The Proper Econometric Speci…cation of the Gravity Equation: A Three-Way Model With Bilateral Interaction E¤ects

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Abstract

We argue that the proper speci…cation of a gravity model should include main (exporter, importer, and time) as well as time invariant bilateral e¤ects. In a panel of 11 APEC countries, the latter are highly signi…cant and account for the largest part of variation.

Keywords: Gravity equation; Panel econometrics
JEL classi…cation: C33; F14; F15

1 Introduction

The gravity model has become one of the most successful tools for estimating bilateral trade relations. In recent years the discussion about the proper econometric speci…cation has shown that conventional cross-section formulations without the inclusion of (in most cases …xed) exporter and importer e¤ects are misspeci…ed (see Mátyás, 1997; Egger, 2000). Consequently, the now familiar econometric speci…cation is in three ways with the main time, exporter, and importer e¤ects.

We demonstrate that the traditional formulation in a three-way setting is only a restricted version of its more general counterpart which additionally includes bilateral interaction e¤ects. The related restriction of zero interaction e¤ects can be tested and in our application for a panel of 11 APEC countries it is …rmly rejected. In contrast to the traditional gravity model which includes main e¤ects and time invariant trade impediment measures (distance, common language and border dummies, etc.), the proposed speci…cation is more general since it accounts for any (to some extent unobserved) bilateral e¤ect.

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2 The Gravity Model

The traditional basic speci…cation of the gravity model includes supply factors of the export country (population and GDP), demand factors of the import country (population and GDP), and trade supporting and impeding determinants (mostly transport costs or proxies thereof, geographical and cultural measures of bilateral proximity, etc.). Fixed exporter (importer) e¤ects[1] capture the general propensity to export (import) of a country. Fixed time e¤ects account for the business cycle and changes in openness across all countries.

Although broadly accepted, this three-way gravity model is not that general as has been previously assumed. From an analysis of variance (ANOVA) point of view, the three orthogonal dimensions (factors) - time, exporter and importer e¤ects - do not span the whole vector space of possible treatments (in ANOVA terms) explaining variations in bilateral exports. Possible interactions between the exporter and importer dimensions are omitted[2]. From an econometric point of view, it "would be unwise to ignore this possible source of interaction" (Christensen, 1987, p. 127), if interactions have a signi…cant impact (which can be tested for). Under these circumstances, omitting the interaction e¤ects may yield biased estimates. From an economic point of view, the interaction terms also …nd some useful interpretation: while the exporter (importer) e¤ect measures the general openness of a country with respect to its partner countries included in the sample, the bilateral e¤ect accounts for any time invariant geographical, historical (e.g. wars), political, cultural (di¤erent languages, etc.), and other bilateral in‡uences which lead to deviations from a country pair's "normal" propensity to trade. Since the major part of these in‡uences usually remains unobserved, including bilateral interaction e¤ects is the natural way to control for them. The inclusion of the interaction term is more general than bilateral time invariant trade supporting or impeding measures like cultural and geographical dummies as well as distance measures. Note that especially the latter are proxies of only limited value for costs of transportation and not included in all speci…cations (see e.g. Bergstrand, 1985; Helpman, 1987; Hummels & Levinsohn, 1995).

Additionally, many traditional gravity applications intend to project

[1] Note that these e¤ects could either be treated as random (Baldwin, 1994; Mátyás, 1998) and being part of the error term or as …xed (Mátyás, 1997; Egger, 2000). The proper treatment of the e¤ects depends on the underlying interests and the data sample.

[2] Note that interaction terms between the time and exporter or importer dimension are not considered as explanatory variables with meaningful economic interpretation (population, GDP, etc.) and variation in these dimensions are included.

bilateral trade (and more recently also FDI) relations. With the inclusion of only the main effects, the projection of bilateral trade relations may be misleading and give imprecise "forecasts" with unnecessary large confidence intervals (see Breuss & Egger, 1999, for an estimate using a traditional model).

The proper specification includes the three main effects and additionally accounts for time invariant bilateral interactions. Note that not all contrasts in the interaction space can be defined given that there are main effects in the model (resulting in a set of restrictions which guarantee the orthogonality between main and interaction effects). The more general specification then reads[3]

$$y_{ijt} = \beta_0 + X\beta + \alpha_i + \gamma_j + \delta_t + \varepsilon_{ij} + u_{ijt} \qquad (1)$$

With $\sum_i \alpha_i = 0$, $\sum_j \gamma_j = 0$, $\sum_t \delta_t = 0$, $\sum_i \varepsilon_{ij} = 0$, and $\sum_j \varepsilon_{ij} = 0$ being the corresponding restrictions. It is easy to show that this generalized three-way specification is identical to a two-way model with time and bilateral effects only (see Christensen, 1987).

We use a specification introduced by Mátyás (1997), which uses the traditional supply (exporter: i) and demand (importer: j) factors represented by GDP and population (POP) together with foreign currency reserves of the importing country (FCR) and the real exchange rate between two partner countries (RER) as the explanatory variables:

$$\begin{aligned} \ln EXP_{ijt} = {} & \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln POP_{it} + \beta_4 \ln POP_{jt} \\ & + \beta_5 \ln FCR_{jt} + \beta_6 \ln RER_{ijt} + \alpha_i + \gamma_j + \delta_t + \varepsilon_{ij} + u_{ijt} \end{aligned} \qquad (2)$$

For the parameters we would expect a positive sign for β_1, β_2, β_5, and β_6[4]. The larger countries are, the more they are known to be self-sufficient. Therefore, we would expect a negative sign for β_3 and β_4 (see Baldwin, 1994).

[3] Although we concentrate on fixed effects, the argument also holds true in a random effects formulation. The three-way estimation results with random exporter and importer effects and fixed time effects likewise could substantially deviate from the more general two-way (only bilateral random effects) counterpart.

[4] Note that RER_{ijt} is defined by an exporter's currency units per unit of an importer's currency. Hence, the higher RER_{ijt} the cheaper are products from i for consumers/firms in j.

3 Data and Empirical Results

We analyze a panel of bilateral exports for 11 APEC[5] countries over the period 1982-1998. To obtain real bilateral exports (base year 1995), we take nominal export …gures from UNO and convert them by export de‡ator numbers from IMF (International Financial Statistics). Real GDP and population data come from the World Bank (World Development Indicators 2000). Foreign currency reserves and bilateral real exchange rates (based on consumer price index) are also from IMF (International Financial Statistics). We removed 28 outliers from the sample having studentized residuals larger than 3.5 in absolute value and therefore ended up with 2029 observations.

> Table 1 <

Table 1 presents the results for the ANOVA table of our gravity model with bilateral interactions. Among all the explanatory variables, the interaction e¤ects (besides the constant, not reported) explain the largest part of variation in bilateral exports (about 12.4 percent of total sum of squares) and substantially increase the goodness of …t.

> Table 2 <

Table 2 compares the estimation results of the generalized (column 1 and 2) and the traditional three-way model (with main e¤ects only; column 3). The generalized formulation is superior to the traditional in terms of adjusted R^2 and the Wald test indicates a highly signi…cant contribution of the interaction terms in addition to the main e¤ects. In both …xed e¤ects speci…cations the time invariant main e¤ects are also highly signi…cant. This holds not true for time e¤ects which are only signi…cant in the generalized setting. There is also a slight di¤erence in the continuous explanatory variables and the constant. Applying the Ramsey RESET test we reject the hypothesis of proper formulation (missing variables and/or functional form) of the traditional model (column 3). This leads to a clear rejection of the latter formulation from both the economic and the econometric point of view.

For the generalized speci…cation we compare the …xed e¤ects formulation with the corresponding two-way random e¤ects model[6]. The Hausman test …rmly leads us to the conclusion that we should reject

[5] Due to lacking and partly unreliable data we exclude Brunei from the sample which then contains: Australia, Canada, Indonesia, Japan, Korea, Malaysia, New Zealand, the Philippines, Singapore, Thailand and the United States as exporters and importers together with the EU15 as an importer only.

[6] We treat time as …xed and allow for randomness of bilateral treatments.

the random e¤ects model in favor of the …xed e¤ects speci…cation. The di¤erence in the coe¢cients (especially population, where even the parameter sign is di¤erent) indicates that the random e¤ects and some explanatory variables are correlated severely violating the main assumption of the random e¤ects model.

4 Conclusions

We demonstrate that the proper speci…cation of gravity models comprises time and bilateral e¤ects leading to a two-way rather than a three-way panel. This could be either of the random or the …xed e¤ects type, which depends on the interests of the analysis, the country sample, the data properties, and the theoretical model. In a …xed e¤ects framework the estimation of a gravity model for 11 APEC countries indicates that bilateral interaction terms account for a large part of variation in addition to the main e¤ects (time, exporter and importer) and are highly signi…cant. Therefore, choosing a traditional three-way formulation ignores some (probably) relevant information.Although it is not the case for the present estimations, this may cause an omitted variable bias. For example, one may obtain "wrong" measures for the export and import propensities of countries. Moreover, the projection of bilateral trade relations is misleading and gives imprecise "forecasts" with unnecessary large con…dence intervals.

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Table 1: Analysis of Variance with Main and Bilateral Interaction Effects of the Gravity Model
Dependent Variable is Log of Real Bilateral Exports

Source	Partial Sum of Squares		Degrees of	Mean
	Absolute	In percent of Total	Freedom	Square Error
Model	7642.7	98.5	142.0	53.8
Exporter effect (α_i)	754.0	9.7	10.0	75.4
Importer effect (γ_j)	451.9	5.8	11.0	41.1
Time effect (λ_t)	4.1	0.1	16.0	0.3
Bilateral interaction (δ_{ij})	964.6	12.4	99.0	9.7
Exporter GDP (ln GDP_{it})	31.1	0.4	1.0	31.1
Importer GDP (ln GDP_{jt})	9.2	0.1	1.0	9.2
Exporter population (ln POP_{it})	0.1	0.0	1.0	0.1
Importer population (ln POP_{jt})	4.6	0.1	1.0	4.6
Importer foreign currency reserves (ln FCR_{jt})	2.9	0.0	1.0	2.9
Real exchange rate (ln RER_{ijt})	10.5	0.1	1.0	10.5
Residual	117.9		1886.0	0.1
Total	7760.6	100.0	2028.0	3.8

Table 2: Unbalanced Gravity Equation Panel Estimates

Dependent Variable is Log of Real Bilateral Exports

	Main and bilateral interaction fixed effects		Main and bilateral interaction random effects		Main fixed effects	
	Coefficient (β)	t-statistic[a)]	Coefficient (β)	t-statistic	Coefficient (β)	t-statistic[a)]
Exporter GDP (ln GDP_{it})	1.07	19.9 **	1.03	25.0 **	1.08	7.7 **
Importer GDP (ln GDP_{jt})	0.66	10.5 **	0.68	14.9 **	0.67	4.3 **
Exporter population (ln POP_{it})	0.28	1.2	-0.39	-6.2 **	0.27	0.5
Importer population (ln POP_{jt})	1.58	7.2 **	-0.05	-0.8	1.57	3.5 **
Importer foreign currency reserves (ln FCR_{jt})	0.11	6.1 **	0.14	8.7 **	0.10	2.3 **
Real exchange rate (ln RER_{ijt})	0.44	12.2 **	0.36	11.8 **	0.45	4.9 **
Constant	-67.61	-11.7 **	-21.63	-12.9 **	-67.73	-4.7 **
		p-value		p-value		p-value
Number of Observations	2029		2029		2029	
Adj. R^2	0.98		0.80		0.86	
Root Mean Square Error	0.25				0.74	
σ_u (of bilateral random effects)			1.04			
σ_e			0.25			
RESET: F(3, 1883)[b)]	1.39	0.24			14.92	0.00
Heteroskedasticity: $\chi^2(1)$[c)]	126.39	0.00			2.44	0.12
Hausman (fixed versus random effects): $\chi^2(22)$			124.37	0.00 **		
Wald-Tests[d)]:						
Exporter effect (α_i): F(10, 1985)	185.54	0.00			111.65	0.00
Importer effect (γ_j): F(11, 1985)	282.24	0.00			59.93	0.00
Time effect (λ_t): F(16, 1886)	3.78	0.00			0.41	0.98
Bilateral interaction (δ_{ij}): F(99, 1886)	256.37	0.00				
No time invariant (main and interaction) effects: F(120, 1886)	285.32	0.00				

a) t-statistic is heteroskedasticity robust (White, 1980). - b) Using powers of the predicted dependent variable (Ramsey, 1969). - c) Using the fitted values of the dependent variable to explain the estimated squared residuals (Cook & Weisberg, 1983). - d) Based on the estimated variance-covariance matrix of the respective estimator.

Note: we removed 28 outliers from the sample having studentized residuals larger than 3.5 in absolute value.