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Kaliappa Kalirajan ^a

^a Foundation for Advanced Studies on International Development and National Graduate Institute for Policy Studies,

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Gravity model specification and estimation: revisited

Kaliappa Kalirajan

*Foundation for Advanced Studies on International Development and
National Graduate Institute for Policy Studies
E-mail: Kalirajan@grips.ac.jp*

The gravity model is one of the most frequently estimated empirical relationships in economics. However, the most commonly used form of the relationship is not correctly specified. This article discusses the specific sources of imprecision in modelling and estimation of gravity equations and suggests a method to correct the specification bias.

I. Introduction

The gravity model has been extensively used to examine several research questions such as the testing of the Linder hypothesis (Arnon and Weinblatt, 1998; Choi, 2002) and the impact of regional groupings on world trade (Sharma and Chua, 2000; Thornton and Goglio, 2002). As these questions are important from trade policy point of view for several countries, the specification and estimation of gravity models are crucial. Generally, gravity models relate the bilateral trade flows between two countries to their gross domestic products, population and geographical distance. However, it is argued in the literature that the standard gravity model is misspecified and inappropriately estimated (Matyas, 1997). The objective of this article is to identify specific sources of imprecision in specification and estimation, which facilitate a suggestion to improve modelling and estimates of gravity equations.

The following section discusses the imprecision that is inherent in the specification of the gravity model, which is generally overlooked by researchers. A methodology to overcome this limitation is explained in the next section. The final section brings out the overall conclusions of this article.

II. The Gravity Model: The Inherent Imprecision in Specification

In the standard gravity model, theoretical discussion by Anderson (1979), a term, which represents the 'economic distance between (country) i and (country) j relative to a trade weighted average of the economic distance between i and all points in the system' (Anderson, 1979, p. 113), is often replaced by 'geographical distance' in empirical work. This does lead to biased estimates because economic distance includes not only geographical distance, but also other country-specific factors such as historical and cultural ties between countries, the tying up of aid and the lines of communication between countries, which influence the intensity of trade between pairs of countries, as argued by Roemer (1977). Further, this imprecise specification is overlooked by the ordinary least squares (OLS) estimation. If the omitted or left-out variables of country-specific characteristics are correlated with the included explanatory variables such as the geographical distance, which is the case mostly in gravity models, the OLS estimators will be biased and inconsistent. The variance of the included independent variables will contain an upward bias. Therefore, the test on significance of the estimators would not lead to correct conclusions.

Also, the lack of any measure to account for this imprecise specification of using only geographical distance in empirical studies of international trade could be insightful. It could provide an explanation as to why the fit of a gravity equation varies significantly between data sets despite using the same independent variables. A method to contend with this imprecision has been provided by Anderson (1979). However, his method does suffer from a reduction in efficiency.

In simple terms, the specific source of inherent imprecision in specifying a gravity model is not including 'economic distance' properly between countries. This imprecision in modelling gravity equations leads to heteroscedastic error terms and the log linearization of the empirical model in the presence of heteroscedasticity leads to inconsistent estimates because the expected value of the logarithm of a random variable depends on higher-order moments of its distribution (Silva and Tenreiro, 2003). Also, this imprecise specification affects the normality assumption of the error term. Fixed effects models proposed to tackle the issue of heterogeneity problem by Matyas (1997) are not formulated based on economic theory.

III. The Gravity Model Specification and Estimation: A Suggested Methodology

In a sense, heteroscedasticity and nonnormality are interrelated. Heteroscedasticity is a property of the conditional distribution of the dependent variable in a regression model and the effect of heteroscedasticity with respect to the variables that move variances around is generally nonnormality. This kind of situation, where the structure of heteroscedasticity is unknown, is quite common in many empirical analyses in economics. For example, given a technology and comparable inputs, at a given time, if the production performances of a sample of firms are examined, there is often a wide variation in their production levels, which is not easily explained. This type of deviation from homoscedastic residuals appears to be mainly due to characteristics specific to observations that are not easily quantifiable. In the case of the standard gravity equation, the 'economic distance' variable is not easily quantifiable as discussed by Roemer (1977, p. 318). In this situation, OLS estimation leads to biased results. Drawing on the procedures developed for estimating stochastic frontier production functions (Aigner *et al.*, 1977; Meeusen and van den Broeck, 1977), this study proposes a method to estimate standard gravity

equations taking into account of heteroscedasticity and nonnormality, when the researchers do not know the structure of heteroscedasticity.

What could be the possible determinants of heteroscedasticity arising from not including 'economic distance' and therefore, the bias? We would like to elaborate on this by concentrating on important means to promote trade flows between countries. One such means is trade liberalization. Trade liberalization, from a theoretical viewpoint, promotes efficiency by re-allocating resources to productive uses, stimulates competition, increases factor productivity, increases trade flows and thereby promotes economic growth (Wacziarg, 1997). However, empirical facts on trade flows across countries do not always support this theoretical viewpoint. This shows that either the implementation of trade liberalization policies in home country have fully not removed the constraints that exist prior to the reforms or trade openness is not effective in partner countries. Put in another way, there are still some elements of trade frictions between home country and its trading partners, which many of the (trade) reforms have not addressed in either countries. These 'left-over' factors are very difficult to identify individually and could be due to socio-economic, institutional and political factors in home country and its bilateral partners. For example, large government size (Rodrik, 1998), weak and inefficient institutions in home and partner countries in terms of, e.g. custom and regulatory environments, port efficiency and e-business (Rodrik, 2000; Levchenko, 2004; Wilson *et al.*, 2004) and political influences through powerful lobbying by organised interest groups (Gawande and Krishna, 2001) have been found to affect trade flows, among other things. Nevertheless, the combined effects of these earlier mentioned trade constraining factors, which may be interpreted as 'economic distance' factor, on trade flows can be measured. Thus, apart from the geographical distance constraint, there are other constraints that are not captured explicitly by the standard gravity model. Such constraints are country-specific constraints (home and partner countries), which are due to social-political and institutional factors. Unless this influence is measured; its sources are identified and corrected by appropriate policies, there will always be variances between actual and potential trade. Unfortunately, most of the empirical trade models do not consider this deficiency, as they do not incorporate these factors into their trade model.

The gravity equations can be estimated by the stochastic frontier approach (SFA) to provide more meaningful estimate based on the earlier-mentioned

theoretical discussions. The frontier gravity equation for exports can be estimated, e.g.

$$X_{ij} = f(Z_i; \beta) \exp(-u_i + v_i)$$

where the term X_{ij} represents the actual exports from country i to country j . The term $f(Z_i; \beta)$ is a function of the determinants of potential bilateral trade (Z_i) and β is a vector of unknown parameters. The single-sided error term, u_i is the combined effects of inherent 'economic distance' bias referred by Roemer (1977) and Anderson (1979). This bias, which is specific to the exporting and importing countries, creates the difference between actual and potential between the two countries concerned. $\exp(u)$ takes values between 0 and 1. When $\exp(u)$ takes the value 0, this means that the inherent 'economic distance' bias or country-specific factors are not important and the actual exports and potential exports are the same, assuming there are no statistical errors. When $\exp(u)$ takes the value other than 0 (but less than or equal to 1), this means that the combined effects of 'economic distance' bias or country specific factors are important and they constrain actual exports from reaching potential exports. Thus, the term $-u_i$, which is bilateral observation specific, represents the difference between potential and actual output in logarithmic values that is a function of the inefficiencies that are within the exporting and importing countries' control. Thus, unlike the conventional approach, the SFA of estimating the gravity model does not exclude the influence of 'economic distance' bias on trade flows between two countries. The double-sided error term v_i captures the influence on trade flows of other variables, including measurement error that are randomly distributed across observations in the sample.

Maximum likelihood methods can be used to estimate the stochastic gravity model and the bias. Popular computer software such as STRATA, LIMDEP, FRONTIER, E-VIEWS facilitate stochastic gravity model estimation.

IV. Conclusions

Drawing on the procedures developed for estimating stochastic frontier production functions, the methodology suggested in this article to estimate specification bias-free gravity models is the specification and estimation of a stochastic frontier gravity model.

The advantages of the suggested method of estimation are as follows. Firstly, it does not suffer from a loss of estimation efficiency. Second, it estimates the combined effects of the 'economic distance' bias term, which is creating

heteroscedasticity and nonnormality, isolating it from the statistical error term. This isolating property will enable us to analyse the determinants of this bias term. Third, the suggested approach provides potential trade estimates that are closer to free trade estimates. Since, this approach represents the upper limits of data, which come from, those economies that have liberalized trade restriction the most. Finally, the suggested method bears strong theoretical and trade policy implications.

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