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MEASURING TRADE AND TRADE POTENTIAL: A SURVEY

Shiro Armstrong

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MEASURING TRADE AND TRADE POTENTIAL: A SURVEY

This paper provides a survey and a brief critical review of the literature on the widely used gravity models of trade, as a prelude to the justification of its use with the stochastic frontier methodology. The important papers on the theoretical foundations of the gravity model are reviewed and related to papers applied to explain determinants of trade flows. Then some shortcomings of the gravity model are discussed. The paper introduces the stochastic frontier gravity model as a way of estimating trade resistances and overcoming some of the shortcomings of conventional gravity models in their use for that purpose.

Introduction

The gravity model of trade is based on the idea that gross trade volumes between two countries depend on the sizes of the two countries and the distance they are apart. This simple model has been used extensively in analysing trade and has been successful to a high degree in explaining trade. It has enjoyed many different applications, some to test standard trade theories, others to explain trade and the effect of certain policy measures on trade volumes. Earlier criticisms of the weak theoretical foundations of the gravity model have been rectified in numerous theoretical derivations[1] but there are still many improvements to be made in analysing trade and the costs associated with trading (Anderson and van Wincoop 2004).

However, the literature has not been able to deal satisfactorily with trade resistances that might limit or promote trade between particular trading partners, often relying on a number of variables to proxy total trade resistances, including trade related costs, such as physical distance. In fact, it has become common to 'control' for the difficulty in measuring trade resistances by differencing them out in panel data sets and making the assumption that these resistances are stable over time. Here we review a relatively new stream in the literature and demonstrate that it can potentially take account of all these trade frictions and find a measure of them relative to the trade that is occurring. The basic idea in production economics of trying to perform on the frontier is applied to defining a trade frontier using the stochastic frontier methodology.

This paper gives a brief overview of the theoretical derivations of the model, reviews some of the important applications in measuring trade potential, and introduces a relatively new, and as yet little used, method of combining it with a stochastic frontier analysis.

The paper is roughly divided into two parts, the first on the conventional gravity model and the second on the stochastic frontier gravity model. The next section briefly reviews the theoretical foundations of the gravity model and some of its links with standard trade theories, followed by a section on some of the applications and their implications. Then there is a brief discussion of some of the shortcomings in its current use. The second half of the paper introduces the stochastic frontier gravity model, explains the concept of a trade frontier, justifies its use as a tool for measuring trade potential and suggests a specification for its use.

Gravity models

The gravity model and trade theory

The search to link gravity models to trade theory has led to the model being derived from different theories and the gravity model's being used to find empirical evidence of, or to test, trade theories (Harrigan 2001). The main criticism of the gravity model previously was that its theoretical foundations were weak, but recent work has rectified this to the point where in 1997, Frankel, Stein and Wei claim the gravity model has 'gone from an embarrassing poverty of theoretical foundations to an embarrassment of riches!' (Frankel 1997:53).

Anderson (1979) was the first to give the gravity model theoretical legitimacy. He derived the gravity equation from expenditure systems where goods are differentiated by country of origin (Armington preferences) and all transport costs are proxied by distance. Bergstrand made the next significant contribution to giving the model a theoretical underpinning, using the same assumption of Armington preferences and deriving the model as a 'partial equilibrium subsystem of a general equilibrium model' (Bergstrand 1985:1). Prices are generally considered endogenous in gravity models because they are general equilibrium models with exporter supply and importer demand clearing, but Bergstrand (1985; 1989) introduces and justifies the use of prices from underlying production functions and utility functions where he argues that strong assumptions, such as perfect international commodity arbitrage, are clearly not met in reality.

Helpman (1987) derives the gravity model from an imperfect competition model and Deardorff (1995) derives it from the Heckscher–Ohlin model. Indeed, the gravity model can be derived from numerous trade theories in one form or another and can be used to find empirical evidence of many trade theories with different assumptions about preferences and whether goods are differentiated or homogeneous (Deardorff 1995; Harrigan 2001).

The theoretical foundations of the gravity model as described by Anderson (1979), Bergstrand (1985), Helpman (1987) and Deardorff (1995) start with the assumption of frictionless trade or iceberg[2] transport costs[3] and then, with the exception of Bergstrand, derive a model where trade volumes between country pairs are proportions of the product of incomes or total world trade. Trade shares 'fall naturally into a gravity-equation' (Deardorff 1995:2). This probabilistic method is comparable to the analysis of trade intensities (Drysdale 1967; Drysdale and Garnaut 1982) which uses the relative size of an economy's trade as a benchmark for what that country is expected to trade. Although they give the gravity equation theoretical backing, the assumptions of frictionless trade or iceberg transport costs to capture all the frictions are strong but are a poor proxy for trade friction. The models 'fit' the data well, but frictions of trade are assumed to be captured in the error term and dealt with better in a stochastic frontier gravity model that is discussed below.

The 'border puzzle', of large unexplained trade costs when goods are traded across a national border, has been the focus of much of the literature since McCallum (1995). McCallum applied the gravity model to estimate a value for the loss in trade volume accounted for by goods crossing the US–Canada border as compared to intra-national trade (between states or provinces) in both countries. The findings show that international border effects are inferred and that they matter even with two economies that share a large border and are highly integrated through a regional trade arrangement (RTA) such as NAFTA. Trading across borders will cause a disconnect in relative prices as insurance, freight, tariffs, non-tariff barriers, and different regulatory structures cause uncertainty and impede trade to some degree (Rossi–Hansberg 2005). Anderson and van Wincoop (2003) claim to solve the border puzzle using McCallum's data by deriving the gravity equation from expenditure functions and importantly adding what they call multilateral resistance.[4] The multilateral resistance terms are important and mean that if country *i*'s trade with country *j* is being analysed and there is no movement in the trade determinants, a change in country *k*'s trade with country *i* will affect trade between *i* and *j*, as would be expected. Their specification explains away most of the border puzzle. McCallum (1995) found that trade between US and Canada was lower than trade within their borders by a factor of 22 (2,200 per cent), but Anderson and van Wincoop (2003) reduce this unexplained border effect to the border's lowering trade by 44 per cent. Anderson and van Wincoop assumed symmetric trade costs to solve their model, which is a significant but unrealistic assumption. The results of Anderson and van Wincoop are disputed in an important paper by Balisteri and Hillberry (2006) who find that the theory-consistent model of Anderson and van Wincoop does not explain away the border puzzle. Balisteri and Hillberry relax the assumption of symmetric border costs and account for structural bias in Anderson and van Wincoop that arises from the incorrect treatment of an adding up constraint which is implicit in the Anderson and van Wincoop model.[5] The correct estimation of the Anderson and van Wincoop (2003) derivation shows that the literature still cannot explain the border puzzle, or what we prefer to describe here as unexplained resistances. The failure of the gravity model is that it consistently estimates trade costs to be significantly higher than what we observe in reality.

Applications of the gravity equation

Linnemann (1966) was the first to extend the gravity model of Tinbergen (1962) to include other trade explanators such as population, and more importantly, complementarity. A complementarity index would reflect how the commodity compositions of two trading partners would complement each other or not. In one conception of the determinants of trade, complementarity can be thought of as a proxy for relative resource endowments and can show how much scope there is for further trade. Linnemann's was the first attempt to link the factor-proportions theory of trade into the gravity model.[6] Drysdale and Garnaut (1982) suggest that the complementarity variable developed in Drysdale (1967) is more appropriate for this purpose and there has not been any significant improvement on a similar proxy since.[7]

A different hypothesis is advanced by Linder (1961) which suggests that countries with similar income levels will trade more. With the complementarity variable's inclusion in the form of a relative resource endowment variable the expected result will be that countries which are less similar, and hence have different comparative advantage, will have complimentary trade structures and be expected to trade more — result contrary to the Linder hypothesis. However, its inclusion in the form of a variable more directly related to revealed structures of commodity trade, such as that proposed by Drysdale (1967) and Drysdale and Garnaut (1982), may not have the disadvantage of excluding the Linder hypothesis. Surprisingly, the use of a complementarity variable has been extremely limited in gravity models. One explanation is that is not easily incorporated in to any accepted demand side derivation of the gravity model.

Linnemann started a process in the literature of adding trade explanators and inhibitors to the gravity model.[8] Frankel, Stein and Wei (1997) undertake a comprehensive study of regional trading blocs using the gravity model as the main tool. There are many studies that measure the effects of bilateral and multilateral trade arrangements, both discriminatory and nondiscriminatory[9], but perhaps none as comprehensive and convincing as that of Frankel, Stein and Wei. They are able to quantify the amount by which different preferential trade arrangements (PTAs) and regional arrangements such as APEC, increase trade by adding trade agreement dummy variables into the standard gravity model. Analysis of regional or multilateral trade arrangements using gravity models is now commonplace and important in applied trade theory.

Although exchange rate volatility had been commonly included as a trade explanator in the gravity model,[10] Rose (2000) made an important contribution as the first to include a common currency dummy variable to explain trade. The finding that an economy which is so highly integrated with another economy that there is a common currency, increases trade three fold, as his European Union dummy suggested, had a large impact on the literature with significant policy implications. The idea of increased trade from a common currency is intuitive, but the magnitude was surprising. Baldwin and Taglioni (2006) reduce the magnitude of the common currency effect significantly using Anderson and van Wincoop (2003)'s structural estimation with multilateral resistance.

Baldwin (1994), Nilsson (2000)[11] and Egger (2002) are the most prominent examples in the literature that use the term trade 'potential' as the expected volume of trade between country pairs that the gravity model predicts. They then measure how far above or below potential trade actual trade is. Egger corrects for serial correlation, uses different panel data methods to find the best specification, and then performs the simple exercise of finding the ratio of actual to potential trade. This gives a measure of how well a bilateral trade flow performs relative to the mean as predicted by the model.

Shortcomings of the gravity model

The main criticism of the gravity model used to be that it has weak theoretical foundations, but now much more attention in the use of gravity models is being paid to econometric problems. The wide use of the model, and the policy implications drawn from its application that are quite significant in absolute dollar terms, have led to concentration in the literature on improving on the accuracy of the econometric specifications and techniques. From Tinbergen's (1962) very first use of the model, there have been many attempts to improve on it and much progress has been made. The next section reviews some of the major statistical problems that remain and points out some of the inconsistencies in the use of key variables such as population and distance.

Differing econometric specifications of the gravity equation are numerous. The question of using population as an explanatory variable is one example where the gravity equation is inconsistent. The theoretical underpinnings derived by Anderson (1979) Helpman (1987) Deardorff (1995), do not justify the inclusion of population, and its effect is positive sometimes and negative other times. A positive effect, implying that a country with a higher population trades more, would be the expected result for developing economies as they tend to be specialised in labour-intensive exports. A negative effect for population size could be due to economies with larger populations having an absorption effect (Martínez–Zarzoso and Nowak–Lehmann 2003). Then why do so many researchers include population? Including the log of GDP and log of population separately in the log linearisation of the gravity model for estimation, is equivalent to including the log of GDP per capita with a restriction on the estimated coefficients of GDP and population separately. However, many papers do not explicitly say this, and the population term is included in the model to control for country size but often ignored in the analysis. The reason GDP per capita is included in so many models is that it has meaning in the context of using the Linder hypothesis in explaining trade flows.[12]

Baldwin and Taglioni (2006) summarise errors that are frequently repeated in the literature. What they call the gold medal error, so named because of the relatively high effect it has on the estimates of all trade resistance variables, is due to the omission of the Anderson and van Wincoop (2003) multilateral resistance terms which are explained above. The second most important error they identify is related to when trade between countries *i* and *j* is analysed as an average of both trade from *i* to *j* and trade in the other direction. The error arises in the arithmetic of taking the log of the average of uni-directional flows rather than the average of the logs.

Related to the problem of the difficulty of quantifying trade costs discussed below, there are bilateral country-specific unobserved effects that are correlated to export performance. The assumption of a normally-distributed random disturbance term is violated with the omission of unobservable trade resistances variables, which biases the estimates and causes heteroscadisticity with an unknown structure (Kalirajan and Findlay 2005). Cheng and Wall (2005) review some of the literature on fixed effects in panel data to control for some of the unobserved effects and conclude that their unrestricted version of the fixed effects model is preferred statistically. The panel data method is commonly used to find more accurate estimates of income elasticities and other influences on trade that are not fixed over time. The trade-off in obtaining more accurate estimates of explanators that change over time is that some of the more interesting factors (institutional, cultural and historical) that determine trade volumes are differenced out. The other problem is that this approach discards the overwhelming majority of the variation in the data, in the cross-section of country pairs (Harrigan 2001:45).

Anderson and van Wincoop (2004) attempt to quantify trade costs (all transaction costs involved in trading a good) but concede that the literature is still in the early stages of understanding and measuring what the real costs are. Indeed, Baldwin and Taglioni use *t(distance, other stuff)* to explain trade costs, split all trade costs into man-made, cultural and natural trade costs, and describe the bias from omitting these variables but then themselves use only a few variables in their estimation. The arbitrary choice of resistance terms included in gravity model studies leads to different degrees of omitted variable bias that is often only controlled for by using fixed effects estimation that assumes constant country pair resistances. Tariffs and easily measurable trade barriers, for which there are good data available, seem to be among the lowest trade costs. All other trade costs that the literature usually proxies for with distance — border dummy variables, regional grouping dummy variables, preferential trade agreement variables and language differences — are supposed to capture the rest. In their paper, Anderson and van Wincoop (2004) estimate that all trade costs could be thought of as a 170 per cent *ad valorem* tax on traded goods for developed countries. Although this is a useful exercise and confirms the magnitude of trade costs that are needed to overcome trade restrictions and resistances, as they concede, it is unrealistic to apply such a constant rate to all traded goods and, they may have added, all country pairs. The aim of Anderson and van Wincoop (2004) is not to give a value such as this to trade costs but to survey how trade costs are treated in the gravity model literature. They conclude that there is still a lot of work to be done in measuring trade costs.

The literature makes it clear that the use of relative distance is preferred to absolute distance in explaining gross trade volumes (Drysdale and Garnaut 1982; Harrigan 2001). There have been numerous indexes of relative distance (or remoteness) derived[13], but most of the gravity model literature neglects this. The use of relative distance is important as two remote countries, for example Australia and New Zealand, would trade more with each other than two similar sized economies that have many trading partners relatively close by, such as neighbouring economies in Europe. Deardorff (1995) is an example of a derivation from theoretical foundations with relative distance, and it is now commonly recognised that using only absolute distance leads to mis-specification of the model (Harrigan 2001).

There are also well recognised problems in the estimation of gravity model coefficients. Two papers, Anderson et al. (2005) and Ghosh and Yamarik (2004), provide strong evidence of overestimation of coefficients in gravity models, as applied widely, and show that results in the literature are sensitive to empirical specification.[14] Anderson et al. (2005) run Monte Carlo simulations to show the spurious nature of many large data sets used in gravity model estimations cause significant bias in results. Indeed, many variables are falsely found to be statistically significant in explaining trade due to spurious data. Ghosh and Yamarik also cast doubt on the accepted empirical results of regional trade arrangements (RTAs) significantly increasing trade. Using extreme bounds analysis, they show that the results of RTA dummy variables are somewhat suspect and sensitive to the prior beliefs of the researcher conducting the estimations.

The stochastic frontier gravity model

Conventional gravity models estimate the mean effects of the determinants of trade. Of the resistances to trade which Drysdale and Garnaut (1982) call *objective* resistances, such as distance and official barriers to trade, only some can be controlled for in gravity models but the majority are difficult to quantify and so they are lumped together into the unobserved disturbance term. *Subjective* resistances, such as asymmetric and imperfect information and internal constraints, are not controlled for at all.[15] Do we then have to settle for the unsatisfactory fixed effects estimation and hope that we control for all these bilateral factors that are assumed to be fixed over time? The next section argues that stochastic frontier analysis applied to a gravity model is an acceptable and appropriate way to deal not only with the unobservable resistances to trade, but also to estimate them.

Stochastic frontier analysis is used to measure production efficiency and was developed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). In production literature, the argument is that the '[production] process is subject to two economically distinguishable disturbances, with different characteristics' (Aigner et al. 1977:24) and so the error term is 'composed' into a non-negative term which captures production inefficiencies and a more conventional symmetric error term which captures random disturbances. The ability to split the disturbance terms allows that a farmer (producer) who experiences a drought (random disturbance) is unlucky, not inefficient (Aigner et al. 1977).

A similar concept can be applied to measuring trade flows.

The unobservable, or difficult to quantify, institutional characteristics and other resistances that affect trade in a bilateral relationship will be captured in the unobservable term in the conventional gravity model, but captured as a cause for reducing trade in a stochastic frontier gravity model. Drysdale and Garnaut (1982) recognised that this distinction is blurred, as unmeasurable disturbances make it difficult to get an accurate estimate of 'potential trade'. The literature on conventional gravity models has still not been able to deal with this distinction satisfactorily.

The problem of applying stochastic frontier analysis to the gravity equation is that this application requires a leap of faith in assuming that all trade restrictions are captured in the *inefficiency* term, the non-negative disturbance, just as all of a producer's inefficiency in producing an output is captured in the inefficiency term in the conventional use of the stochastic frontier method.

One of the strongest assumptions in conventional gravity models is that the mean of the unobservable effects is zero. Here the argument is that the unobservable effects reduce trade and so have a negative correlation in respect of the dependent variable trade. Policy variables, and other trade increasing measures such as a regional trade arrangement (RTA), are thought of as reducing the resistances.

Here a new meaning of the term *trade potential* is introduced. Trade potential is conceived of as the maximum possible trade that can be achieved, not the average as previous use of the term in gravity model analysis meant. Trade potential is characterised by the *frontier* as described in the production literature and can be used as an estimate of what trade would be in the hypothetical case of most frictionless and free trade possible under present circumstances observed throughout the world (realistically, the estimate of the frontier is based on the best achievable 'trade technologies' – Kalirajan 1999; Kalirajan and Findlay 2005).

As discussed above, the theoretical foundations of the gravity model have only gone as far as including relative distance and border effects to capture the resistances.

The non-negative disturbance that reduces, or impedes, trade means no one can achieve trade on the frontier — there will always be asymmetric decision making, port inefficiencies, uncertainty, risk and scope for trade facilitation. Trading across borders will cause a disconnect[16] between relative prices in two jurisdictions as insurance, freight, tariffs, non-tariff barriers, and different regulatory structures cause uncertainty and impede trade to some degree. So this one-sided disturbance measures the distance from the frontier and can be thought of as the trade inefficiency term that captures trade resistances that are not specified in the gravity model. The only trade resistance terms that need to be included in the gravity model to estimate the frontier are relative distance, border effects and languages, as explained below.

Just as in the case for production, there is a random disturbance term that has the usual symmetric properties which are found in conventional gravity models. The random disturbance term captures and distinguishes disturbances that are not reflected in the bilateral trading country characteristics from disturbances which are specific to that bilateral relationship.

Now instead of finding the average effects of impediments (borders, tariffs and other quantifiable barriers) and whether a country is performing better or worse than the mean sample, as intensity analysis does using trade shares as benchmarks, a measure of how much trade resistance exists in a bilateral trade relationship can be estimated.

Stochastic frontier analysis was first used for analysing agricultural output. Its application is also prevalent in social efficiency literature where a government's ability to deliver social services to those most in need are analysed.[17] Applying stochastic frontier analysis to the gravity model may be more applicable than its application to measuring aggregate social efficiency, as empirical trade gravity models have theoretical foundations whereas the models of social indicators do not. It may therefore be more justifiable to impose and extract a latent 'inefficiency' feature from a theoretical gravity model than from a social indicator model.

Suggested model specification

This section proposes specifications for two stages of estimation, one for the trade frontier and the other for measuring the trade resistances. It suggests that many variables that are usually included in gravity models would be better left for explaining the gap between actual and potential trade, as opposed to estimating it.

Even in the production and social efficiency literatures, there is ambiguity as to which variables should be included in the first stage, measuring inefficiency, and the second stage, explaining the inefficiency (Kumbhakar and Lovell 2000; Ravallion 2003).

Here the suggestion is that estimation of the frontier, or potential trade, is made using only fundamental, or core, determinants of trade as the theoretical derivations would suggest: economic size (GDPs), relative distance, border, and other determinants which cannot be changed in the short to medium term, such as language and complementarity. We can call these the *natural* determinants of trade.

To see how this can be split in a gravity model framework, we take the trade resistance term between i and j, t_{ij}, which Baldwin and Taglioni (2006) define as

$$t_{ij} = f\,(dist_{ij},\ other\ stuff) \qquad (1)$$

and split this into man-made and natural resistances[18]:

$$t_{ij} = f\,(resist_{ij}) = f\,(natural_{ij},\ manmade_{ij}) = h(natural_{ij})\,g\,(manmade_{ij}) \qquad (2)$$

which can be further decomposed to

$$h(natural_{ij}) = rDist_{ij}^{\alpha_1} exp(border_{ij}^{\alpha_2} + landlocked_i^{\alpha_3} + landlocked_j^{\alpha_4} + lang_{ij}^{\alpha_5})$$

where $rDist_{ij}$ is relative distance between countries i and j, $border_{ij}$ is a dummy variable that takes the value one if i and j share a border, and zero otherwise; *landlocked* is a dummy variable with value one if a country is landlocked; and $lang_{ij}$ is an index of language similarity. There is scope for inclusion of a complementarity variable to reflect the comparative advantage of the trading nations. Man-made resistances are mainly policy variables and can be defined as

$$g(manmade_{ij}) = g(trade\ agreements_{ij},\ political\ dist_{ij},\ regional\ blocs,\ tariffs,\ institutions\ldots)$$

Where $trade\ agreements_{ij}$ is a dummy variable indicating a trade agreement between i and j (this can be split into different types of trade agreements), $political\ dist_{ij}$ is a measure of political closeness between *i* and *j*, and there is scope for inclusion of tariff measures, institutional settings and other man-made resistances that are discussed below. Therefore the trade resistances would all be captured in

$$\ln t_{ij} = \ln h\,(natural) + \ln g\,(manmade)$$
$$= \alpha_1 \ln rDist_{ij} + \alpha_2 border_{ij} + \alpha_3 landlocked_i + \alpha_4 landlocked_j + \alpha_5 lang_{ij} + \ln g(manmade)$$

By restricting the function for man-made resistances to be non-negative, a frontier can be estimated using the natural resistances and the man-made resistances can be explained in a second stage regression. A standard gravity model will look like:

$$\ln x_{ijt} = \ln\beta_0 + \beta_1 \ln y_{it} + \beta_2 \text{n}\, y_{jt} + \beta_3 \ln h(natural) + \sum_m \beta_m \ln Z_m + \varepsilon_{ijt} - u_{ij} \qquad (3)$$

Where $u_{ij} = \lambda(manmade_{ij}) \geq 0$

and x_{ijt} is trade from *i* to *j* at time *t*, y_{it} is country *i*'s size (GDP) at time *t*, y_{jt} is country *j*'s size (GDP) at time *t* and *Z*'s are other trade determinants with the potential of including Anderson and van Wincoop's multilateral resistance terms.[19] Here ε_{ijt} is a conventional mean zero random disturbance term and u_{ij} is non-negative and commonly has a half-normal, exponential or folded normal distribution.

Measuring the determinants of the gap between actual and potential trade, or resistances, can be undertaken simultaneously in the statistical analysis (Coelli 1996; Kumbhakar and Lovell 2000) and this was done in Drysdale et al. (2000). It is proposed here that it is in this second stage of the 'inefficiency' estimation, that policy variables that affect trade, and other short-to-medium term determinants, are properly placed. These can be thought of as man-made trade determinants. This allows for a proper estimation of the determinants of trade in the gravity model, consistent with the probabilistic model described by Deardorff (1995). All trade-increasing policy variables (PTAs, regional arrangements and trade organisations such as the WTO) and trade-reducing policy variables (official and non-official trade barriers) able to be quantified, can then be used to explain trade resistances as a secondary regression. This allows a further measure of how much of the trade resistance is explained by the quantifiable factors and how much is due to other resistances. For example, the inclusion of an APEC dummy variable, taking on a value of one if an exporter and an importer are both members of APEC and zero otherwise, would be expected to have a positive effect (as it did in Drysdale et al., (2000)) on the ratio of actual to potential trade, meaning that APEC helps in reducing trade resistances.

Furthermore, to identify the most important factors among many potential factors affecting trade efficiency, the use of a method such as principal components analysis would be appropriate. In models such as Rose's (2004; 2005) with many variables (up to 21), the most important, or principal components, can be identified while controlling for potential inter-correlation between explanatory variables (multicollinearity). For example, many indicator variables such as WTO membership, PTAs, regional trade arrangements (APEC) can be included with average tariff and tax rates, measures of openness, indices of economic freedom, indices of competitiveness[20] and other measures.[21] Principal components analysis would identify the most significant contributors to reducing or increasing trade resistances.

An important part of the empirical analysis of trade policy is the analysis of preferential trade arrangements (PTAs), and the effect of trade policy variables, on the welfare of trading partners. The standard gravity model has been employed to do this by identifying the impact of PTAs on trade flows between members and non-members.

How does the frontier gravity model deal with trade creation and trade diversion, first introduced by Viner (1950)? Trade creation is the amount of increased trade attributable to a PTA or lowering of tariffs preferentially, and trade diversion is the reduction in trade with third party non-members that results from a shift away from the lowest cost non-member to a higher-cost PTA partner. The net effect for the country granting tariff concessions, the PTA members, and for the world as a whole is unclear in principle because the welfare effects, beyond the net change in trade volumes, are difficult to measure (Adams et al. 2003). Adams et al (2003) employ the gravity model to measure the impact of PTAs on trade using a series of PTA indexes and dummy variables, importantly including third party non-member effects, and find that there is net trade diversion among most of the PTAs they analyse.

How will the frontier gravity model capture trade diversion and trade creation?

A policy variable such as membership of a PTA can be included in the explanation of the gap between the actual and potential trade values — estimating the determinants of high or low actual to potential trade ratio. A positive coefficient would mean the policy helps explain why trade is achieving higher actual trade along that bilateral route and reducing the resistances in achieving closer to potential trade. A positive coefficient for a bilateral relationship would also mean trade creation but only if all other factors are controlled for (natural and man-made). A reduction in trade efficiency for third country routes (non-PTA members) would signify trade diversion. To capture this properly, a dummy variable to measure the extent of additional trade between a PTA member and non-member can be included — a negative coefficient would show trade diversion or a corresponding increase in resistances. The net effect of the intra-PTA and extra-PTA dummy variables is the simplest way to measure whether the PTA has been trade increasing or reducing.

The complementarities and the multilateral resistance terms used in the estimation of the natural resistances shape the frontier whereas policy resistances explain the distance to the frontier.

If the multilateral resistance terms are able to be split into man-made and natural resistances, trade diversion will be reflected in the man-made multilateral resistance terms in the second stage regression, explaining the gap between actual and potential trade. Over time, trade liberalisation and improvements in trade technologies — including transport technologies and reductions in subjective resistances — shift the frontier out blurring the distinction between man-made and natural resistances. This will be important in estimations over longer time periods.

Applications

Stochastic frontier analysis has been applied to gravity equations in a handful of papers (Drysdale et al. 2000; Drysdale and Xu 2004; Kalirajan and Findlay 2005). Drysdale et al. estimate the model using a large enough set of countries to allow it to be defined as a world trade frontier. That is, their trade frontier is one whose estimated coefficients are based on best practice, or least trade resistant trade characteristics within all world trade flows. Kalirajan and Findlay use only Australian exports to define a country specific frontier. Export performance in a bilateral relationship can be compared to any other bilateral trade flow or measured against average performance by any country if the world frontier is used.

Drysdale et al. (2000) find that on average, bilateral trade flows are achieving 34 per cent of the estimated trade potential for 1991–1995 while Kalirajan and Findlay find Australian exports are achieving 65 per cent for the time period 1999–2002. The difference is explained by the way in which the frontiers are defined, the different countries being analysed in each study (and so results are not comparable), the different time periods and perhaps the different specification of the distribution of the non negative disturbance term (Kumbhakar and Lovell 2000).[22] The relatively low ratios of actual to potential trade in these studies, especially in Drysdale et al., is evidence of high trade resistances but also a result of high variation in the sample.

The empirical results support the use of a stochastic frontier as Drysdale et al. find that 78 per cent of the variation in trade flows is due to the variance in the inefficiency term[23], which dominates the rest of the variation, from the stochastic disturbance term. There are other applications of stochastic frontier gravity models which use a varying coefficients version of the model (Drysdale et al. 1997; Kalirajan 1999).

Differences in trade patterns across different regions of the world, different time periods and countries at different levels of development mean that the estimated elasticity coefficients of gravity models, or frontier gravity models, could be improved if they are allowed some flexibility. Since developing countries tend to produce more homogeneous goods and developed countries produce and sell more differentiated products, it would make sense to allow for coefficients to vary between the groups. Further, allowing the coefficients to vary for each estimate is desirable as it is reasonable to assume they will be different because of different stages of development, different preference structures or having a stronger 'home market' effect. Also, income elasticities are likely to change over country pairs and over time. The stochastic varying coefficients gravity model is used in Kalirajan (1999) and Drysdale et al. (1997). In these applications, coefficients are allowed to vary and the model predicts a different coefficient for each observation, at each time.

Armstrong (2007) looks at Japan–China trade and finds evidence of that trade relationship underperforming. The high resistances faced in the relationship are attributed mainly to political distance between the two nations but the analysis could be extended by using a measure of political closeness, or what the political science literature calls a conflict-cooperation variable to estimate whether the political relationship will affect the subjective trade resistances.

The inclusion of a WTO variable and APEC variable in the context of explaining the gap between actual and potential trade could have implications for some controversial results in the literature. Rose repeatedly finds a lack of empirical evidence of WTO membership increasing trade (Rose, 2004; Rose, 2005) and Polak (1996) disputes that APEC increases trade. An alternative hypothesis is that these multilateral institutions reduce subjective trade resistances and therefore narrow the gap between actual and potential trade.

There is potential for the any number of man-made trade determinants to be used to explain the distance of a trade performance relative to the frontier: measures of domestic, bilateral and multilateral institutions, governance quality, freedom and corruption indexes and conflict-cooperation variables are examples of how the application of this methodology can be extended.

Conclusion

The widely used and highly successful conventional gravity model still has problems, perhaps the biggest of which is dealing with unobservable trade frictions. In this paper, the relatively new, and to date little used, stochastic frontier gravity model is explained and justified in its use to overcome these problems. Instead of differencing out the unobservable trade costs and resistances, or assuming they are captured in the random symmetric disturbance term with an average effect of zero, they are captured and measured as the distance between actual trade and potential trade that lies on the frontier.

Previous studies use the term potential trade to mean the value of trade that the model predicts, given the average effects of all trade determinants. Here, trade potential is explained as the maximum possible value of trade that could hypothetically be attained using the most open trade policies, trading institutions and trading practices observed.

There has been limited use of this technique for modeling the trade frontier but the argument above suggests that its wider use in measuring trade potential is justified, especially because the frontier estimation allows account to be taken of all trade resistances without risk of omitted variable bias.

Notes

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1 Harrigan (2001) and Anderson and van Wincoop (2004) contain comprehensive reviews.

2 Iceberg transport costs assume the value of the good being transported 'melts' away in its transportation. The further a good travels, the more it loses value.

3 Helpman (1987) does not include distance at all in his model and sticks to the strong assumption of frictionless trade. Deardorff (1995) uses frictionless trade in the first of his two derivations and with zero transport costs, his second model converges to his first model.

4 Baldwin and Taglioni (2006) call this the gravitational un-constant.

5 See pages 18–19 in Balisteri and Hillberry (2006).

6 There has been use of different indexes for the same purpose such as an index of resource endowment similarity which was used in a stochastic frontier gravity model in Drysdale et al. (2000).

7 Linnemann's complementarity index of country *i*'s exports to country *j*'s imports is

$$C_{ij} = \cos\alpha_{ij} = \frac{x_i m_j}{|x_i| \cdot |m_j|}$$

Where α is the angle between country *i*'s export vector and country *j*'s import vector which gives a measure of how well the two countries' trade patterns 'fit' each others'. It can be found by dividing the scalar product of country *i*'s export vector, x_i, and country *j*'s import vector, m_j, by the scalar product of their absolute values.

Drysdale and Garnaut (1982) argue Linneman's complementarity index does not take into account the closeness or fit of both countries' trade relative to the world trade structure. Drysdale's (1967) complementarity index is defined as

$$C_{ij} = \sum_k \left(\frac{X_i^k}{X_i} \cdot \frac{M_w - M_i}{M_w^k - M_i^k} \cdot \frac{M_j^k}{M_j} \right)$$

Where X_i^k is country *i*'s exports of commodity *k*, M_i^k is country *i*'s imports of commodity *k*, M_j^k is country *j*'s imports of commodity *k*, X_i is *i*'s total exports, M_w^k is total world imports of commodity *k*, M_i is *i*'s total imports, M_j is *j*'s total imports and *Mw* is total world imports.

8 Rose (2004), in his widely cited study, uses 17 explanatory variables to claim the WTO does not increase trade and then in Rose (2005) uses 21 explanatory variables.

9 Roberts (2004) estimates that a China–ASEAN free trade agreement will create US$ 1.23 trillion worth of trade.

10 See Thursby (1987) and Frankel and Wei (1997) for example.

11 I am indebted to an anonymous referee for the first two of these references .

12 Again, Frankel (1997) provides a brief review of the empirical evidence of the Linder Hypothesis.

13 Drysdale and Garnaut (1982) and Harrigan (2001) have reviews of different indexes.

14 This section is prompted by comments from an anonymous referee which are greatly appreciated.

15 Linnemann (1996) calls these psychic costs. These would be expected to free in the course of globalisation with increased migration, transport technology improvements, communication technology improvements, and improved financial markets which may allow for hedging against risk and therefore reduce uncertainty.

16 Rossi–Hansberg (2005) provides an idealised theoretical model which demonstrates the large effects of small tariffs or barriers at borders.

17 See Ravallion for a review of stochastic frontier analysis used in measuring aggregate social efficiency.

18 Man-made and natural resistances are different ways to think of trade resistances as compared with objective and subjective resistances. Man-made resistances can be both objective and subjective, as can natural resistances. The distinction is for conceptualising resistances.

19 This would require the assumption of multilateral resistances being defined from the sum of all trade relationships except for the partner country which the particular observation is covering. The multilateral effect of trade from *i* to *j*, for country *j* will be a sum over all *k* not equal to *i*.

$$P_j = \left[\sum_{k \neq i} \left(\beta_k P_k t_{kj} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

Where t_{ij} is the iceberg trade cost factor, P is a true cost of living index, σ is the constant elasticity of substitution (which is exogeneous). Anderson and van Wincoop sum over all *i* but this would create problems when splitting the term t_{ij} to facilitate an error components model for frontier estimation. Here it is argued that without the inclusion of country i in country *j*'s multilateral resistance term, when trade between *i* and *j* is being explained, there will be very little bias and the effect of the multilateral term will be the same.

20 The World Economic Forum's Global Competitiveness Report is one source for potentially many trade related variables such as port efficiencies, transport efficiencies and many policy indices.

21 Drysdale et al. (2000) obtain some unexpected results and explain that their freedom index includes a tax component which is another explanatory variable. Principal components analysis would control for this.

22 When dealing with a cross-sectional data it is necessary to specify, or force a distribution, for the non-negative disturbance whereas with a panel, the model fits the best distribution to the disturbance. The most commonly used distributions are exponential or a half normal.

23 This is the value of gamma which is the proportion of total variation (from both the disturbance terms) that is explained by the variance of the non-negative disturbance term.

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