A Note on the Proper Econometric Specification of the Gravity Equation

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Abstract

Since the revival of the gravity literature in the early nineties most work has been done with cross-section data. Just a few more recent contributions made use of panel data. So far that research left open the question whether to treat time and country effects as random or fixed. This note sheds some light on the problems that are associated with a random effects approach. Arguments for the superiority of the fixed effects model are given both along intuitive and econometric lines based on a Hausman test.

Key words: gravity equation, panel econometrics
JEL: C33, F14, F15

1 Introduction[1]

Among the huge empirical literature on gravity models published in the last decade most studies have been done with a cross-section methodology. However, a panel framework reveals several advantages over cross-section analysis: On the one hand panels allow to capture the relationships between the relevant variables over a longer period and to identify the role of the overall business cycle phenomenon (in cross-section research one usually employs data averages over a certain period to lower the influence of outliers[2]). On the other hand within a panel approach

[1] I wish to thank W. Kohler, R. Kunst, R. Winter-Ebmer, the participants of a research seminar of the University of Linz, Department of Economics, and especially M. Pfaffermayr for their useful comments and discussions.

[2] Note that from cross-section parameters we get only valid predictions of the comparative statics if we are in the equilibrium (Schmalensee, 1988). Offside the equilibrium the estimated parameters would deviate from those out of a panel analysis. In such circumstances the estimated sign of the coefficients could be wrong in the extreme case. Panels also allow to draw on the time dimension and do not need the assumption of identical steady-states in levels across groups.

one is able to disentangle the time invariant country specific effects. Above all, one should take into account that the interpretation of the estimated coefficients is crucially different from that of cross-section analysis. In a panel framework one controls for cross-section deviations and is thus able to interpret the parameters as elasticities of the influence of independent variables on the dependent one (within interpretation). In cross-section analysis in many cases one is tempted to interpret the coefficients in the same way which is conceptually wrong, as in fact they should be read as composite within and between effects (see Hsiao, 1986). Nevertheless, so far just a few authors in this field investigated a panel framework (Baldwin, 1994, Mátyás, 1997). But it seems not clear whether one should apply a random (REM) or a fixed effects model (FEM)[3]. Looking at some of the latent variables that one would argue to stand behind the country-specific and time invariant export and import effects will shed some light into the problem. Fixed effects are due to omitted variables that are specific to cross-sectional units (export and import effects) or to time periods (Hsiao, 1986). Some of the main forces behind the fixed export effects should be tariff policy measures and export driving or impeding "environmental" variables. The formers can be thought of as average tariff or non-tariff barriers (tariffs, taxes, duties, bureaucratic legal requirements, etc.) either on the export side of the reporter or on the import side of the whole sample of partner countries. The latters could be size of country, access to transnational infrastructure networks, geographical and historical determinants (e.g. the relatively huge role of trade relations between the CEECs because of former membership in COMECON, etc.). As most of those effects are not random but (e.g. because of path dependencies, membership in supranational organisations, etc.) deterministically associated with certain historical, political, geographical, and other facts, a FEM would be the right choice from this intuitive point of view. Another argument which favours the FEM comes along with the problem of sample selection. In many applications the gravity model is used to calibrate integration effects and thus to project trade flows between EU or OECD and the Central and Eastern European Countries (CEECs). In that cases one is not interested in the estimation of typical trade flows between a randomly drawn sample of countries but between an ex ante predetermined selection of nations[4]. One would like to know, how the

[3]While Baldwin (1994) employs a REM, Mátyás does not favour the FEM over the REM or vice versa.

[4]This Mátyás (1998) has in mind noting that for large country samples (e.g. when one's interest lies in the general evaluation of the effects of transportation costs and other variables on bilateral trade volumes) one should treat the country specific

typical trade relations between e. g. a CEEC and a EU member country would look like if those relations would behave in the manner of a typical relationship between EU countries. Under such circumstances the FEM would be the right choice, since the sample is exhaustive. This note tries to show that also because of pure econometrical reasons preference is given the FEM over the REM. As the theoretical content of the gravity equation was criticised (Deardorff, 1995) because it is derivable from any plausible model of trade in this note a specification is chosen which is as close as possible associated with an H-O model under product differentiation.

The following section briefly introduces the econometric specification and Hausman-test procedure, section 3 provides information on the database and estimation results, section 4 concludes.

2 A Model with Time and Country Effects

Mátyás (1997) argued that the correct gravity specification is a three way model. One dimension is time (reflecting the common business cycle or globalisation process over the whole sample of countries) and the other two dimensions of group variables are time invariant export and import country effects. According to Helpman and Krugman (1985) and Helpman (1987) an endowment based 2 x 2 x 2 model is choosen, where one of the two goods is differentiated and the other is homogeneous. The two factors of production are the stock of capital and the labor force (proxied by population). In such a framework the total volume of trade of each country could be defined as the sum of inter- and intra-industry trade volumes. The corresponding reduced form equation to estimate the world volume of trade in such a model reads

$$X_{ijt} = \beta_0 + \beta_1 RLFAC_{ijt} + \beta_2 GDPT_{ijt} + \beta_3 SIMILAR_{ijt} + \beta_4 DIST_{ij} + \beta_5 INTER_{ij} + \alpha_i + \gamma_j + \delta_t + u_{ijt} \quad (1)$$

Where X_{ijt} is the log of country i's exports to country j in year t. β_0 is the constant. $RLFAC_{ijt} = \mid \ln \frac{K_{jt}}{N_{jt}} - \ln \frac{K_{it}}{N_{it}} \mid$ measures the distance between the two countries in terms of relative factor endowments. This variable could take a minimum value of 0 (equality in relative factor endowments). According to theory, the larger this difference, the higher is the volume of interindustry (and overall) trade, and the lower the share of intra-industry trade. $SIMILAR_{ijt} = \ln[1 - \left(\frac{GDP_{it}}{GDP_{it}+GDP_{jt}}\right)^2 - \left(\frac{GDP_{jt}}{GDP_{it}+GDP_{jt}}\right)^2]$ captures the relative size of two countries in terms of

(import and export) effects as non-observable random variables.

GDP. This index is bounded between 0 (absolute divergence in size) and 0.5 (equal country size). The larger this measure and thus the more similar two countries in terms of GDP are, the higher the share of intra-industry trade. It is also clear that the total volume of trade should be higher, the larger the overall economic space $GDPT_{ijt} = \ln(GDP_{it} + GDP_{jt})$ of the two countries (the world) for given relative size and factor endowments. $DIST_{ij}$ is the log of the distance variable which is a proxy for transportation costs. Looking at the factor box to such a model without transport costs, we would associate $GDPT$ with the length of the diagonal of the box, $SIMILAR$ with the location of the consumption point along this diagonal, and $RLFAC$ as a measure of distance between the endowment point and the consumption point along the relative factor price line. $INTER_{ij}$ is an interaction term which reports the distance measure again whenever country i is the same as country j (exports of a country to itself). δ_t reflects the time effect which is due to all countries[5], α_i and γ_j are the country specific fixed effects.

According to Baltagi (1995) and Greene (1995) Hausman's chi-squared statistic for testing random versus fixed effects is applied. Therefore one has initially to compute the (feasible) GLS (FGLS) regressors. This is done by splitting up the total variance into its three components $(\widehat{\sigma}_{\varepsilon}^2 + \widehat{\sigma}_x^2 + \widehat{\sigma}_m^2)$. The first term $(\widehat{\sigma}_{\varepsilon}^2)$ is equivalent to the variance from the FEM (within group variance) and the other two components are parts of the between-variances for the export and import country factor. There are now three ways to estimate those components[6] which are equivalent if β_{OLS} is consistent. (1) One can run the group means estimations to get the variance components and furthermore the weights to construct the FGLS estimator. Unfortunately in our case this procedure yielded perfectly collinear group means estimations as the time dummies do not exhibit any variances in the export or import country dimension ($\widehat{\sigma}_x^2$ and $\widehat{\sigma}_m^2$ could not be estimated). So we had to look for another possibility. (2) Alternatively one can start directly from the OLS estimator to figure out $\widehat{\sigma}_x^2$ and $\widehat{\sigma}_m^2$. This proved to result in a negative for $\widehat{\sigma}_x^2$ and $\widehat{\sigma}_m^2$ in our case which indicates the inconsistency of the OLS-estimator. (3) $\widehat{\sigma}_x^2$ and $\widehat{\sigma}_m^2$ can also be based on the sample variance of the fixed effects from the FEM. This last possibility, however, is only available if one has initially fitted the FEM but guarantees positive estimates of $\widehat{\sigma}_x^2$ and $\widehat{\sigma}_m^2$. The variance components are used to calculate the corresponding weights needed for the variables in the REM (see Greene, 1995, p. 313

[5]It is not tested for the randomness of time-effects, however, as the overall cycle, the general development of openness, or whatever is measured be that factor, generally should not be treated as random.

[6]I just will refer to the case of a balanced sample (see Greene, 1995).

or Baltagi, 1995, p.32). Whether the REM or the FEM is the econometrically more appropriate setup heavily depends on the correlation of the individual effects with the regressors. However, it is a basic assumption in the REM that there is no such correlation. If some variables are omitted the REM may suffer from that. The Hausman chi-squared statistic tests for the orthogonality of the random effects and the regressors, this is thus a test for misspecification. The test statistic is asymptotically distributed as central chi-square. A significant test statistic reveals a high importance of group-specific effects and their correlation with the right-hand variables and is an econometric argument at hand that underpins the importance to control for permanent unobserved differences across groups. In such a case the random-effects estimates are significantly inconsistent (see Hsiao, 1986, p. 49).

3 Data and Empirical Results

The data series cover a period of 12 years (1985-96). All variables are in nominal terms. Bilateral export data were taken from OECD Statistics of Foreign Trade. GDP, population, and gross fixed capital formation (GFCF) are from OECD National Accounts. The distance variable is measured in miles between capitals and was computed in the following way (see Schumacher, 1997)

$$D_{ij} = r \cdot ar\cos[\sin(\varphi_i) \cdot \sin(\varphi_j) + \cos(\varphi_i) \cdot \cos(\lambda_j - \lambda_i)].$$

Where r is the earth radius in miles, φ_i and φ_j are radian measures of the parallel of latitude of the two countries' capitals, and $(\lambda_j - \lambda_i)$ is the radian measure of the difference in meridians of the two countries' capitals. For trade relations of countries with themselves $(i = j)$[7] the distance variable was computed as follows: Assume that all countries are are of a circular area. Then one could compute the radius $(r)$for all countries as data on land areas are provided in the Internet. When production is concentrated in the center of the circle (the country's capital or economic center) the average distance (m) between the center and the other points on the circular area is derived from the following condition:

$$m^2\pi = r^2\pi - m^2\pi.$$

Thus, the circular area is splitted in an inner and an outer concentric circular area of the same size. Solving for m yields

$$m = \sqrt{\frac{r^2}{2}}.$$

[7] A country's exports to itself were included to get a balanced data set and thus to avoid the problems which arise for unbalanced panels. The inclusion of an interaction term controls for the special relationship between distance and exports to itself. This was mainly done as the construction of the distance variable for those cases could result in an under- or overstatement of average transport distance or average transport costs.

This is now taken as a crude measure for average distances of transport for the countries' exports to themselves. To separate the influence of these numbers from the inter country distance numbers an interaction variable is included which consists of zeros for all inter-country relations but takes the value of the distance variable whenever country $i = j$.

Capital stocks have been calculated according to the following methodology

$K_{1984} = 5 * (GFCF_{1983} + GFCF_{1984})$

Furthermore I assumed all countries' capital stocks to depreciate at a constant rate of 10%. So the capital stock of the following years becomes

$K_t = 0.9 \cdot K_{t-1} + GFCF_t$.

The country sample contains all 15 EU member countries. As Belgium and Luxemburg were treated as a single country we end up with 14 countries. Whenever $i = j$ (exports of a country to itself) X_{ijt} are defined as the sum of the components of internal demand for goods[8]. This was done to avoid the inherent unbalancedness of a typical gravity panel data set. Note that the commonly used setup of the gravity equation is unbalanced sui generis even because no country is exporting to itself. Thus even in the case of equal group sizes the panel would be unbalanced. The within and between transformations prove rather messy for the unbalanced 2-way case (see Wansbeek and Kapteyn, 1989, and Baltagi, 1995) and are not elaborated for the 3-way model so far[9]. As in any case one is better off to use a balanced set of data, especially in our case as we employ a 3-way framework where 2 ways are allowed to be random. Because of the balancedness of our data set we come up with 2352 data points for the estimation.

<table about here>

Note that the OLS estimation was shown as it had to be estimated for the Lagrange multiplier test. As we are about to test whether the country specific (export and import) effects should be modeled by a FEM and not a REM, time effects are treated as fixed for all estimations (also for OLS). From the Lagrange multiplier test statistic we see that the pooling assumption of OLS, i. e. that there is no groupwise heteroscedasticity, is rejected. All the estimated coefficients have the expected sign and are highly significant either in the FEM or in the REM[10]. The scaling

[8] (final consumption - services) +gross fixed capital formation + intermediate consumption of the government sector. As far as possible data were taken from OECD National Accounts. In the case of too short time series of the required components I assumed constant shares in GDP. For missing components I assumed similar shares in GDP for similar countries (e.g. BENELUX, EU South, etc.).

[9] Mátyás (1998) provides a solution for the estimation of the variance components from the OLS residuals in a 3-way unbalanced gravity panel model.

[10] By expected sign I have the following in mind: In the 2x2x2 model of the afore-

variable $GDPT_{ijt}$ and the transport cost variable $DIST_{ij}$ exhibit major influence. The likelihood ratio tests in the FEM reveal that there is coming a lot of information from country-effects and thus out of the cross-section. The restriction of time-effects to be zero is also rejected. The highly significant Hausman statistic in our case is mainly driven by the differences between the variance-covariance matrices of the models and not so by differences in the parameter estimates. It nevertheless demonstrates that the FEM is consistent, but REM (FGLS) is not.

4 Conclusions

As mentioned above, most of the contributions to the empirical gravity literature made use of cross-section data. Wang and Winters (1991) and Hamilton and Winters (1992) followed this line as well as Collins and Rodrik (1991). A panel framework has many advantages vis-à-vis the cross-section approach. First of all it allows to disentangle country-specific and time-specific effects. The present note demonstrates that the proper econometric specification of a gravity model would be such one of fixed country and time effects. This was demonstrated by the Hausman chi-sqared test and was motivated by the explanation of country effects as widely predetermined because of geographical, historical, or political contexts.

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mentioned type it is clear that growing economic space (sum of GDPs) c. p. is associated with a growing trade volume. The same holds true for a ceteris paribus change in factor endowments which increases the volume of trade whenever the possibility of a factor intensity reversal is excluded (see Breuss, F., Egger, P., 1998). The analysis of the impact of c. p. changing relative country size on the volume of trade is not so easy. There the effect depends on how and whether at all relative factor endowments are adjusted. For equally endowed countries the result is an increase in the volume of trade which is due to an increase intra-industry trade. All that holds true for endowment situations within the factor price equalisation region.

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Table 1: Estimation Results

	OLS		FEM		REM	
	β	t	β	t	β	t
RLFAC	0.49	9.6**)	0.21	6.5**)	0.31	6.5**)
GDPT	1.41	90.3**)	1.24	8.8**)	1.29	82.5**)
SIMILAR	0.52	22.2**)	0.41	5.7**)	0.44	19.6**)
DIST	-1.29	-56.5**)	-1.24	-59.7**)	-1.35	-58.4**)
INTER	0.51	41.3**)	0.52	48.3**)	0.43	36.0**)
CONST.	-7.86	-17.2**)	-3.89	-1.1**)	6.77 a)	-
N	2352	-	2352	-	2352	-
$\overline{R}^2$	0.93	-	0.96	-	0.90	-
μ	21.42	-	21.42	-	6.44	-
σ	0.61	-	0.41	-	0.48	-
$\widehat{\sigma}_x$	-	-	-	-	0.30	-
$\widehat{\sigma}_m$	-	-	-	-	0.23	-
LR-X b) χ^2	-	-	-	986.3**)	-	-
	-	-	-	(14) g)	-	-
LR-M c) χ^2	-	-	-	575.3**)	-	-
	-	-	-	(14) g)	-	-
LR-T d) χ^2	-	-	-	26.5**)	-	-
	-	-	-	(12) g)	-	-
Hausman e) χ^2	-	-	-	961.2**)	-	-
	-	-	-	(16) g)	-	-
LM f) χ^2	-	175.6**)	-	-	-	-
	-	(28) g)	-	-	-	-

Note: Country and time effects are not reported.

a) Constant was computed according to Greene, 1995, p. 312: $C = \overline{\overline{\overline{y}}}_{...} - b'\overline{\overline{\overline{x}}}_{...}$

b) Likelihood ratio Test, Greene, 1997, p. 161. Fixed export effects

c) Likelihood ratio Test: Fixed import effects.

d) Likelihood ratio Test: Fixed time effects.

e) Hausman χ^2-statistic: $(\widehat{\beta}_{lsdv} - b_{gls})'\{Var[\widehat{\beta}_{lsdv}] - Var[b_{gls}]\}^{-1}(\widehat{\beta}_{lsdv} - b_{gls})$, Greene, 1997, p. 633.

f) Breusch-Pagan Lagrange multiplier Test, Baltagi, 1995, p. 62. Testing for random effects. Note, that the test was computed for the average year: $LM_1 = \frac{XM}{2(M-1)}[\frac{\sum_x(\frac{1}{12}\sum_m u_{xm})^2}{\frac{1}{12}\sum_x\sum_m u_{xm}^2}$ and $LM_2 = \frac{XM}{2(X-1)}[\frac{\sum_m(\frac{1}{12}\sum_x u_{xm})^2}{\frac{1}{12}\sum_x\sum_m u_{xm}^2}$ with $LM = LM_1 + LM_2$. As we observe 12 years, the corresponding residuals and residual squares are divided by this number to obtain time averages. X and M are the group sizes for exporters and importers, each 14 in our case.

g) Degrees of freedom in parenthesis.

**) significant at 1%.