographic distance, identified by d. The β's are the unknown parameters of the model.

The association of the statistically independent error element μ incorporates all the other factors that cannot enter the econometric model due to their complexity. Nonetheless, the correlation between international trade and equation 2, results in the following equation:

$$X_{ij} = \beta_0 Y_i^{\beta_1} Y_j^{\beta_2} D_{ij}^{\beta_3} \mu_{ij} \tag{3}$$

Since Tinbergen's fundamental work, many empirical efforts used his approach to analyse and quantify the driving forces of international trade empirically. Anderson (1979) was able to present theoretical foundations for the gravity equation at a product level by developing a model assuming Cobb-Douglas type preferences, and considering a function with constant substitution elasticity (CES). Then Bergstrand (1985), by also using the CES function, assumed that consumers have preferences that differentiate products by their origin and concluded that domestic and imported goods are not perfect substitutes.

Anderson and Van Wincoop (2003) demonstrated the gravitational equation of trade performs poorly when used to understand regional trade. They showed that the gravity model estimation suffers from the omission of variables. Thus, the authors developed a more consistent and efficient method, which estimation includes Multilateral Resistance Terms. These variables are associated with multilateral and bilateral trade resistances, and they can capture the costs of trade with other trading partners.

Because in the model there are parameters that do not behave linearly, it is not possible to estimate equation 3 by using the Ordinary Least Squares (OLS) method (Gujarati & Porter, 2011). For this reason, it was performed a logarithmic form of the equation, to linearise it and correct it. This led to the following equation:

$$lnX_{ij} = \beta_0 + \beta_1 \ln Y_i + \beta_2 \ln Y_j + \beta_3 \, ln \, D_{ij} + \mu \tag{4}$$

Another advantage of logarithmic transformation, according to Gujarati and Porter (2011) is that the angular coefficient measures the percentage change in Xij for a percentage change in Yi, that is, the elasticity of Xij in relation to Yi.

In order to improve the results, dummy variables were included, which introduce qualitative characteristics to the model, as they indicate the presence or absence of a certain common characteristic such as language, contiguity and origin of colonization, which can generate positive impacts on the flows between countries possessing such similar characters (Azevedo, 2004).

OLS, Fixed Effects (FE), Random Effects (RE), Poisson pseudo-maximum-likelihood (PPML) and others could as well be employed to estimate the model. The process of comparison of the methods derives from running tests such as Lagrange Multiplier Test (LM), Hausman Test, Reset Test and others.

The Lagrange Multiplier Test (LM), formulated by Breush and Pagan (1980), is executed in order to confront the OLS Pooled and Random Effects (EA) methods. The test examines the hypothesis that the variance of the intercept is equal to zero. In this sense, in the case of rejection of the null hypothesis, the EA method is pointed as the most appropriate.

The comparison between the RE and FE methods is based on the Hausman test, whose null hypothesis considers the non-correlation between the error and the regressors. If both are correlated, the EF method is more appropriate for the analysis. However, in the non-rejection condition of the null hypothesis, the EA method becomes the most effective (Gujarati and Porter, 2011).

Ramsey (1969) proposed the Reset Test to detect specification errors. Considering that the null hypothesis is that the model does not present omitted variables, methods that do not reject this hypothesis are considered as more adequate.

Santos Silva and Tenreyro (2006) stressed that the OLS can lead to biased estimates because it can omit the heterogeneity of different countries. Instead, they proposed the use of the PPML method, since, in addition to being consistent in the presence of heteroscedasticity, it provides a natural way to deal with the dependent variable, when it presents values equal to zero (zero trade flows), being evaluated as the one with the best performance when compared to others.

Critiques and limitations

Although widely utilised, the gravitational model received a lot of criticisms as well. For example, the model uses geographical distances as the primary parameter. At an economic level, distance is an expression of transportation costs, making evident that the distance represents a strong determinant for trade flows. As a consequence, we would expect that countries sharing a common border or with a relatively small geographical distance would trade more than countries far away from each other. However, Polak (1996), concerned with the misspecification and biases, concluded that the model asks for a differentiated measure of distance. The author suggested that the gravity model could improve with the introduction of relative distance. This concept implies that the distance between the two countries should be divided by the average distance of the importing country from its trading partners.

Porojan (2000) expanded the model by exploring the presence of spatial effects among different countries. With his study, he revealed that the traditional gravity equation underestimates the amount of trade flows happening between countries who have trading neighbours. Also, he discovers that the model overestimates the trade flows of 'island' countries.

In general, geographical distances per se do not say much. For example, water transportation is cheaper than any other means. In that sense, Marimoutou, Pequin and Feissolle (2010) demonstrated that, although distance reduces trade flow, the magnitude of this effect diminishes the higher the partner's GDP. Thus the influence of the distance can be counterbalanced by the commercial partner's market size.

Baldwin and Taglioni (2006), identified some specification errors in the gravity model. The omission of variables, for example, generates an error correlation with the regressors, leading to endogeneity problems that would overestimate the coefficients associated with cost variables. The authors also criticise the fact that a lot of studies utilise the sum or the average of export as the dependent variable. This conception does not follow the theory of the gravity model, and it can make the robustness of the obtained results questionable. As the model explains the unidirectional bilateral trade, empirical studies should consider the volume of export or import to identify from where the trade is coming and where is it going.

Mele and Baistrocchi (2012) do an appraise to the gravity model in an econometric perspective stating that it was unsuccessful in explaining the adaptation of the gravitational constant of Newton's original equation in a regression. For them, when authors adapt g to the constant α they are committing an implicit "error acceptance".

In general, the gravity model is related to bilateral trade flow and country-specific characteristics of trading partners; it analyses the impact of specific variables on trade, such as GDP, population size, geography distance, price of the product, common language, trade agreements, and others (Ulengin et al., 2015).

Knowing its limitations, the gravity model has undergone modifications over time that have strengthened it, both in its theoretical and econometric basis. The model became more robust and reliable, with the intent to formulate efficient estimators that generate consistent results. Therefore, it is now an excellent tool to the analysis of trade flow, and there's still a strong tendency for its further improvement over the time, in order to became more robust and even more accepted in the economic environment.

Empirical studies

Raimondi and Olper (2011) showed that reducing tariffs would increase world trade. The authors used the gravity equation for a large sample of developing and developed countries between 2002 and 2004 to estimate trade substitution elasticities. They explored different estimation methods and concluded that the elasticities are sensitive to the estimator used. In disagreement with Santos Silva and Tenreyro (2006), they suggested the use of the standard Heckman sample-selection two-step estimator.

Figueiredo et al. (2014) verified, by using the gravity model, the border effect for Brazilian international trade in the 1998-1999 period. The coefficient of the distance variable indicated a negative relationship between the geographic distance and the commercial flow, which is largely corroborated by the existing literature. In addition, a contiguity variable, significant at 1%, showed that there is a greater trade between border regions.

Considering the same econometric model, Ulengin et al. (2015) aimed to investigate the impact of road transport quota determined by European countries, if it provides barriers that are significant to the increase of Turkish's trade potential by analysing its export to 18 EU countries for the period of 2005 to 2012. Their finding confirms that quotas do have a significantly adverse effect on Turkish exports carried by road transportation. They estimated that a 10.6 billion dollars' increase in Turkey's exports via road transportation could happen if there were no quotas. Moreover, according to the results, there is no robust evidence regarding a negative impact of quotas on total Turkish exports, which implies that Turkish companies have used other means of transport when necessary, which can be a competitive disadvantage due to higher costs. The authors also found a negative effect of the quotas on the Turkish textile sector in particular.

Santana-Gallego et al. (2016), aiming to provide empirical and theoretical evidence that tourism affects international trade, modified the gravity equation to introduce tourism flows and studied the dataset of 195 countries for the year 2012. In this perspective, they observed that tourism is a very relevant variable that affects international trade. Specifically, when tourist arrivals increase by 1%, the volume of exports increases by 9% and the probability of exporting by 1.25%.

Arevalo, Andrade, and Silva (2016) analysed the determinants of coffee export supply from Brazil, Colombia and Peru between 2000 and 2013. Using the gravitational model, they verified that an increase in Brazilian GDP causes an increase in exports, as the global price increase of this product also positively affects its trade. The index of business freedom positively affected exports, as well as the appreciation of the exchange rate. Accordingly, the distance between the countries showed that the increase in distance does not favour the coffee trade. There is a negative relationship also between exports and income of the importing country. The authors also verified that the estimation of the model for the export of Colombian coffee and Peruvian coffee showed a positive impact of the income of the destination country, the income of the exporting country and the international price on the export intentions of this product. It is noteworthy that the distance variable presented, as expected, negative values for both cases.

Cantore and Cheng (2018) used the gravity model to test the determinants of bilateral flows of environmental goods, in particular, if environmental policies, such as taxes, affect the imports of environmental goods and in which direction, using trade data over 71 countries from 1999 to 2014. Their findings confirm that environmental regulatory rigidity is a crucial determinant of environmental goods trade and that there is a substitution effect between environmental regulation stringency and trade of environmental goods. They underline that environmental policies could serve both for environmental protection and industrial development. An environmental tax, for example, can control emissions and pollution and also decrease the level of imports of environmental goods, what indicates that it stimulates competitiveness of firms and countries and increases capacity of a domestic firm to satisfy the local demand by replacing imports with production. In that way, environmental regulations incentives demand and domestic markets of cleaner technologies.

Duarte et al. (2019), with the purpose of studying the determinants of global virtual water trade (VWT) flows between 70 countries from 1965 to 2010, also worked with the gravity model. Their findings support that economic and population growth, in the long term, led to an increase in VWT. Furthermore, environmental conditions also influence VWT and commercial agreements increase trade and consequently water transfers.

Conclusion

The gravity model has several features that make it the ideal framework to analyse international trade. According to its central theory, trade flows are directly proportional to the size of economies and inversely proportional to the geographical distance that separates them.

As noted above, taking into account the gravity equations and previous literature on international trade, the larger the GDP of trading partner countries, and the greater trade between them. Similarly, sharing a mutual border or common language, having colonial relation and belonging to the same free trade agreement are all elements expected to increase trade, as they may reduce its costs. On the other hand, we can assume that distance could reduce international trade, as it may increase trade costs. Nonetheless, we should counterbalance this assumption with the fact that the larger the partner's GDP, the smaller the influence of distance.

Altogether, the gravity model has suffered several critiques and evolved since its creation; but it is well acknowledged as one of the most robust and reliable tools to understand and analyse trade flows.

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