The Role of Distance in the Gravity Model: From the View of Newton, International Economics and Quantum Mechanics

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ABSTRACT

The gravity model widely used in international economics in order to explain bilateral trade flows between countries has its roots in physics and the common variable suggested in both of the equations used in physics and economics is "distance". Although several variables expected to have significant effect on trade are added to the analysis in the field of international economics lately; distance is always considered as the first issue because of its correlation with transportation costs. Similarly, from it was first suggested by Newton in the equation of the universal gravity law to Einstein and to the recent finding in the field of quantum mechanics much attention has been paid to distance in physics research too. The aim of this paper is to examine the role of distance in the gravity models considering economic and physics perspectives with an eye to Newton's equation, Einstein's relativity and quantum mechanics.

Key Words: gravity model, international economics, international trade, quantum mechanics.

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Introduction

Newton's universal law of gravity equation is applied to international economics to explain trade by Jan Tinbergen. It will be useful to briefly introduce Tinbergen to better understand that his contribution to economics is not a coincidence (Squartini and Garlaschelli, 2014); Tinbergen had PhD in physics with the entitled thesis 'Minimum Problems in Physics and Economics' in 1929 which was a result of Tinbergen's and his supervisor Paul Ehrenfest' interest in the analogies between economics and physics. He became Ehrenfest's assistant, the private teacher of Ehrenfest's son, and a frequent visitor of Ehrenfest's house which was being visited also by Einstein, Bohr, Heisenberg, Fermi and Pauli in those days. After a while Tinbergen decided to do a career on economics despite Ehrenfest's insistence to convince him to remain a physicist. Jan Tinbergen is the first Nobel Memorial Prize recipient in Economics.

According to the universal law of gravity objects apply force to each other; directly proportional to their masses and inversely proportional to the distance between them. In other words, the force is strong when the masses are higher and the force gets weaker with the distance. Gravity model is applied to international economics keeping the same rationale with the universal law of gravity in order to explain bilateral trade flows between countries. The model suggests that bigger countries (countries with higher GDP -gross domestic product- values) trade more, whereas more distant countries trade less.

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The remainder of the paper is organized as follows. Section I presents the literature about the gravity model. Section II explains theoretical background of the gravity model in international economics. Section III focuses on the role of distance in international trade. Section IV examines distance in the gravity model from Newton to Quantum Mechanics. Section V concludes.

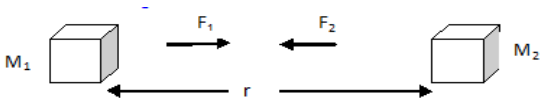
I. Literature

There is a considerable amount of research investigating bilateral trade flows using gravity model in international economics. In spite of the growing literature in the field; gravity equations are usually criticized of not having a theoretical foundation. Analysis estimating gravity equations lay outside of the mainstream trade research from Tinbergen (1962) to 1995 with the criticism that gravity equations were more physics than economics (Head and Mayer, 2013: 27). After Tinbergen's approach has been supplemented with theoretical underpinnings and better estimation techniques; the gravity model has been applied to various economic research topics like migration, foreign direct investment, exchange rates, international portfolio capital movement, WTO membership and other trade agreements, currency unions, internet traffic, decay of colonial linkages, adjacency, common language, religion, technological variables, access to water and area as it is used to model international trade flows. (Starck, 2012:52; Herrera and Baleix, 2009:8).

Linnemann (1966), Leamer and Stern (1971) studied the gravity equation of trade to explain bilateral flows; Bergstrand (1989), Deardorff (1998), Anderson (1979) and Helpman, Melitz and Rubinstein (2008) solved controversies (Herrera and Baleix, 2009:3). Ravenstein (1889), Krugman (1980), Bergstrand (1985, 1989), Helpman (1987), McCallum (1995), Deardorff (1998), Feenstra, Markusen, and Rose (2001), Rose and van Wincoop (2001), Eaton and Kortum (2002), Anderson and van Wincoop (2003), Bernard, Eaton, Jensen, and Kortum (2003), Melitz (2003), Feenstra (2004), Haveman and Hummels (2004), Redding and Venables (2004), Rose (2004), Brun et al. (2005), Bernard et al. (2007), Mayer and Ottaviano (2007), Chaney (2008), Helpman et al. (2008), Melitz and Ottaviano (2008) examined gravity model in inter/intra industry trade and applied it to various economic research topics like migration, foreign direct investment, international portfolio capital movement, WTO membership, other trade agreements and currency unions. Ravenstein used gravity for migration patterns in the UK in 1889 (Anderson, 2011:2, Ravenstein, 1889). McCallum (1995), Rose and van Wincoop (2001), Rose (2004) used gravity model for currency union considering borders (Starck, 2012:5). Helpman et al. (2008) developed a system of gravity equations to estimate the effects of trade barriers on the intensive and extensive margins of trade (Zarzoso *etal.,* 2014:7, Helpman *et al.,* 2008).

II. Theoretical background of the gravity model in international economics

Likewise, various precedents the gravity model in economics has its roots in physics; in Newton's Universal Gravity Law. According to the gravity law; the gravity force between two masses is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them.



$$F_1=F_2=g(M_1xM_2)/r^2$$

- F is the gravitational force between the two masses
- g is the gravitational constant (6.674×10^{-11} N (m/kg)^2)
- m_1 is the first mass
- m_2 is the second mass
- r is the distance between the centers of the masses

The gravity equation was first applied in the field of international trade by Tinbergen in 1962 (Starck, 2012:4). Tinbergen suggested the gravity equation below:

$$X_{ij} = A\frac{Y_i^{\alpha}Y_j^{\beta}}{D_{ij}^{y}}$$

- α is the elasticity of the exporting country's GDP
- β is the elasticity of the importing country's GDP
- γ is the elasticity of distance

As it is seen from the equation that when α=β=1 and γ=2 Tinbergen's equation is Isaac Newton's universal gravitation equation.

The theory of the gravity model is developed by James E. Anderson in 1979 for the first time. Anderson (1979) also employed the

assumption of the product differentiation by country of origin which is suggested by Armington in 1969 and known as the ''Armington assumption''* (Reinert:568). Anderson suggested multilateral resistance and stated that the more resistant to trade with all others a region is, the more it is pushed to trade with a given bilateral partner (Anderson and Wincoop, 2003:170). Anderson pointed out that distance is not the only barrier and if it were; its functional form in the remoteness index is at odds with the theory (Anderson and Wincoop, 2003:170).

In 1995 McCallum analyzed trade patterns between Canadian provinces and U.S. states and founds that trade between two provinces is more than 20 times larger than trade between a province and a state using the gravity equation below (McCallum, 1995:616):

$$\mathbf{x_{ij} = a + by_i + cy_j + d\ dist_{ij} + e\ DUMMY_{ij} + u_{ij}}$$

- x_{ij} is the logarithm of shipments of goods from region i to region j,
- y_i and y_j are the logarithms of gross domestic product in regions i and j,
- $dist_{ij}$ is the logarithm of the distance from i to j,
- $DUMMY_{ij}$ is a dummy variable equal to 1 for interprovincial trade and 0 for province-to-state trade
- u_{ij} is an error term.

Border puzzle proves that even if countries are culturally and economically very similar to each other, borders seem to have a significant effect on trade patterns between countries (Mc Callum, 1995:615, Starck, 2012:24).

In 2003 by augmenting Anderson's (1979) model and aiming to break the deadlock of McCallum's (1995) border puzzle; Anderson and van Wincoop developed a new theoretical framework for the gravity equation includes a theoretical specification for the multilateral resistance term (Herrera and Baleix, 2009:6). Anderson and Van Wincoop (2003) suggested two additional variables; outward multilateral resistance captures the fact that exports from country i to country j depending on trade costs across all possible export markets and inward multilateral resistance captures the dependence of imports into country i from country j on trade costs across all possible suppliers deflating exports as special price indices (UNITED NATIONS ESCAP:14, 15). Anderson and Wincoop (2003) applied theoretical gravity model to border puzzle, added multilateral resistance variables to McCallum's equation and found that national borders reduce trade between industrialized countries by 20-50 %. Anderson and Wincoop (2003) showed that their approach can be used to compute the impact of borders both on intranational and international trade.

III. The role of distance in international trade

"While the role of economic size is well understood, the role played by distance remains a mystery" (Chaney, 2011:1).

According to the gravity model larger country pairs are expected to trade more whereas countries further apart are expected to trade less (UNITED NATIONS ESCAP:9). The volume of trade between two countries are determined by GDP and distance. The formula shows that the volume of trade is directly proportional to the product of the two countries' GDPs and inversely proportional to the distance between them. Thus, the formula is compatible with a known fact that higher GDP leads to more trade whereas more distance (and barriers, borders) leads to less trade referring to transportation costs.

Trade costs includes tariffs and non-tariff barriers as policy barriers, transportation costs like freight and time costs, communication costs, information costs, enforcement costs, exchange rate costs, legal and regulatory costs and local distribution costs (World Trade Report, 2008:81). In a functional form (Behar and Venables, 2010: 5,10):

Trade = f(income, policy, cultural affinity, transport costs)

Transport costs = f(distance, geography, infrastructure, trade facilitation, technology, fuel costs,.....)

Distance "is the bilateral physical distance between the economic centers of countries" (Bergstrand and Egger, 2011:1) and is almost always measured using the "great circle" formula. This formula approximates the shape of the earth as a sphere and calculates the minimum distance along the surface." (Head, 2003:5). Although it is the geographical distance between the economic hubs of the trading partners or distance between capital cities measured in nautical or land miles implied by distance in the original gravity model (in line with Newtonian Gravity Model); research shows that the distance variable absorbs many

* Armington (1969) distinguishes goods by their kind and by their place of production.

different varieties of trade barriers in time (Starck, 2012:5).

Due to the relative simplicity of measurement; distance is a proxy for various factors such as transportation costs, tariffs and taxes, contract, information costs, distribution costs time elapsed during shipment, synchronization costs, communication costs, transaction costs or cultural distance (Starck, 2012:1,5; Head, 2003) and used as an approximate to these costs.

Recent research shows that the influence of distance on bilateral trade results from a combination of three parameters; the distance elasticity of transportation costs, the price elasticity and the degree of firm heterogeneity (Crozet and Koenig, 2008:30).

Basically, more distance means higher transport costs. Transportation costs are defines as the direct costs associated with distance which is readily observable" (AABRI Academic Journals, Henderson *et al.,* 2001: 5). Rates, minimum weights, loading and unloading facilities, packaging and blocking, damage in transit are stated to be included in transportation costs. (AABRI Academic Journals, Coyle *et al.,* 2003:342).

However recent changes in transportation suggest that the grasp of distance should be weakening (Hummels, 2007:151). Especially for long distance shipments; it is stated that air transport tends to be preferred to ocean transport (Hummels, 2007:151; Harrigan, 2005). Hummels showed that the marginal cost of an additional mile of air transport is dropping rapidly and stated that long distance trade becomes relatively more attractive as the level of air transport costs drop relative to the level of ocean transport (Hummels, 2007:151). McFarland (1985) proposes growing excess capacity particularly in ocean shipping and technological innovations like wide-bodied jets, containerization, large-scale tankers and large-scale dry bulk carriers as the two reasons for the fall in transportation costs despite the sharp rise in fuel prices during 1976-1981. Advances in technology lead to a sharp decline in costs as long as fuel price and port costs are at a reasonable level. Otherwise the positive effect of the technological revolution in transportation can be easily eliminated by the sharp increases in the fuel price and port costs.

IV. Distance in the gravity model: From Newton to Quantum Mechanics

According to Newtonian Physics gravity between two objects decreases as the distance between them increases. In other words, gravity force is inversely related to the distance. Albert Einstein expressed special theory of relativity in 1905 and general theory of relativityin 1915. While special theory of relativity is not valid when there is gravitational force; general theory of relativity shows that Newton's Law of Gravitation breaks down when gravitation becomes very strong. General theory of relativity considers gravity at large distances (Sahoo, 2009:902).

Gravity decreases at the infinite levels of smallest scales according to relativistic view. On the other hand, gravity decreases at the infinite levels of cosmic scales in quantum mechanics. While Relativity works for cosmic dimension but doesn't for smallest scales, quantum mechanics does. It is stated that quantum mechanics works at very small distances (Sahoo, 2009:902). At distances and time intervals (Herzenberg, 2010);
-larger than the Planck scale, spacetime is generally treated as having a smooth and continuous structure, as described in classical physics and special and general relativity.
-below the Planck scale, the structure of spacetime is often regarded as losing its well-defined continuous character and becoming grainy at distances near the Planck length, and as exhibiting highly energetic and noisy behavior at smaller scales referring to quantum indeterminacy where the concepts of size and distance break down and departures from classical behavior seen.

String theory is suggested by a group of physicists and mathematicians in 1960s in order to harmonize general relativity with quantum mechanics (Powell, 2015). String theory includes both concepts of distance; large distance where gravity is important and small distance which quantum mechanics considers (Sen,2005: 2045). As for superstring theory; allows to overcome non-renormalizability** problem where short-distance behaviour of interactions do not let carry out meaningful calculations (Caltech).

"Distance" has always been attractive and thus called into question since Newton and has been examined by several researches. What make distance such popular are the consequences if it will be reached to different results than expected. Eventually current research has shown that despite the great distance there is still an interaction between objects. Violating the principle of locality. What is more this finding

** Eliminating infinities from calculations of physical quantities is called "renormalization" (Caltech).

means that information could travel faster than light!

Researchers at Delft University of Technology in the Netherlands tested local effect[***]and showed that two particles could influence each other instantly, even though they were a mile apart (Powell, 2015). The Delft experiment tested if two electrons 1.3 kilometers apart affect each other and reported a "spooky" action at distance (Hensen *et. al.,* 2015). The interaction between particles even if they are separated by huge distances is called quantum entanglement which means that when an object is measured, the state of its entangled twin also becomes set contravening the universal law states that nothing can travel faster than the speed of light (Merali, 2015:14). After the researchers at Delft University of Technology in the Netherlands; NIST (National Institute of Standards and Technology, U.S.) provided evidence for quantum entanglement; showing interaction between photon pairs 126, 132 and 184 miles apart. confirming "spooky action at a distance" (Ost, 2015). This finding impair Einstein introduced nothing could travel faster than light!

V. Conclusion

The universal law of gravitation has been applied to international economics in order to explain bilateral trade between two countries. Similar to the law of gravity equation; the basic form of the gravity model includes two components. What is common in both of the equations is the distance variable.

Although other variables expected to have an effect on international trade like migration, foreign direct investment, exchange rates, international portfolio capital movement, international trade organizations and trade agreements partnership/membership to economic and other trade agreements, currency unions, internet traffic, decay of colonial linkages, adjacency, common language, religion, technological variables, access to water and area are added to the model in time; distance have never lost its popularity and still remains as a controversy in the papers. While there is a research suggesting that distance is losing its importance in international trade, some papers prove evidence that it is still the first issue to be considered.

Distance has been a notable component in physics research too. Because of its relationship between the keystone concepts and potential to reach further findings; distance have been always called into question in physics from Newton to quantum mechanics. Latest discovery in the field is providing evidence for an interaction between objects miles apart from each other violating locality and furthermore representing the end of sovereignty of speed of light.

On the other hand, what makes distance such a considerable variable in trade is its role on the transportation costs. However, language, cultural and colonial differences have negative effects on communication and transaction costs. Besides it is seen that despite of having borders; countries don't trade because of political and security problems. Today, to the contrary to the theories; distance seems to be ignored or to lose its place on the top of the list at least. Countries trade in spite of considerable distances. By regulations in bilateral, multilateral, preferred, regional trade agreements, regional economic integrations, customs unions, the progress in e-trade and in technology, widespread use of internet in several fields all over the world and diversification and improvements in transportation facilities it is aimed to reduce costs and compensate the negative effects of distance on trade. As a result of the indispensable output of the globalization the countries all over the world have an interaction with each other economically, politically and socially.

[***]"The principle of locality states that an object is influenced directly only by its immediate surroundings"(Choi, 2014).

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