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Estimates of Trade Costs using Gravity Equation in Mixed Effects Model

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Abstract

By using a log-linear Taylor-series expansion to linearize the multilateral resistance terms, this study aims to estimate the theory-based gravity equation in mixed effects model to obtain not only unbiased and consistent but also efficient coefficient estimates of trade cost variables. We show that coefficient estimates of trade cost variables estimated using mixed effects model are close to those found by the existing literature; however, only those in this paper are efficient as a result of accounting for unobserved country heterogeneity and approximation errors.

Keywords: Trade Costs, Gravity Equation, Mixed Effects Model

JEL Codes: C50, F10

1. Introduction

The gravity equation is perhaps one of the most frequently used models to explain the determinants of bilateral trade flows. In a traditional gravity model, the dependent variable bilateral trade flows from origin to destination is regressed on the GDPs of exporter and importer countries, bilateral distance and a variety of binary variables that proxy for trade costs or the absence of trade costs. However, the traditional gravity equation does not account for the effects of third-country on international trade between pairs. It consequently produces biased and inconsistent estimates. The seminal work by Anderson and van Wincoop (2003) (Hereafter, A-vW) developed multilateral resistance terms (or prices) to control the interactions of pairs with the rest of the world (or third-country effects). Although the theoretical gravity equation with multilateral resistance terms provides unbiased estimates, it has not been widely adopted as it requires a non-linear estimation procedure.

Building also on the theoretical model of A-vW, Baier and Bergstrand (2009) (Hereafter, BB) use a log-linear Taylor-series expansion (TSE) to linearize the multilateral resistance terms so that the model can be estimated using ordinary least squares (OLS) method. These approximations not only allow for “Bonus Vetus” OLS, but also provide unbiased and consistent estimates since they are equal to multilateral resistance terms. Yet, the analysis of BB was mainly on a simple first-order TSE in which higher-order terms (approximation errors) were eliminated. However, elimination of these terms causes inefficient estimates of trade cost variables (Wooldridge, 2009). Furthermore, unobserved heterogeneity still remains in trade flows among countries as a result of not controlling for approximation errors (random effects). Thus, the primary objective of this study is to estimate the theory-based gravity equation using BB's motivation in mixed effects model while accounting for higher-order terms. In short, the coefficient estimates of models based on A-vW and BB are unbiased and consistent, but only those of mixed effects model are efficient due to the introduction of random effects and unobserved country heterogeneity.

2. Background

2.1 Theory

The empirical-based gravity model can be derived from several theoretical models (c.f. Anderson, 1979; Baier and Bergstrand, 2001; Eaton and Kortum, 2002; Helpman et al., 2008; Head and Mayer, 2014). Referring to the general gravity model, individuals in country j have constant elasticity of substitution (CES) preferences and can purchase up to N varieties of goods from N exporter countries. Considering firms within a country, the marginal cost of production is constant but there is a fixed entry cost. In addition, production takes place under the conditions of monopolistic competition and increasing return to scale technology. Because all firms within country i have access to identical technology, prices of each differentiated goods exported from i to j are equal to $p_{ij}(z) = p_{ij} = p_i * T_{ij}$ where p_i denotes domestic prices of varieties, and T_{ij} represents trade costs (i.e. transportation, insurance, tariff) that firms in origin i face exporting the goods to destination j. In conjunction with these assumptions, market-clearing conditions and several algebraic calculations compose the gravity equation as:

$$X_{ij} = \left(\frac{Y_i Y_j}{Y_w}\right)\left(\frac{T_{ij}}{\Pi_i P_j}\right)^{1-\sigma} \quad (1)$$

where X_{ij} is the volume of bilateral trade flows from i to j, Y_i and Y_j are incomes of exporter and importer countries, and Y_w is world income that is constant across countries and thus buried into the constant parameter along the further analyses. The parameter σ is the elasticity of substitution between varieties of goods. The variables accounting for the importance of third-country prices are outward and inward multilateral resistance terms explicitly written by:

$$\Pi_i^{1-\sigma} = \sum_{j=1}^{C}\left(\frac{T_{ij}}{P_j}\right)^{1-\sigma}\theta_j$$

$$P_j^{1-\sigma} = \sum_{i=1}^{C}\left(\frac{T_{ij}}{\Pi_i}\right)^{1-\sigma}\theta_i$$

where θ_i (θ_j) stands for country i's (country j's) share of world income. Note that because true values of trade costs between countries are unobservable, as is common to the international trade literature we approximate them by:

$$T_{ij} = dist_{ij}{}^{\alpha_1}\exp(\alpha_2 lang_{ij} + \alpha_3 adj_{ij} + \alpha_4 col_{ij})$$

where the variable $dist_{ij}$ denotes the bilateral distance between origin i to destination j, the dummy variable $lang_{ij}$ is equal to one when countries share the offical language and 0 otherwise, the binary variable adj_{ij} is equal to unity when countries are adjacent and 0 otherwise, col_{ij} is a dummy variable assuming the value 1 when two countries have ever shared a common colonizer and zero otherwise. In the framework of A-vW, the dependent variable based on a theory is formulated as bilateral trade flows divided by the product of exporter and importer incomes. Thus, we also impose unitary income elasticities to be consistent with their econometric model. Then, the gravity model in equation 1 can be written in log-level form for the sake of empirical analysis:

$$\ln(X_{ij}/Y_i * Y_j) = \ln(Z_{ij}) = \beta_0 + \beta_1\ln(dist_{ij}) + \beta_2 lang_{ij} + \beta_3 adj_{ij} + \beta_4 col_{ij}$$
$$+ (\sigma - 1)\ln(\Pi_i) + (\sigma - 1)\ln(P_j) + \varepsilon_{ij} \quad (2)$$

where $\beta_i = \alpha_i(1-\sigma)$, (i=1,...,4). A-vW estimated equation 2 using customized nonlinear least squares (CNLS), minimizing the sum of squared errors. In the subsequent sections, we discuss several distinguished approaches. They are by definition analogous to equation 2 in terms of non-biasedness and consistency.

2.2 Fixed-Effects Approach

Despite the fact that CNLS can produce unbiased and consistent estimates of equation 2, the non-linear approach has not been widely adapted. Nevertheless, A-vW and Feenstra (2004) proposed to replace multilateral resistance terms for country-specific fixed effects as an alternative specification that can be estimated by ordinary least squares (OLS) techniques. This method not only takes relatively less time but also produce unbiased and consistent coefficient estimates of β_i as well. Fixed effects version of equation 2 is defined as:

$$\ln(Z_{ij}) = \beta_0 + (1-\sigma)\ln(T_{ij}) + v_i + u_j + \varepsilon_{ij} \quad (3)$$

where the parameters v_i and u_j represent exporter and importer fixed effects, respectively, and ε_{ij} is a normally distributed error term. Note that although both CNLS and fixed effects approaches reveal unbiased and consistent coefficient estimates as both estimation techniques account for prices, it does not necessarily mean that the coefficients on trade costs would be identical. This matter is further discussed in the estimation results section. Both of these empirical formulations only reveal the average treatment effect and the general equilibrium effects cannot be easily obtained.

2.3. Bonus Vetus OLS

Building also on the theoretical model of A-vW, Baier and Bergstrand (2009) (Hereafter, BB) use a log-linear Taylor-series expansion (TSE) to linearize the multilateral resistance terms so that the model can be estimated using OLS. These approximations not only allow for "Bonus Vetus" OLS, but also provide unbiased and consistent estimates since they are formally equal to multilateral resistance terms. In addition, conditional general equilibrium effects can be obtained. To understand the implication of TSE on mixed effects model, following BB the multilateral resistance terms in equation 2 can be expressed as:

$$(\sigma - 1)\ln(\Pi_i) = \beta_i(\dot{T}_i - \ddot{T}) + \delta_i$$

$$(\sigma - 1)\ln(P_j) = \beta_j(\dot{T}_j - \ddot{T}) + \delta_j$$

where $\dot{T}_i = \frac{\sum_{k=1}^{N} T_{ik}}{N}$, $\dot{T}_j = \frac{\sum_{k=1}^{N} T_{kj}}{N}$, $\ddot{T} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} T_{ij}}{N^2}$ are the approximation errors capturing higher-order terms (or random effects). As is consistent with random effects model in Wooldridge (2009), we assume that δ_k, (k=i,j) is not correlated with explanatory trade cost variables, cf. equations 8-9. In addition, under strict erogeneity on independent variables we also assume that random effects δ_k is partially correlated with the multilateral resistance terms that may be constant distortions or not captured by the linearization, but not correlated with error terms, cf. equations 4-7.

$$E[(\sigma-1)\ln(\Pi_i)|\,T_{ij}] = \varphi + \varphi_i \dot{T}_i \quad (4)$$

$$E[(\sigma-1)\ln(P_j)|\,T_{ij}] = \varphi + \varphi_j \dot{T}_j \quad (5)$$

$$E[(\sigma-1)\ln(\Pi_i)|\,T_{ij}, \delta_i] = \varphi + \varphi_i \dot{T}_i + \delta_i \quad (6)$$

$$E[(\sigma-1)\ln(P_j)|\,T_{ij}, \delta_j] = \varphi + \varphi_j \dot{T}_j + \delta_j \quad (7)$$

$$E[\delta_i|\,T_{ij}] = 0 \quad (8)$$

$$E[\delta_j|\,T_{ij}] = 0 \quad (9)$$

A relevant question is "In what aspects does this study differ from BB?" The analysis of BB was mainly on a **simple first-order TSE** with the assumptions of 4-5 in which higher-order terms were not explicitly included and instead eliminated as BB noted "... a simple fixed-point iteration procedure that eliminates the approximation errors without using a higher-order Taylor expansion which, as for modern dynamic macroeconomic models, is very difficult and outside the paper's scope". However, elimination of δ_k causes inefficient estimates of trade cost variables, cf. Wooldridge (2009). Furthermore, unobserved heterogeneity,ε_{ij}, remains in trade flows among countries as a result of not controlling for approximation errors. Thus, the primary objective of this study is to estimate the theory-based gravity equation by mixed effects model while accounting for higher-order terms[1]. After identifying that equations 6-7 have the same form as the correlated random effects, we can thus substitute them into equation 2 to obtain:

$$\ln(Z_{ij}) = \mu + \beta_1 \ln(dist_{ij}) + \beta_2 lang_{ij} + \beta_3 adj_{ij} + \beta_4 col_{ij} + \dot{T}_i + \dot{T}_j + \delta_i + \delta_j + \eta_{ij} \quad (10)$$

The above equation now resembles a two-way correlated random effects (or mixed effects) model. Because an intercept is explicitly shown in the above model, we assume that the random effects are normally distributed with a zero mean as in Wooldridge (2009). As mentioned earlier in this section, the econometric model in equation 10 is similar to that in BB except omitting the parameters δ_i and δ_i[2].

3. Data

A cross-sectional data of 189 countries for 2005 is employed within this study. A complete list of countries is posted in appendix. The data on GDPs as proxy for incomes are drawn from the World Bank's "World Development Indicators" (http://data.worldbank.org). The data on bilateral trade flows for each pair come from UNCTAD. The data on trade cost variables are taken from different sources. The variables distance and common colonizer are drawn from "Centre d'Etudes Prospectives et d'Informations Internationales" (CEPII). We use the distance measure associated with distance in kilometers between the most populous cities in countries. A number of studies have shown that the amount of trade flows is negatively correlated with bilateral distance. Intuitively, marginal costs (i.e. transportation costs) and fixed costs (i.e. searching cost) rise as $dist_{ij}$ increases. A colonial relationship refers to a historical tie between countries that can increase international trade among them. The variables common language and common border are obtained from Head et al. (2010). Expected sign of speaking the same official language is positive as Helliwell (1997) noted "A common language provides evidence of common cultural roots, shared literature and lore, and even shared codes of law." In addition, a pair of adjacent countries is expected to have cultural and economic similarities that encourage international trade between countries.

4. Estimation Results and Conclusion

Starting with the fixed effects specification, we apply constrained OLS approach to estimate the model in equation 3 using country-specific fixed effects to control for the multilateral resistance (prices) terms. The coefficients estimates and estimated average treatment effects (ATEs) for trade cost variables are reported in column (1) of table 1 wherein coefficient estimates of fixed effects are not reported for the sake of brevity. Considering BB's first-order Taylor

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[1]For this purpose, the STATA xtmixed code can be commanded in equation 10 assuming that the intercepts for the source and destination countries are random.

[2]The other difference related to equation 10 is that we approximate trade costs by dist, lang, adj and col whereas BB defined trade costs by only dist and adj just as in A-vW.

expansion, we also employ OLS to estimate the econometric model in equation 10 excluding random effects δ_k. Estimates of the effects of trade cost variables are presented in column (2) of table 1. Then, we estimate equation 10 including approximation errors capturing higher-order terms by using mixed effects approach. The estimates of β_i and estimated ATEs for trade cost parameters are posted in column (3) of table 1.

In advance to reporting estimation results of the models in this paper, it is critical to elaborate the findings of previous studies related to this study. BB showed by taking a first-order Taylor expansion and using "true" trade flows in a Monte Carlo simulation that the coefficient estimates of distance and common border are nearly identical to fixed effects and CNLS estimates in A-vW and Feenstra (2004)[3]. However, it is noteworthy that by using "observable" trade flows of US-Canada for 1993 instead, BB indicated that the border effect was somewhat different than that estimated using CNLS and fixed effects methods. Based on the same US-Canada data, Feenstra (2004) also compared the border effect obtained using fixed effects to that found by A-vW applying CNLS. The author reported that the ATE for common border in fixed effects model was 4.7 and quite close to average effect of 5.2 explored by A-vW accounting for endogenous multilateral resistance terms. We close the review by noting that the estimates of distance and common border in fixed effects model, BB and A-vW are all consistent since they control for prices. As distinct from these studies, mixed effects model produces not only consistent but also accounts for approximation errors. Assuming these errors are normally distributed lead to more efficient estimation of equation 10 because it simultaneously accounts for prices and unobservable country heterogeneity.

Table 1. Estimation Results

	Fixed Effects (1)		Bonus Vetus (2)		Mixed Effects (3)	
regressors	Coeff.	ATE	Coeff.	ATE	Coeff.	ATE
ln(dist)	-1.62		-1.58		-1.64	
	(0.02)		(0.02)		(0.02)	
lang	0.82	2.27	0.72	2.01	0.75	2.12
	(0.05)		(0.06)		(0.05)	
adj	0.87	2.38	0.86	2.36	0.79	2.20
	(0.12)		(0.14)		(0.12)	
col	1.00	2.71	0.92	2.51	0.95	2.59
	(0.07)		(0.08)		(0.07)	
cons	-42.14		-16.63		-12.59	

Note: Numbers in parenthesis are standard errors. All coefficient estimates are statistically significant at 1% level.

Returning back to analyses in this paper, column (1) reports that the coefficients on distance, common language, common border and common colonizer are -1.62, 0.82, 0.87 and 1.00, respectively, and statistically significant at 1% level. The ATEs for lang, adj and col are 2.27, 2.38 and 2.71, in order. Rather than those in fixed effects equation, column (2) based on BB posts that the ATEs for lang, adj and col are 2.01, 2.36 and 2.51. Note that the dist coefficients of both models are identical and the ATEs for binary variables of both models are close to each other as expected. The estimates of β_i, (i=1,...,4) of equation 10 are -1.64, 0.75, 0.79 and 0.95, respectively, referring to column (3). Although, the ATEs for trade cost variables are slightly different than those in fixed effects and BB, they are once again quite close to each other in the way we anticipated. We end this section by noting that the coefficient estimates in columns (1)-(3) are unbiased and consistent; however, only those in column (3) are efficient due to the introduction of random effects and unobserved country heterogeneity.

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Appendix

Country List

Afghanistan	Dominica	Laos	Qatar
Albania	Dominican Rep	Latvia	Sao Tome and Principe
Algeria	Ecuador	Lebanon	Saint Kitts and Nevis
Angola	Egypt	Lesotho	Saint Lucia
Antigua And Barbuda	El Salvador	Liberia	Saint Vincent and the Grenadines
Argentina	Equatorial Guinea	Libya	Samoa
Aruba	Eritrea	Lithuania	San Marino
Armenia	Estonia	Luxembourg	Saudi Arabia
Australia	Ethiopia	Macao, China	Senegal
Austria	Faeroe Islands	Macedonia, Fyr	Seychelles
Azerbaijan	Fiji	Madagascar	Singapore
Bahamas	Finland	Malawi	Slovak Republic
Bahrain	France	Malaysia	Slovenia
Bangladesh	Gabon	Maldives	Somalia
Barbados	Gambia	Mali	Solomon Islands
Belarus	Georgia	Malta	South Africa
Belgium	Germany	Marshall Islands, Rep	Spain
Belize	Ghana	Mauritania	Sri Lanka
Benin	Greece	Mauritius	Sudan
Bermuda	Grenada	Mexico	Suriname
Bhutan	Greenland	Micronesia, Fed.Sts.	Swaziland
Bolivia	Guatemala	Moldova	Sweden
Bosnia and Herzegovina	Guinea	Mongolia	Switzerland
Botswana	Guinea-Bissau	Morocco	Syria
Brazil	Guyana	Mozambique	Taiwan
Brunei Darussalam	Haiti	Myanmar	Tajikistan
Bulgaria	Honduras	Namibia	Tanzania
Burkina Faso	Hong Kong	Nepal	Thailand
Burundi	Hungary	Netherland	Togo
Cambodia	Iceland	New Caledonia	Tonga
Cameroon	India	New Zealand	Trinidad (Trinidad And Tobago)
Canada	Indonesia	Nicaragua	Tunisia
Cape Verde	Iran	Niger	Turkey
Cayman Islands	Iraq	Nigeria	Turkmenistan
Central African Rep.	Ireland	Norway	Uganda
Chad	Israel	Oman	UK
Chile	Italy	Pakistan	Ukraine
China	Ivory Coast	Panama	United Arab Emirates
Colombia	Jamaica	Papua New Guinea	Uruguay
Comoros	Japan	Paraguay	USA
Congo, DR	Jordan	Peru	Uzbekistan
Costa Rica	Kazakhstan	Philippine	Vanuatu

Croatia	Kenya	Poland	Venezuela
Cuba	Kiribati	Portugal	Vietnam
Cyprus	Korea	Romania	Yemen
Czech Republic	Kuwait	Russia	Zambia
Denmark	Kyrgyzstan	Rwanda	Zimbabwe
Djibouti			