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The Econometrics of Gravity Models[+]

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Abstract

Gravity type models have often been used to analyse trade flows between countries and trading blocs. Previously however, these models were only applied to either cross-section data, or to single country time-series data, which imposed severe explicit (or implicit) restrictions on the specification of the model. Recently Gravity models have been generalised and adapted to a panel data setting, where several time-series of cross-section data sets were *pooled*. This approach not only increases the degrees of freedom, it also enables the proper specification of source and target country effects and time (or business cycle) effects. In this paper, we review in a unified framework, the recent developments in the econometric methodology of Gravity models, and refine the estimation techniques to account for any possible simultaneity bias. Although a fully specified *fixed effects* Gravity model has been estimated previously, this paper contains the first ever results of its *random effects* counterpart. We also suggest an extension to the basic model, which accounts for the fact that contemporaneous trade flows are likely to be strongly related to previous ones. Once more, this appears to be the first application of such a model in the literature. Finally, all of these various models and methods are illustrated with an application to export flows in the APEC region. The results clearly suggest that it is important to properly specify the model, in terms of source, target and business cycle effects. If this is not the case, policies could be instigated that do not take into account, for example, that some countries have "naturally" higher propensities to import than others. Moreover, if these effects are not properly specified the affect of other important driving factors, *e.g.* population will be wrongly estimated. In both cases, policy will be misguided. Important explanatory variables are found to be domestic and target country GDP, and dependent upon specification, local and domestic population, the exchange rate and foreign currency reserves. Also, there is strong evidence that current export flows are highly correlated with those of the previous year.

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1. Introduction

The imminent arrival of full Monetary Union in Europe, and the presence of already well defined economic trading blocs (for example, the European Community – EU, and the Asia-Pacific Economic Cooperation – APEC, group) requires acute awareness of policy makers worldwide, of the determinants of trade flows. As a facet of this, is the need to ascertain just how effective such trading blocs are in promoting trade. To answer such questions, "Gravity models" have been extensively used in the past (see, for example, Tinbergen [1962], Linnemann [1966], Aitken [1973], Thursby and Thursby [1987], Anderson [1979], Bergstrand [1985], Oguledo and MacPhee [1994], Brad [1994], Frankel *et al.* [1995], Mátyás [1997, 1998] and Mátyás *et al.* [1997]).

Although Gravity models have been criticised for their lack of theoretical underpinnings, empirically (especially in forecasting) they seem to perform particularly well, and are therefore well suited for policy analysis. A major drawback of all studies prior to Mátyás (1997, 1998) and Mátyás *et al.* (1997) lies in the nature of the data used, and the explicit (or implicit) model restrictions implied by it. Invariably, inference was drawn either upon a *cross-section* of country data in *one* time period, or upon single *time-series* of data in a country by country approach. However, heterogeneity across countries in trade flows is extremely likely, and should therefore be accounted for in the model.[1] Moreover, the business cycle (*i.e.*, "time") will also undoubtedly affect bilateral trade flows. Erroneously ignoring either of these effects will lead to seriously miss-specified econometric models and biased and miss-interpreted parameter estimates.

To identify these effects, and hence correctly specify the econometric model, one requires a pooled time-series of cross-sections (*panel* data) of the countries of interest. The major advances of Mátyás (1997, 1998) and Mátyás *et al.* (1997), were twofold. Firstly, to increase degrees of freedom, and to enable identification of business cycle and *local* (or *exporting*) country effects, panel data in general was advocated. Secondly, to correctly account for *target* (or *importing*) country effects. Such effects can be treated as constants and estimated (a *fixed effects* - FE - model). A major advantage of this is that one is able to separately identify those countries which have strong propensities to export *and* import, once one has already accounted for divergences in such other factors as GDP and population. Indeed, this was the focus of Mátyás *et al.* (1997). However, in this paper, we additionally consider a more parsimonious representation of the data, in which the effects are treated as random and absorbed into the error term (a *random effects* – RE - model). Although the theory and structure of the RE triple-indexed Gravity model was the subject of Mátyás (1998), this is the first ever empirical application of such a model/specification.

[1] That is, heterogeneity not adequately accounted for by divergences in recorded country statistics, such as GDP.

In this paper, we extend the advances of Mátyás (1997, 1998) and Mátyás *et al.* (1997), to account for likely simultaneity bias (a result of national accounting identities and other reasons). The method suggested below is that of instrumental variables. Finally, these methods are further extended to allow for a correlation between contemporaneous trade flows and those of the previous year, yielding a *dynamic* model of export flows. This *habit-persistence* in export flows is likely, due to (amongst other things) political ties. Once more, this appears to be the first time that either of these methods have been considered and moreover estimated, in the literature.

The results clearly suggest that it is important to properly specify the model in terms of source, target and business cycle effects. For the APEC block, important explanatory variables are domestic and target country GDP, and dependent upon specification, local and domestic population, the exchange rate and foreign currency reserves. Moreover, there is compelling evidence that current export flows are highly correlated with those of the previous year.

The plan of this paper is as follows. In Section 2 below, we review and generalise the recent developments in the field of empirically evaluating Gravity models. Extensions to these models and estimation techniques, are presented in Sections 3 and 4 (for the FE and RE specifications, respectively). These extensions include the use of suitable instrumental variables to account for any simultaneity bias, and also the inclusion of a lagged dependent variable as an important explanatory variable. Section 5 describes the data used for the empirical application (from the APEC region). Section 6 contains the detailed results for the FE specification and Section 7 those for the RE. In Section 8, we deal with some model selection issues, and finally some concluding remarks are drawn in Section 9.

2. The Gravity Model

We use the basic form of the Gravity model, augmented by some financial variables, where the real exchange rate acts as a proxy for prices, such that

$$X_{ijt} = \beta_0 + \beta_1 X_{ijt-1} + \beta_2 Y_{it} + \beta_3 Y_{jt} + \beta_4 POP_{it} + \beta_5 POP_{jt} + \beta_6 FCR_{jt} + \beta_7 ER_{ijt} + \alpha_i + \gamma_j + \lambda_t + u_{ijt}, \quad (1)$$

where:

- all monetary variables are expressed as natural logarithms of \$1990US;
- β_0 an unknown constant and β 's 1 to 7 unknown response coefficients;
- X_{ijt} is the volume of exports from country *i* to *j*, in year *t*;
- $X_{ij,t-1}$ is the volume of exports from country *i* to *j*, in the previous year;
- Y_{it} is domestic country *i*'s GDP in year *t*;
- Y_{jt} is target country *j*'s GDP in year *t*;

- POP_{it} is domestic country *i*'s population in year *t*;
- POP_{jt} is target country *j*'s population in year *t*;
- FCR_{jt} is target country *j*'s foreign currency reserves in year *t*;
- ER_{ijt} is the real exchange rate between countries *i* and *j*, in year *t*;
- a_i are the source county effects, which allow countries to have differing propensities to export, after controlling for divergences across GDP *etc.* (see above);
- γ_j are the target county effects, which allow countries to have differing propensities to import, after similarly controlling for divergences in variables,
- λ_t are the business cycle (time) effects;
- u_{it} are the usual white noise disturbance terms;
- $i = 1,\ldots,N$; $t = 0,\ldots,T - 1$; and $j = 1,\ldots,J = N + 1$, where the additional "country" is the *rest of the world* (note that subsequently we denote J -1 as J^*).

Equation (1) nests most of the common specifications of the Gravity model previously considered in the literature (models a) to c)).

a) Setting $\beta_1 = \alpha_i = \gamma_j = \lambda_t = 0, \forall\ i, j \text{ and } t$ yields the "basic Gravity model".[2]

b) Setting $\beta_1 = \gamma_j = 0, \forall\ j$ yields the "standard panel Gravity model".

c) Setting $\beta_1 = 0$ yields the models of Mátyás (1997a,b) and Mátyás *et al.* (1997) – the "triple-indexed Gravity model", and

d) the fully unrestricted "dynamic triple-indexed Gravity model".

It is recommended in this paper, that one initially start from model d) and then test for the validity of more parsimonious models by standard procedures for parameter restrictions. In doing so, one must first decide on how to formalise the time, target and source country effects. If one is specifically interested in their values, and/or wishes to forecast export flows; they should be treated as fixed unknown parameters and estimated. If, on the other hand, one is primarily interested in the response parameters β (as in the case of a world model, for example) a more parsimonious representation of the data would be to treat them as random, and estimate equation (1) accordingly (see Section 4 below).

3. The Fixed Effects Gravity Model

3.1 The Static Approach: Models a), b) and c)

[2] Although this generally estimated on either cross-section or time-series data, hence one would lose the *t* and *i* subscripts, respectively.

The fully unrestricted (static) model c) involves augmenting the basic Gravity model by three sets of dummy variables. That is, there are N sets of exporting (local) country dummies (D_N), T sets of time dummies (D_T) and J sets of importing (target) country dummies (D_J). For example, the source county dummy for i = 1 equals 1 whenever country 1 is exporting and 0 otherwise. The target dummy for j = 1 equals 1 whenever country j is being exported *to* and 0 otherwise, and the time dummy for t = 0 is 1 only in the first time period and 0 otherwise, and so on. Note that for every *ijt* block of observations, there are only J^* (= J – 1) target country effects (as opposed to J) as countries cannot export to themselves. Assuming the typical $(N \times J^* \times T) \times 1$ data vector X_{ijt} is stacked as

$$X_{ijt} = (X_{120}, X_{130}, \ldots, X_{1J0}, X_{121}, \ldots, X_{1J1}, \ldots, X_{12,T-1}, \ldots, X_{1J,T-1}, \ldots, X_{N10}, \ldots, X_{NJ0}, \ldots, X_{NJ,T-1}),$$

the matrix forms of these dummy matrices can be expressed in terms of the identity matrix of order Q (I_Q) and the unit vector of order R (l_R) as $D_N = I_N \otimes l_{J^*T}$ and $D_T = l_N \otimes (I_T \otimes l_{J^*})$. The D_J matrix is a bit more complicated. Firstly, define D_J^* as $D_J^* = l_{NT} \otimes I_J$ and $\tilde{l}$ the $NJT \times 1$ selection vector as

$$\begin{array}{l} \qquad\qquad\qquad J+1 \qquad\quad (T-1)J+1 \quad TJ-1 \\ \tilde{l}^1 = (1\ 0\ \ldots\ 0\ 1\ 0\ \ldots\ 0\ 1\ 0\ \ldots\ \ldots\ 0) \\ \tilde{l}^2 = (0\ 1\ 0\ \ldots\ 0\ 1\ 0\ \ldots\ 0\ 1\ 0\ \ldots\ 0) \\ \quad \vdots \qquad \vdots \qquad \vdots \qquad \vdots \\ \tilde{l}^N = (0\ \ldots\ 0\ 1\ 0\ \ldots\ 0\ 1\ 0\ \ldots\ 0\ 1\ 0) \end{array}$$

and

$$\tilde{l} = (\tilde{l}^1, \tilde{l}^2, \ldots, \tilde{l}^N),$$

the D_J matrix is obtained by deleting the appropriate rows of $D_J^{\hat{}}$ given by a one in the vector l.[3]

Models a) and b) are obtained simply by deleting the appropriate sets of dummies.

Once all these dummies have been specified, due to the obvious perfect collinearity between all three sets of dummies and the constant term, one can either estimate (1) directly by OLS, including the constant term, but removing (arbitrarily) one column from each of the three sets of dummies. Alternatively, one can include all dummies and the constant, but restrict the sum of each of the three dummy variable sets to sum to unity.

[3] Effectively this is removing the rows corresponding to where $j = j$, as countries cannot export to themselves.

A point not often addressed in the literature, is the extent to which the explanatory variables of (1) can be considered strictly exogenous. For example, via national accounting identities, GDP and exports are intrinsically linked. Indeed, of the explanatory variables in (1), only population appears to be strictly exogenous. Ignoring this endogeneity, will result in the well know simultaneous bias of the parameter estimates. An obvious way to circumvent this problem is to use *instrumental variables* for the likely endogenous explanatory variables. Here we use lags of the endogenous variables as their instruments.

3.2 The Dynamic Model: Model d)

Consistent series of all the variables in equation (1), for all of the countries of a particular trading bloc, tend to be relatively "short". Thus, irrespective of the endogeneity problem alluded to above, OLS estimation of model d) will be biased – a result of this short time-series and the lagged dependent variable (see, for example, Nickell [1981] for a panel data based discussion).

In the simple dynamic panel data setting (*i.e.* model b) augmented by a lagged dependent variable), one has three standard options of obtaining consistent parameter estimates (see, for example, Harris and Mátyás [1996]). One can estimate the model in levels, using past values of the strictly exogenous values as instruments for the lagged dependent variable. Secondly, one can transform the model into first differences, and again use instrumental variables. Finally, one can generalise the method of IV estimation to Generalised Method of Moments (GMM) estimation, where in addition to the implicit assumption that the instruments and the disturbance term are asymptotically uncorrelated, further such conditions are exploited.

However, in the Gravity model setting, all of these methods are problematic. There appear to be few strictly exogenous variables available for use as instruments for lagged export flows, especially given the previously noted concerns about simultaneity bias. Secondly, a major reason why one would favour the FE specification (over the RE) is that one is actually interested in the source and target country effects. First differencing however, removes both of these, such that they are no longer identified. Finally, GMM estimation involves numerical minimisation of potentially highly non-linear functions with respect to the full parameter vector. In this instance, taking into account all of the source, target and time effects, this would mean optimising over forty plus variables. Thus, it would appear that the triple-indexed Gravity model does not lend itself to a FE setting.[4]

[4] This is not to say that these estimation methods would not be of use in other triple-indexed settings other than the Gravity model. Also, given that the source of the bias is the "short" time-series, if "long" runs of data can be obtained, then simple OLS could once more be used (or possibly IV's, again to account for simultaneity bias).

4. The Random Effects Gravity Model

4.1 The Static Model: Models a), b) and c)

Models a) and b) are simply estimated by OLS and FGLS (Feasible Generalised Least Squares) respectively, the latter being a standard application of a RE model, such as given in Mátyás (1996). For the triple-indexed model, one again requires a FGLS procedure (Mátyás [1998]). What is required is the covariance matrix of v_{ijt}, where $v_{ijt} = \alpha_i + \gamma_j + \lambda_t + u_{ijt}$. If all the effects are homoscedastic and uncorrelated both with each other and with the white noise disturbance terms, the variance of v_{ijt} will be $\sigma_v^2 = \sigma_\alpha^2 + \sigma_\gamma^2 + \sigma_\lambda^2 + \sigma_u^2$. The vector $\underline{v}$ will have a $(NJ^*T \times NJ^*T)$ covariance matrix of the form $\Sigma_v = \Sigma_\alpha + \Sigma_\gamma + \Sigma_\lambda + \Sigma_u$, where $\Sigma_\alpha = \sigma_\alpha^2 (I_N \otimes L_{TJ^*})$, $\Sigma_\gamma^* = \sigma_\gamma^2 (l_{NT} \otimes (l_{NT} \otimes I_J))$, and Σ_γ is obtained by deleting the appropriate rows and columns from Σ_γ^* as defined again by $\tilde{l}$ $\Sigma_\lambda = \sigma_\lambda^2 (l_N \otimes (l_N \otimes (I_T \otimes L_{J^*})))$, where L_{J^*} is a J^* square matrix of ones; and $\Sigma_u = \sigma_u^2 I_{NJ^*T}$.

The required components of Σ_v are estimated from the OLS residuals using the partial sums over j, i, (i, j) and t. The expected values of the squares of these partial sums, gives identifying equations which can be used to solve for the various error components.

4.2 The Dynamic Model: Model d)

Irrespective of any simultaneity bias, equation (1) cannot be consistently estimated by OLS, GLS or FGLS, as the lagged dependent variable will be correlated with the composite disturbance terms due to the presence of both α_i and γ_j (which are both time invariant). Due to the likely existence of simultaneity bias, the most appropriate method of estimation would appear to be GMM.[5]

GMM estimation involves explicit exploitation of theoretical moment conditions. These conditions, which are expressed in terms of data and parameters, are estimated by their sample counterparts. These can be derived easily for a dynamic triple-indexed model, along the lines of those summarised in Harris and Mátyás (1996). Moreover, the triple-indexed nature of the data vastly increases the potential number of conditions. Large sample efficiency arguments suggest that all of the identified orthogonality conditions should be used, but bias ones not so (see, for example, Altonji and Segal [1996] on the bias/efficiency trade-off in GMM estimation). The conditions used in the following application were that: the v_{ijt}'s were centred on zero, homoscedastic, serially independent (over time); and that source and target population were contemporaneously exogenous.[6]

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[5] See, for example, Hansen (1982) and Pagan and Vella (1989) on GMM in general, and Ahn and Schmidt (1995), Crépon *et al.* (1996) and Harris and Mátyás (1996), on GMM and dynamic panel data models.

[6] These were chosen as a combination of numerical, theoretical and *a priori* reasons.

5. The Data

The data is taken from 12 counties of the APEC trading block: Australia, Brunei, Canada, Indonesia, Japan, Korea, Malaysia, New Zealand, the Philippines, Singapore, Thailand and the United States, although Brunei was excluded due to excessive amounts of missing and/or unreliable data. The EU trading block was used as a proxy for the *rest of the world*. Years used were 1982 – 1994. For consistent comparisons, all estimation was undertaken excluding the first year (as for IV estimation, 1982 values were used as instruments).

Most of the data was taken from the International Monetary Fund publications (yearbooks and quarterly issues of International Financial Statistics: 1995, 1996 and September 1996; and the yearbooks of Director of Trade Statistics: 1989, 1995 and 1996). The few missing annual observations were estimated from quarterly observations if possible, otherwise they were imputed using average annual rates of growth over the previous ten (if possible, five if not) years.

The European Union (EU) was used as the *rest of the world* or *other* economic unit/"country". The EU is arguably the most significant economic block of the world, justifying its use as a proxy for the *rest of the world*. The EU over the whole sample period is treated as; Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the UK. EU values of income, population and foreign currency reserves, were treated as the sum of the individual countries' values, and the exchange rate is that of the ECU.[7]

6. The Fixed Effects Results

Table 1 contains the simple OLS results for the fully restricted model – no local or target country effects, and no time effects (model a)). Table 2, augments this model by including these effects, and is estimated by OLS and using IV's (note that we differ from Mátyás *et al.* [1997] in that we delete one dummy of each set, as opposed to restricting them to sum to unity). The first result to note is that using IV's does not appear to noticeably affect the results, suggesting that in this case endogeneity is possibly not a serious problem.

Table 1: Simple OLS Results; Model a) $\alpha_i = \gamma_j = \lambda_t = 0$ ***for all i, j and t***

Variable	Parameter Estimate	*t*-statistic
Constant	-2.520845	-10.934
Y_{it}	0.755621	31.695
Y_{jt}	0.352189	11.175
POP_{it}	-0.301923	-9.885
POP_{jt}	0.076758	2.422

[7] Further information on the data used can be found in Mátyás *et al.* 1997.

FCR_{jt}	0.469492	15.656
ER_{ijt}	-0.047676	-4.934
$\bar{R}^2$ = 0.69938	N = 11; J = 12; T = 1983 – 1994	

Table 2: Simple OLS and IV Results; Model c) α_i, γ_j, $\lambda_t \neq 0$ and Fixed, for all i, j and t

	OLS		IV	
Variable	Parameter Estimate	*t*-statistic	Parameter Estimate	*t*-statistic
Constant	-13.971491	-2.770	-13.418751	-2.537
Y_{it}	0.618600	3.735	0.606856	3.494
Y_{jt}	0.442287	2.347	0.415821	1.779
POP_{it}	1.715213	1.655	1.739678	1.641
POP_{jt}	2.241714	2.066	2.095652	1.794
FCR_{jt}	0.088687	1.379	0.096945	0.865
ER_{ijt}	0.258403	1.295	0.274349	1.269
α Australia[1]	1.802482	3.617	1.807363	3.556
α Indonesia	-0.718621	-0.389	-0.668415	-0.359
α Japan	0.093591	0.057	0.151787	0.0915
α Korea	2.041779	1.886	2.122057	1.834
α Malaysia	2.533231	4.388	2.526025	4.247
α New Zealand	4.075757	1.876	4.102617	1.849
α The Philippines	-0.561864	-0.754	-0.564179	-0.756
α Singapore	6.575127	2.722	6.605877	2.676
α Thailand	0.161053	0.239	0.168766	0.250
α USA	-2.865699	-1.235	-2.896250	-1.222
γ Australia[2]	5.607813	1.680	5.098207	1.406
γ Canada	3.978086	1.417	3.558188	1.178
γ Indonesia	-1.917536	-1.214	-2.214735	-1.292
γ Japan	0.779482	0.454	0.532450	0.291
γ Korea	2.299189	0.796	1.818133	0.585
γ Malaysia	5.900768	1.734	5.337664	1.421
γ New Zealand	8.182466	1.600	7.395354	1.327
γ The Philippines	1.797196	0.828	1.398500	0.592
γ Singapore	10.940053	2.023	10.093889	1.694
γ Thailand	2.128353	0.934	1.714627	0.686
γ USA	0.653973	1.659	0.615467	1.497

Table 2: Continued

Variable	OLS Parameter Estimate	OLS *t*-statistic	IV Parameter Estimate	IV *t*-statistic
λ 1984[3]	-0.053145	-0.538	-0.052736	-0.534
λ 1985	-0.133049	-1.279	-0.133631	-1.285
λ 1986	-0.279986	-2.477	-0.278682	-2.442
λ 1987	-0.257873	-2.031	-0.252698	-1.971
λ 1988	-0.275310	-1.878	-0.266015	-1.788
λ 1989	-0.271320	-1.644	-0.260114	-1.548
λ 1990	-0.313319	-1.714	-0.299307	-1.610
λ 1991	-0.397627	-1.924	-0.380848	-1.814
λ 1992	-0.430419	-1.904	-0.410599	-1.788
λ 1993	-0.470212	-1.909	-0.448643	-1.791
λ 1994	-0.488546	-1.811	-0.463117	-1.685
$\bar{R}^2$	0.8528		0.8528	
RSS	803.83		803.87	
$N = 11$; $J = 12$; $T = 1983 - 1994$				

[1] Omitted country = Canada.
[2] Omitted country = *rest of world*.
[3] Omitted year = 1983.

A Test for the Joint Significance of Time, Target and Local Country Effects

A test of the null hypothesis H_0: $\alpha_i = \gamma_j = \lambda_t = 0 \ \forall i, j \text{ and } t$, can be undertaken. Under the null hypothesis, the quantity

$$F = \frac{(RSS_R - RSS)/(N + J + T - 3)}{RSS/(NJ^*T - N - J - T - K + 3)},$$

has an *F*-distribution with degrees of freedom given by the deflators in the numerator and denominator, and where RSS_R and RSS are the residual sum of squares from the restricted and unrestricted models respectively, and *K* is the number of explanatory variables (excluding the dummies, but including the constant term).

Based upon OLS residuals, the calculated test-statistic of 49.63 clearly rejects the null hypothesis, as is to be expected given the individual significance of many of these effects. This suggests that inference based on results from models such as model a) will be invalid to the extent that the estimation suffers from omitted variable bias. Any inference based therefore on this model (Table 1) would be misleading and incorrect.

The Effect of the Explanatory Variables

Crudely speaking, domestic only variables (*it*'s) correspond to the *supply* of exports, whilst target only variables (*jt*'s) apply to the *demand* for exports. Variables varying by local and target country (*ijt*'s) are a hybrid of both supply and demand factors.

Both domestic and target country GDP are significant and positive, with the former effect dominating. Target country GDP is a measure of the extent that exports are "sucked in" as the foreign economy grows. Local country GDP is simply a measure of the size of the (domestic) economy in terms of available goods - one would expect "larger" economies to export more. Similarly, with population, with now domestic levels helping to define production possibility frontiers, and foreign levels, potential overseas markets/demand. The population effects appear larger than those do for GDP, and now the relative magnitudes of foreign and domestic levels are reversed.

The level of foreign currency reserves of the importing country appear to have only a relatively small effect, and moreover this coefficient's estimated standard error, suggests that it could be considered insignificant. However, this variable may simply represent primarily the accumulation of current and previous trade flows, exchange rate policies *etc.*, and therefore have little bearing on contemporaneous export demand.

More surprising, is the apparent insignificance of the real exchange rate. Defined as units of foreign currency per unit of domestic currency, a domestic currency appreciation is represented by a rise in the (defined) real exchange rate. The effect of a currency appreciation is twofold. Firstly, exports would be instantaneously more expensive. However, this effect will be negated to the extent that imported raw materials would now be cheaper. Overall though, it seems sensible to assume that the former effect will dominate. Thus firstly, the exchange rate variable appears to be perversely signed, and secondly it appears unrealistically insignificant. The insignificance of this variable is possibly suggesting that the two conflicting effects (supply and demand) are canceling each other out.

Source Country Effects

Several of the countries appear to have a relatively high propensity to export, most notably (approximately ranked) Singapore, New Zealand, Malaysia, Korea and Australia. Of the remaining countries, only the USA had negative (and arguably significant) export effect.

Target Country Effects

The economy of Singapore appears to be one of the most open, as it not only has the strongest propensity to export, but also the strongest propensity to import. The economies of New Zealand, Malaysia, Australia, USA and Canada also appear to be relatively open, whereas that of Indonesia appears quite restrictive. The target effects of the remaining countries seem to be insignificant.

Business Cycle Effects

Real export volumes, in general, seem to have followed a decreasing trend over the years in question. The trend was stable over the late eighties, but worsened into the early to mid nineties.

Comparison with Traditional Gravity-Type Model

From the above *F*-test and the individual significance of many of the dummy variables, it is obvious that it is extremely important to properly specify the Gravity model. In doing so, we have been able to identify those countries with strong (and conversely weak) propensities to both import and export. This is extremely important for policy setting both by, and within, the trading bloc. For example, APEC members wanting to pursue export led expansionary policies, would do well to look to Singapore as a potential market. Similarly, countries such as the U.S. should for ways to increasing the demand for, or supply of, exports. If such effects are ignored in policy setting, seriously misplaced policies may be instigated with unpredictable results.

In terms of explanatory variables, if we were to (erroneously) focus on the restricted model, the effect of domestic and foreign GDP would have been would over- and under-exaggerated, respectively. We would also have wrongly concluded that domestic population has a detrimental affect on exports, and severely under-estimated the effect of foreign population. Finally, we would have also incorrectly placed too much emphasis on foreign currency reserves and the real exchange rate (Tables 1 and 2).

In summary then, it is imperative that policy is set in accordance not only with the correct response parameters (based upon the fully specified model), but also that the various member states' propensities to import and export are sufficiently taken into account.

7. The Random Effects Results

The Static Model

The RE results for the static model (model c)) are given in Table 3 below, and those for the dynamic model (model d)), in Table 4. In terms of the static model, the more robust Generalised IV (GIV) estimates, are relatively similar to the simple FGLS ones, with three exceptions (the constant term, target population and foreign currency reserves). However, utilising a GIV estimator, does appear to quite significantly improve estimated standard errors. The explanatory power of the RE specification is still quite reasonable compared to that of the FE model (noting the absence of numerous dummy variables in the former).

Table 3: FGLS and Generalised IV Results; Model c) $\alpha_i, \gamma_j, \lambda_t \neq 0$ and Random, for all i, j and t

	FGLS	Generalised IV

Variable	Parameter Estimate	t-statistic	Parameter Estimate	t-statistic
Constant	-0.223528	-0.297	-1.878614	-7.331
Y_{it}	0.758974	9.139	0.721630	30.664
Y_{jt}	0.229563	2.375	0.350092	10.906
POP_{it}	-0.241090	-1.500	-0.291322	-9.702
POP_{jt}	0.363284	2.369	0.087381	2.795
FCR_{jt}	0.161723	3.413	0.421008	12.833
ER_{ijt}	-0.028715	-0.487	-0.048686	-5.131
$\bar{R}^2$	0.6214		0.6963	
RSS	2114.75		1696.07	
N = 11; J = 12; T = 1983 – 1994				

Comparing IV estimates across fixed and random specifications, it appears that the various dummy variables of the former tend to explain most of the variation in exports, dominating the effects of the other explanatory values. This is evident to the extent that only source country GDP (and the constant term) appeared strongly significant in the fixed effects model (although, all of local and target population and local and target GDP were significant at the 10% level). The effect of local and target country GDP appear quite similar across specifications. In both instances, the capacity effect of domestic GDP outweighs the demand pull effect of target country GDP.

The effect of population (target and source) is however, markedly different across specifications. In the FE specification both effects are “large” and positive, whereas in the RE model, the effects are much reduced and that of domestic population is negative. Foreign currency reserves appear to significantly increase export demand in the RE specification (whilst being insignificant in the FE model). The magnitude of this effect is on a par with that exerted by target country GDP. Finally, the effect of the real exchange rate is significant and negative (reversing the somewhat surprising result of the FE model), suggesting that indeed the effect of the exchange rate is dominated by demand side factors.

The Dynamic Model

The results for the dynamic RE model are presented in Table 4 below (the inconsistent OLS results are included just for comparison purposes). The model appears well specified in general, with a significant rise in explanatory power (up to just under 90%) compared to the GIV and FGLS RE results. It clearly passes both Hansen’s test for over-identifying restrictions (*i.e.*, the moment conditions used are valid), and a generalised LM test for additional variables.

Table 4: Dynamic Model: GMM and OLS (inconsistent); Model d) $\alpha_i = \gamma_j = \lambda_t = 0$ for all i, j and t

	GMM		OLS	
Variable	Parameter Estimate	t-statistic	Parameter Estimate	t-statistic
Constant	-0.665148	-2.530	-0.084107	-1.450

$X_{ij,t-1}$	0.436328	87.812	0.978475	154.795
Y_{it}	0.463670	1.175	0.023036	3.149
Y_{jt}	0.401387	1.003	-0.007776	-0.995
POP_{it}	-0.184831	-0.716	-0.014693	-1.982
POP_{jt}	-0.073289	-0.329	0.010756	1.440
FCR_{jt}	0.099028	22.037	0.023921	3.065
ER_{ijt}	-0.011517	-0.026	-0.002219	-0.966
$\bar{R}^2$	0.8862		0.9846	
Hansen Test (χ^2_{104})	0.9563			
LM Test (χ^2_{104})	0.0198			
$N = 11$; $J = 12$; $T = 1983 – 1994$				

As expected, lagged exports exert a positive and highly significant on current export flows. However, this appears to be at the expense of several previously significant variables, and most notably of local and target GDP.[8] The estimated values of coefficients do though, remain fairly similar across the static and random RE models. It appears that once one has conditioned upon last year's export flows, the only remaining significant influence on current export demand is the target country's level of foreign currency reserves – the higher a country's reserves, the easier it can pay for imports.

8. Model Selection Issues

Although we have subjected the preceding model specifications to various testing procedures, the question of model selection naturally arises. Unfortunately, there appears to be a lack of a rigorous testing framework, which encompasses the GMM estimator.[9] We can however, extend Hausman's specification test for fixed *versus* random effects (see, for example, Baltagi [1986, 1996]).

The test statistic is based upon the fact that the consistency of the RE model is reliant upon the null hypothesis $H_0 : E(X|v_{ijt}) = 0$. Under H_0 both the FGLS estimates of the RE model and OLS estimates of the FE model are consistent. However, if H_0 is not true, the latter remains consistent, whilst the former is not. Thus, we can base a test around the difference $\hat{\underline{q}} = \hat{\underline{\beta}}_{RE} - \hat{\underline{\beta}}_{FE}$. Under H_0 $\text{plim}\,\hat{\underline{q}} = \underline{0}$. The variance of $\hat{\underline{q}}$ will be equal to $\text{var}(\hat{\underline{\beta}}_{FE}) - \text{var}(\hat{\underline{\beta}}_{RE})$, as under H_0 $\text{cov}(\hat{\underline{q}}, \hat{\underline{\beta}}_{RE}) = 0$. The test statistic then is

$$m = \hat{\underline{q}}'[\text{var}(\hat{\underline{q}})]^{-1}\hat{\underline{q}},$$

[8] Note that this appears to be case with simple OLS estimation of this model.

[9] The significance of the lagged dependent variable, does suggest though, that this is indeed, an important explanatory variable.

which is asymptotically distributed as χ^2_{K-1} under H_0 (note that the degrees of freedom exclude the constant term, as it is necessary to remove the appropriate rows/columns from $\underline{\hat{\varphi}}$ and $\mathrm{var}(\underline{\hat{\varphi}})$ which correspond to the constant term, *i.e.*, the test is based on the *slope* coefficients only). Large values of the test statistic argue in favour of the FE specification.

The calculated test statistic (based on OLS and FGLS parameter estimates) was 13.35, with $\chi^2_{6,0.95} = 12.59$. These values are clearly very close, suggesting that (quantitatively) there is little to choose from between the FE and RE models. However, in practice, we expect model selection in these areas to be of a more subjective nature. For example, if one is specifically interested in the "openness" of economies, a FE specification model should be used. For strictly more policy reasons, the RE model may be preferred, as the effects of explanatory variables are not diminished the presence of a relatively large set of dummy variables. Moreover, the RE model may be preferred as it lends itself to a dynamic specification, of which the lagged dependent variable is likely to be highly significant.

We can see that the model selection between the RE and FE model specifications can be carried out using a simple formal test. On the other hand, the choice between the static and dynamic models is not as obvious as there are no well-defined procedures to do so. This is, however, a quite important question as the parameter estimates provided by these specifications are substantially different. The choice then should be based on the purpose of our analysis. If our main goal is forecasting, then the dynamic model is to be preferred. If, on the other hand, structural (policy) analysis is the main objective of the study, the static model is to be used, as the introduction of dynamics (in the form of lagged dependent variables) wipes out almost completely the significance of the structural parameters.

9. Conclusion

This paper has been an attempt at unifying the estimation of Gravity models. It has shown that care must be taken in specifying *all* of the likely effects, otherwise any further analysis is very likely to be flawed. In doing so, one can elucidate on the "openness" of member countries' economies and moreover, specifically and separately, identify both propensities to export and import. If, on the other hand, focus is on the random effects model, the coefficients of the explanatory variables are like to be estimated with greater precision, possibly providing greater insights for policy makers. Finally, there is compelling evidence that exports are strongly autoregressive, a point also to be borne in mind by policy makers when initiating trade policies.

References

Ahn, S.C. and Schmidt, P. (1995); Efficient Estimation of Models for Dynamic Panel Data, *Journal of Econometrics*, Vol. 68, pp. 5-28.

Aitken, N.D. (1973); The Effect of the EEC and EFTA on European Trade: A Temporal Cross-Section Analysis, *American Economic Review*, Vol. 63, pp. 881-892.

Altonji, J.G. and Segal, L.M. (1996); Small Sample Bias in GMM Estimation of Covariance

Anderson, J.E. (1979); A Theoretical Foundation for the Gravity Equation, *American Economic Review*, Vol. 63, pp. 106-116.

Baltagi, B. (1986); Pooling Under Misspecification, Some Monte Carlo Evidence on the Kmenta and Error Components Techniques, *Econometric Theory*, Vol. 2, pp. 429-441.

Baltagi, B. (1996); Specification Issues, in *The Econometrics of Panel Data*, Mátyás and Sevestre, (Eds.), Kluwer Academic Publishers, the Netherlands.

Bergstrand, J.H. (1985); The Gravity Equation in International Trade: Some Micro-Economic Foundations and Empirical Evidence, *Review of Economics and Statistic*, Vol. 67, pp. 474-481.

Brad, C. (1994); World Trade in Apparel: An Analysis of Trade Flows using the Gravity Model, *International Regional Science Review*, Vol. 17, pp. 151-166.

Crépon, B., Kramarz, F. and Trogon, A. (1996); Parameters of Interest, Nuisance Parameter and Orthogonality Conditions: An Application to Error Component Models, Discussion Paper no. 9335, Institut National de la Statistique et des Etudes Economiques.

Frankel, J., Stein, E. and Wei, S. (1995); Trading Blocs and the Americas: The Natural, the Unnatural, and the Super-Natural, *Journal of Development Economics*, Vol. 47, pp. 61-95.

Hansen, L. (1982); Large Sample Properties of Generalised Method of Moments Estimators, *Econometrica*, Vol. 50, pp. 1029-1054.

Harris, M.N. and Mátyás, L. (1996); "A Comparative Analysis of Different Estimators for Dynamic Panel Data Models", Dept. of Econometrics, Monash University, Working Paper no. 4/96.

Linnemann, H. (1966); *An Econometric Study in International Trade Flows*, North Holland, Amsterdam.

Mátyás, L. (1996); Error Components Models, in *The Econometrics of Panel Data*, Mátyás and Sevestre, (Eds.), Kluwer Academic Publishers, the Netherlands.

Mátyás, L. (1997); Proper Econometric Specification of the Gravity Model, *The World Economy*, Vol. 20, pp. 363-368.

Mátyás, L. (1998); The Gravity Model: Some Econometric Considerations, *The World Economy*, (forthcoming).

Mátyás, L., Kónya, L. and Harris, M.N. (1997); Modelling Export Activity in a Multi-Country Economic Area: The APEC Case, Dept. of Econometrics, Monash University, Working Paper no. 1/97.

Nickell, S. (1981); Biases in Models with Fixed Effects, *Econometrica*, Vol. 49, pp. 1417-1426.

Oguledo, V.I. and MacPhee, C.R. (1994); Gravity Models: A Reformulation and an Application to Discriminatory Trade Arrangements, *Applied Economics,* Vol. 26, pp. 107-120.

Pagan, A. and Vella, F. (1989); Diagnostic Tests for Models Based upon Individual Unit Data: A Survey, *Journal of Applied Econometrics*, Vol. 4, Supplement, pp. S29-S59.

Thursby, J.G. and Thursby, M.C. (1987); Bilateral Trade Flows, the Linder Hypothesis and Exchange Risk, *Review of Economics and Statistics*, Vol. 69, pp. 488-495.

Tinbergen, J. (1962); *Shaping the World Economy: Suggestions for an International Trade Policy*, New York.