

gravity models

Gravity models utilize the gravitational force concept as an analogy to explain the volume of trade, capital flows, and migration among the countries of the world. For example, gravity models establish a baseline for trade-flow volumes as determined by gross domestic product (GDP), population, and distance. The effect of policies on trade flows can then be assessed by adding the policy variables to the equation and estimating deviations from the baseline flows. In many instances, gravity models have significant explanatory power, leading Deardorff (1998) to refer to them as a “fact of life.”

Alternative Specifications

Gravity models begin with Newton’s Law for the gravitational force (GF_{ij}) between two objects i and j . In equation form, this is expressed as:

$$GF_{ij} = \frac{M_i M_j}{D_{ij}} \quad i \neq j \quad (1)$$

In this equation, the gravitational force is directly proportional to the masses of the objects (M_i and M_j) and indirectly proportional to the distance between them (D_{ij}).

Gravity models are estimated in terms of natural logarithms, denoted “ln.” In this form, what is multiplied in Equation 1 becomes added, and what is divided becomes subtracted, translating Equation 1 into a linear equation:

$$\ln GF_{ij} = \ln M_i + \ln M_j - \ln D_{ij} \quad i \neq j \quad (2)$$

Gravity models of international trade implement Equation 2 by using trade flows or exports from county i to country j (E_{ij}) in place of gravitational force, with arbitrarily small numbers sometimes being used in place of any zero values. Distance is often

measured using “great circle” calculations. The handling of mass in Equation 2 takes place via four alternatives. In the *first alternative* with the most solid theoretical foundations, mass in Equation 2 is associated with the gross domestic product (*GDP*) of the countries. In this case, Equation 2 becomes:

$$\ln E_{ij} = \alpha + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 \ln D_{ij} \quad (3)$$

In general, the expected signs here are $\beta_1, \beta_2 > 0$. However, the economics of Equation 3 can lead to the interpretation of *GDP* as income, and when applied to agricultural goods, Engels’ Law allows for *GDP* in the destination country to have a negative influence on demand for imports. Hence it is also possible that $\beta_2 < 0$.

In the *second alternative*, mass in Equation 2 is associated with *both GDP and population (POP)*. In this case, Equation 2 becomes:

$$\ln E_{ij} = \varphi + \gamma_1 \ln GDP_i + \gamma_2 \ln POP_i + \gamma_3 \ln GDP_j + \gamma_4 POP_j + \gamma_5 \ln D_{ij} \quad (4)$$

With regard to the expected signs on the population variables, these are typically interpreted in terms of market size and are therefore positive ($\gamma_2, \gamma_4 > 0$). That said, however, there is the possibility of import substitution effects as well as market size effects. If the import substitutions effects dominate, the expected sign is $\gamma_4 < 0$.

In the *third and fourth alternatives*, mass in Equation 2 is associated with *GDP per capita* and with *both gross domestic product and GDP per capita*, respectively. In these cases, Equation 2 becomes one of the following:

$$\ln E_{ij} = \tau + \delta_1 \ln \left(\frac{GDP_i}{POP_i} \right) + \delta_2 \ln \left(\frac{GDP_j}{POP_j} \right) + \delta_3 \ln D_{ij} \quad (5)$$

$$\begin{aligned} \ln E_{ij} = & \mu + v_1 \ln GDP_i + v_2 \ln \left(\frac{GDP_i}{POP_i} \right) + v_3 \ln GDP_j \\ & + v_4 \left(\frac{GDP_j}{POP_j} \right) + v_5 \ln D_{ij} \end{aligned} \quad (6)$$

Since they involve the same variables, the parameters of Equations 4, 5, and 6 are transformations on one another: $\gamma_1 = \delta_1 = v_1 + v_2$; $\gamma_2 = -\delta_1 = -v_2$; $\gamma_3 = \delta_2 = v_3 + v_4$; and $\gamma_4 = -\delta_4 = -v_4$.

Theoretical Considerations

After being introduced by Tinbergen (1962), the gravity model was considered to be a useful physical analogy with fortunate empirical validity. Subsequently, however, connections have been made to key elements of trade theory. The standard assumption of the Heckscher-Ohlin model that prices of traded goods are the same in each country has proved to be faulty due to the presence of what trade economists call “border effects.” Properly accounting for these border effects requires prices of traded goods to differ among the countries of the world. Gravity models have been interpreted in these terms.

Anderson (1979) was the first to do this, employing the product differentiation by country of origin assumption, commonly known as the “Armington assumption” (Armington, 1969). By specifying demand in these terms, Anderson helped to explain the presence of income variables in the gravity model, as well as their multiplicative (or log linear) form. This approach was also adopted by Bergstrand (1985) who more thoroughly specified the supply side of economies. The result was the insight that prices in the form of GDP deflators might be an important additional variable to include in the gravity equations described above. Price effects have also been captured using real exchange rates (e.g., Brun et al., 2005).

The monopolistic competition model of new trade theory has been another approach to providing theoretical foundations to the gravity model (Helpman, 1987 and Bergstrand, 1989). Here, the product differentiation by country of origin approach is replaced by product differentiation among producing firms, and the empirical success of the gravity model is considered to be supportive of the monopolistic competition explanation of intra-industry trade. However, Deardorff (1998) and Feenstra (2004) have cast doubt on this interpretation, noting the compatibility of the gravity equation with some forms of the Heckscher-Ohlin model and, consequently, the need for empirical evidence to distinguish among potential theoretical bases: product differentiation by country of origin; product differentiation by firm; and particular forms of Heckscher-Ohlin-based comparative advantage. In each of these cases, the common denominator is complete specialization by countries in a particular good. Without this feature, bilateral trade tends to become indeterminate.

Alternatively, there are other approaches to gravity-based explanations of bilateral trade that do not depend on complete specialization. As emphasized by Haveman and Hummels (2004), this involves accounting for trade frictions in the form of distance-based shipping costs or other trade costs, as well as policy-based trade barriers. Distance costs can also be augmented to account for infrastructure, oil price, and trade composition as in Brun et al. (2005). The two approaches (complete vs. incomplete specialization) can be empirically distinguished by category of good, namely differentiated vs. homogeneous, as in Feenstra, Markusen and Rose (2001).

Assessment

Due to its log-linear structure, the coefficients of the gravity model are in terms of elasticities or ratios of percentage changes. These “unitless” measures are comparable across countries and goods and give us direct measures of the responsiveness of trade flows to the trade potential variables of Equations 3-6. For GDP and distance, estimated elasticities tend to be close to 1.0 in value. For distance, comparison across groups of countries gives a measure of the degree of integration in the world economy. In addition to these standard variables, the coefficients of policy variables help us to understand the impacts of the represented policies on trade flows. It is also possible to obtain estimates of border effects independently of distance and other variables, as well as to investigate some issues in economic geography as in Redding and Venables (2004). Despite some ambiguity regarding its theoretical foundations, then, the gravity model is an important empirical tool to help us understand trade and other economic flows in the world economy.

See also: Applied General Equilibrium Models, Heckscher-Ohlin Model, Intra-Industry Trade, Monopolistic Competition Model, New Trade Theory, Partial Equilibrium Models, Revealed Comparative Advantage

Further Reading

Anderson, James E. 1979. A Theoretical Foundation for the Gravity Equation. *American Economic Review* 69(1): 106-116. A first attempt to provide theoretical foundations to the gravity model.

Armington, Paul. 1969. A Theory of Demand for Products Distinguished by Place of Production. *IMF Staff Papers* 16(3): 159-176. The key contribution on product differentiation by country of origin.

Bergstrand, Jeffrey H. 1985. The Gravity Equation in International Trade: Some Microeconomic Foundations and Empirical Evidence. *Review of Economics and Statistics* 67(3): 474-481. A second attempt to provide theoretical foundations to the gravity model.

Bergstrand, Jeffrey H. 1989. The Generalized Gravity Equation, Monopolistic Competition, and the Factor-Proportions Theory in International Trade. *Review of Economics and Statistics* 71(1): 143-153. An interpretation of the gravity model in terms of monopolistic competition.

Brun, Jean-François, Céline Carrère, Patrick Guillaumont, and Jaime de Melo (2005) Has Distance Died? Evidence from a Panel Gravity Model. *World Bank Economic Review* 19(1): 99-120. A useful exploration of distance in gravity models.

Deardorff, Alan V. 1998. Determinants of Bilateral Trade: Does Gravity Work in a Neoclassical World? In Jeffrey A. Frankel, ed., *The Regionalization of the World Economy*. Chicago: University of Chicago Press. A helpful review and assessment of the gravity model.

Feenstra, Robert C. 2004. *Advanced International Trade: Theory and Evidence*. Princeton: Princeton University Press. Chapter 5 of this book reviews the gravity model in light of trade theory and also delves into a number of key estimation issues.

- Feenstra, Robert.C., James R. Markusen and Andrew K. Rose. 2001. Using the Gravity Equation to Differentiate among Alternative Theories of Trade. *Canadian Journal of Economics* 34 (2): 430-447. Tests the gravity model over differentiated and homogenous goods, focusing on differences in estimated parameter values.
- Helpman, Elhanan. 1987. Imperfect Competition and International Trade: Evidence from Fourteen Industrial Countries. *Journal of the Japanese and International Economies* 1(1): 62-81. A claim for monopolistic competition models of intra-industry trade using gravity model evidence.
- Haveman, Jon and David Hummels. 2004. Alternative Hypotheses and the Volume of Trade: The Gravity Equation and the Extent of Specialization. *Canadian Journal of Economics* 37(1): 199-218. Explores gravity model explanations both in terms of complete specialization such as in monopolistic competition models and incomplete specialization with trade frictions.
- Redding, Stephen and Anthony J. Venables. 2004. Economic Geography and International Inequality. *Journal of International Economics* 62(1): 53-82. An application of the gravity framework to economic geography.
- Tinbergen, Jan. 1962. *Shaping the World Economy: Suggestions for an International Economic Policy*. New York: The Twentieth Century Fund. The first use of a gravity model to analyze international trade flows.

Kenneth A. Reinert, School of Public Policy, George Mason University