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A Gravity Model under Monopolistic Competition

Kari E.O. Alho

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Abstract

This paper presents an alternative derivation of the gravity equation for foreign trade, which is explicitly based on monopolistic competition in the export markets and which is more general than previously seen in the literature. In contrast with the usual specification, our model allows for the realistic assumption of asymmetry in mutual trade flows. The model is estimated for trade in Europe, producing evidence that trade flows and barriers do indeed reveal strong asymmetry. We then carry out a simulation, based on the estimated model, of the general equilibrium effects (through trade) of the UK's possible entrance into the economic and monetary union.

Key words: Gravity model, trade barriers, asymmetry

JEL classification: F12, F15

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* Kari E.O. Alho is with the University of Helsinki and ETLA, Research Institute of the Finnish Economy at Lönnrotinkatu 4 B, 00120 Helsinki, Finland (e-mail: kari.alho@etla.fi). This is a part of the project on Integration, Location and Growth within the Northern Dimension, carried out jointly by ETLA and the Turku School of Economics, and financed by the Academy of Finland (Grant No. 78240). Comments by Professor Mika Widgrén of the Turku School of Economics, CEPR, CESifo and ETLA along with those from participants of the XXVII Annual Meeting of Finnish Economists are gratefully acknowledged. The usual disclaimer applies.

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1. Introduction

Frequent use has been made of the classical gravity model to analyse trade in recent years, for example to analyse the trade effects of currency unions. There are, however, two shortcomings in these applications. First, it is commonly assumed that trade barriers are symmetric, i.e. identical in trade from country i to j and in trade from j to i, and no emphasis is paid to differences in exports and imports or the factors underlying them. Second, the theoretical basis of the estimated gravity model is insufficient and often lacking totally.

This assumption of symmetry is very dominating in the empirical application of the gravity model,[1] but it is in sharp conflict with the actual situation. Take for instance trade flows within Europe. In 1999, the average absolute difference between the logs of the bilateral trade flows of 27 European countries was as high as 0.66, which implies that on average, the smaller of the bilateral trade flows is only 52 % of the larger. Therefore, it is not surprising that using a gravity model to explicitly test for the symmetry of trade barriers in Europe produces the outcome that they are strongly asymmetric (see Alho, 2003).

James E. Anderson and Eric van Wincoop (2003) presented an important and novel analysis that claims to solve the famous 'border puzzle' concerning the effects a border has on trade, originally found by McCallum (1995) to be extremely large with respect to the US and Canada. They build on the early derivation of the gravity model by Anderson (1979). Assuming CES-preferences, symmetric trade barriers and imposing the general equilibrium constraint for trade, i.e. that total sales equal total production, Anderson & van Wincoop explicitly derive the following gravity equation for bilateral trade,

$$X_{ij} = \frac{Y_i Y_j}{Y_W} \left(\frac{t_{ij}}{P_i P_j}\right)^{1-\sigma} \tag{1}$$

here X_{ij} is exports from country (region) i to country j, Y_i is the income (GDP) of country i, Y_W denotes that for the whole world, t_{ij} is the trade barrier factor (inverse of unity minus the ad valorem barrier per unit of exports) between countries (regions) i and j, assumed to be the same as t_{ji}, and P_i is their key notion of aggregate trade resistance, or simply, the consumer price index of country i. The parameter σ is the elasticity of substitution between imports from various origins. The authors' estimation results of (1) produce a much smaller impact of the US-Canadian border on trade than what was determined by McCallum.

What is striking about (1) is that it implies total symmetry in trade flows, i.e. $X_{ij} = X_{ji}$, which does not prevail in reality, as mentioned above. Therefore, a more general approach is in place. In this paper we derive a model for bilateral trade flows, expanding on the framework used by Anderson & van Wincoop, by explicitly introducing monopolistic competition in the export market and by also allowing for asymmetry in trade. We estimate the model for trade flows between European countries to determine the factors behind the trade asymmetries.

The paper proceeds as follows. The gravity model is derived in section 2 and in section 3 we present its estimation for trade flows between 27 European countries in 1999. Section 4 illustrates how to use

[1] For instance, the recent analyses of the impact of economic and monetary union on trade by Micco et al. (2003) and Barr et al. (2003) both build their trade models on the sum of exports and imports and thereby omit the differences existing between them.

the estimated model to derive the general equilibrium effects of trade policies, which is then applied to evaluate the effect, (through trade) of the UK joining the economic and monetary union (EMU). Here again, the issue of asymmetry turns out to be quite crucial to the magnitude of the effects of integration policies.

2. A model of bilateral trade

The specification of the demand for imports from various countries here follows that of Anderson & van Wincoop, with some minor modifications. The import demand functions in country j, j = 1,…,N, are derived from a CES utility function for aggregate consumption D_j,

$$D_j = \left[\sum_{i=1}^{N} a_{ij}^{1/\sigma} Q_{ij}^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)} , \sigma > 0, \qquad (2)$$

where Q_{ij} is the volume of exports from country i to j, the a_{ij}'s are the country-specific positive preference (distribution) parameters summing to unity and σ is, again, the elasticity of substitution between imports from various origins. The import demand functions are then

$$Q_{ij} = a_{ij} D_j (\frac{p_{ij}}{P_j})^{-\sigma}, \qquad (3)$$

where p_{ij} is the price set by the exporters of country i in the market of country j, inclusive of the cost of trade barriers and, being dual to the quantity index (2), P_j represents the CES price index of the consumption basket in country j,

$$P_j = \left[\sum_{i=1}^{N} a_{ij} p_{ij}^{1-\sigma} \right]^{1/(1-\sigma)} . \qquad (4)$$

From (3) we can derive the market share of the value of exports $X_{ij} = p_{ij}Q_{ij}$ in country j, in relation to its GDP, yielding

$$\frac{X_{ij}}{Y_j} = a_{ij} (\frac{p_{ij}}{P_j})^{1-\sigma}, \qquad (5)$$

where Y_j is the GDP (in nominal terms) of country j and the budget constraint $Y_j = P_j D_j$ is imposed.

We next consider the export supply decision of a monopolistic firm of country i in the market of country j. For this we need to specify that aggregate demand D_j is given by the function

$$D_j = b_j P_j^{-\varepsilon}, \varepsilon > 0, \qquad (6)$$

where b_j is a scale factor representing the size of the country concerned. Note that typically ε < σ. Let there be K_i identical exporting firms in country i. The optimal supply decision of an exporter in country i maximising profit in market j is given by

$$p_{ij} (1 + \varepsilon(p_{ij}, Q_{ikj})) = t_{ij} c_i, \qquad (7)$$

where c_i is the marginal cost of production in country i and Q_{ikj} denotes the volume of exports of firm k of country i in the market of country j, t_{ij} is, as in Equation (1), the trade barrier factor (inverse of unity minus the ad valorem barrier per unit of exports) between countries (regions) i and j, and $\varepsilon(z_i,z_j)$ denotes the elasticity of the variable z_i with respect to the variable z_j.

Using (3), (6) and the general result from index number theory that $\varepsilon(D_j,Q_{ikj}) = s_{ikj} = X_{ikj}/Y_j$, i.e. the market share of exporter k in the market of country j, and summing over the identical K_i firms, we derive the following from (7),

$$p_{ij}\left[K_i(1-\sigma^{-1})+(\sigma^{-1}-\varepsilon^{-1})(s_{ij}+h_j(1-s_{ij}))\right]=K_i c_i t_{ij}\,. \tag{8}$$

Here h_j is the conjectural variation parameter in the proportional output game[2] (see e.g. Smith & Venables, 1988, Alho, 1996 and the appendix for more details) and s_{ij} is the aggregate market share of country i in the market of country j, $s_{ij} = \sum_{k=1}^{K_i} s_{ikj} = X_{ij}/Y_j$. The supply equation (8) allows for price discrimination between various export markets. It is therefore more general than the approach of Anderson & van Wincoop, who assume uniform pricing, which takes place when competition is perfect ($h_j = -s_{ij}(1-s_{ij})^{-1}$ and σ approaches infinity. Note that under perfect competition, the export price only depends on the unit cost and the respective trade barrier. But otherwise under imperfect competition, the larger the country, measured by the number of firms, the lower the export price that its firms charge.

We next need a model for the determination of the cost levels c_i, and therefore introduce the following framework. Assume simply that labour L is the only factor of production and that there are constant returns to scale, $Q_i = A_iL_i$, where Q is the volume of GDP. Let the utility function U of workers be simply, in a standard manner, $U_i = \log(D_i) - \frac{1}{\nu}L_i^{\nu}$, where $\nu > 0$. Now optimising under the budget constraint $P_iD_i = W_iL_i + \pi_i$, where W is the wage rate and π aggregate profits, we derive the result for wage formation,

$$W_i = P_iD_iL_i^{\nu-1} = Y_iL_i^{\nu-1}\,. \tag{9}$$

In the next step, in deriving the unit cost $c_i = W_i/A_i$, we could take two approaches. First, we could take it that technology, as incorporated in the parameter A, is identical in all the countries. But, as the countries in our empirical sample of European countries, on which we shall estimate the gravity model, differ widely as to their income levels and thereby productivities, this assumption of uniformity is not very sensible. Therefore, we allow for differences in productivities and write A_i, being the average labour productivity, as $A_i = Q_i/L_i = Y_i/P_iL_i$.[3] So, we derive for the unit cost

$$c_i = W_i / A_i = P_iL_i^{\nu}\,. \tag{10}$$

Whether ν is positive depends simply on the price level in the country and positively on the size of the country measured by the labour force, which is captured below by population.

We further assume that that the average size $\overline{Q}$ of the firms is identical in all the countries, so that $K_i\overline{Q} = Q_i = Y_i/P_i$. Then normalise this average size to unity and insert this result and (10) into (8). By equating export demand (4) with supply (8), we can then solve for export price p_{ij} from the equilibrium condition,

$$AY_i\left[P_i^{-1}(1-\sigma^{-1})-\frac{t_{ij}L_i^{\nu}}{p_{ij}}\right]-\frac{h_j}{1-h_j}=a_{ij}\left(\frac{p_{ij}}{P_j}\right)^{1-\sigma}, \tag{11}$$

where $A^{-1} = (\varepsilon^{-1}-\sigma^{-1})(1-h_j) > 0$.

[2] More specifically, the parameter h_j is in relative terms the output response by the competitors to a 1% rise in the output of the firm concerned in market j. If h_j is, for example zero, we have the case of Cournot competition.

[3] Note that as aggregate demand is identically Equationual to aggregate supply (GDP), i.e. $P_i^Q Q_i = P_i D_i$ where P_i^Q is the price on GDP, these prices P_i^Q and P_i are also identical.

Next insert this equilibrium solution (11) for the export price in market j into the export demand Equation (5). Using the approximation that log(x + y) ≈ log(x) + log(y) + o(x^2) + o(y^2), we can solve for the bilateral exports to be as follows, returning back to a power function specification,

$$X_{ij} = \frac{Y_j Y_i^{\mu} t_{ij}^{-\mu} a_{ij}^{\mu}}{P_i^{\mu} P_j^{-\mu} L_i^{\mu\nu}} \text{ , where } \mu = \sigma^{-1}(\sigma - 1). \tag{12}$$

The parameter μ is thus positive and smaller than unity, if the elasticity of substitution σ is higher than unity. In addition, the function (12) includes higher order terms for Y_i, P_i, and P_j and the parameter h is assumed to be uniform in all markets. Note that as mentioned above, under perfect competition the Y_i variable is not present in (11) nor in (12).

There are several differences between specifications (12) and (1). The coefficients of Y_i and Y_j are normally different from each other in (12) and the coefficients of the price level in the exporting and importing countries are now also equal, but of opposite sign in contrast to Equation (1) where they are identical.

3. Estimation and testing for asymmetry in European trade

As an illustration, let us estimate the basic trade Equation (12) for trade flows between 27 European countries in 1999 (the first year of EMU), and compare it with specification (1) of Anderson & van Wincoop. We consider the following regions of countries in our estimations with different trade barriers between them: those countries belonging to EMU, the EU, EU accession countries in Central and Eastern Europe, EFTA and Russia. We specify the preference parameters a_{ij} to be simply a function of common language, representing a common culture in the exporting and importing country. The trade barriers are captured by the following specification,

$$t_{ij} = c d_{ij}^{\lambda} e^{\varsigma b_{ij} + \delta n_i + \phi n_j + \sum_{k,m} \beta_{km} r_{ij}(k,m)} . \tag{13}$$

Here d_{ij} is the distance between countries i and j, b_{ij} is the common-border indicator, equal to unity if countries i and j share a common border and zero otherwise, n_i is unity if i is an island. The term $r_{ij}(k,m)$ is the regional integration indicator for exports from the region of countries k to region m, and equals unity if country i belongs to region k and country j belongs to region m, and zero otherwise. So, we allow for trade barriers to be potentially asymmetric in exports from region k to m and from m to k, i.e. that β_{km} may be different from β_{mk}.[4] Trade within the EU internal market is the reference point.

The relative price indices, P_j relative to that in other countries, are calculated here from measured price data as the relation between the current exchange rate of the currency concerned in terms of USD and its corresponding purchasing power parity (PPP) rate. Anderson & van Wincoop (2003) recommend against using measured prices because they are largely based on the prices of non-tradables. Normally, however, the prices for non-tradables and tradables are positively related to each other. On the other hand, this information on relative prices between the countries is readily available. Its use also offers a neat way to carry out a general-equilibrium type of simulation related to changes in trade barriers (see section 4).

The estimation results, using SUR, are the following. The common culture variable did not turn out to be significant and is therefore omitted from the results. The inclusion of the labour force in the exporting country, captured here by population, which should have a negative coefficient (see (12)), was met as to this property, but otherwise this specification was not satisfactory in the sense that then the coefficient of the income variable Y_i resulted in a coefficient that is higher than unity and which is against our theoretical model (12).

[4] EMU is a subset of the EU, which has to be taken into in the interpretation of the coefficients of the respective dummy variables.

Therefore, we imposed in (12) the constraint that the disutility of labour parameter ν goes to zero, which removes the labour force from the unit cost c_i (see (9) above). The estimation results in Table 1 are presented using this specification.

Table 1. Estimation of the bilateral trade model for European countries (the log of the market share of bilateral exports X_{ij}/Y_j as the dependent variable)

Explanatory variable	Model 1 (Eq. (1)) Coeff.	(St. error)	Model 2 Coeff.	(St. error)	Model 3 (Eq. (12)) Coeff.	(St. error)
Constant	−8.650	(0.143)	−7.560	(0.259)	−7.497	(0.831)
Log(Y_i)	1.000	(0)	0.949	(0.019)	0.846	(0.037)
Log(P_j)	−0.360	(0.026)	−0.454	(0.022)	0.846	(0.037)
Log(P_i)	−0.360	(0.026)	−0.151	(0.052)	−0.846	(0.037)
Y_i^2		-		-	0.0 +	
P_j^2		-		-	−0.944	(0.136)
P_i^2		-		-	1.176	0.132)
Log(distance)	−1.231	(0.020)	−1.313	(0.016)	−1.164	(0.062)
Common border	0.179	(0.031)		-	0.150	(0.104)
i island	0.129	(0.079)		-	0.251	(0.110)
j island	−0.216	(0.052)		-	−0.227	(0.122)
Regional integration dummies	Yes*		No		Yes	
R_C^2	0.559		0.801		0.916	
F-test of symmetry of regional trade barriers	11.487**		-		13.338**	
F-test of coeff. of Y_i being unitary	-		7.590***		-	

* The barriers are constrained to be symmetric, $\beta_{km} = \beta_{mk}$ for all k, m, in Equation (12), similarly as in Equation (1).
** $p < 0.001$
*** $p < 0.01$
\+ The t-statistic of this coefficient is 1.8.

We see that the Anderson & van Wincoop model, presented in Equation (1) above, is not very well supported by the data (see Model 1 in Table 1) and its rather weak explanatory power in comparison with the other models. Models 2 and 3 are instead based on our preferred specification in Equation (12) and its versions. Model 3 is based on our gravity equation as specified above in (12) and its constraints imposed.

The hypothesis that trade barriers representing the various stages of regional economic integration are symmetric, i.e. that $\beta_{km} = \beta_{mk}$ for all pairs of k and m, is clearly rejected, as shown in the estimation results of Model 3 and also Model 1. Also, the coefficient of Y_i differs significantly from unity, which points to another asymmetry in the specification of the trade equation in contrast to Equation (1). The effect of a common border on mutual trade is found to be 21%, which is similar to the estimate by Anderson & van Wincoop concerning the effect of the Canadian-US border on trade. The estimate of the elasticity of substitution, σ, is 6.5 on the basis of Model 3, as solved from Equation (12) above.

4. Simulation of a change in trade policies

Simulating changes in trade barriers t_{ij}, so that their general equilibrium effects through the price variables and income levels are taken into account, is an important issue raised by Anderson & van Wincoop. We suggest a computationally straightforward way to carry this out. Like Anderson & van Wincoop, we first need to make an assumption about the elasticity of substitution σ. But what is neat in our model, is that at the same time the estimation of it produces an estimate of σ (see (12)). The change in the trade barrier t_{ij} has both a direct impact on trade and an indirect one through a change in the price level P_j. The latter is a result of the fact that the equilibrium export price p_{ij} also changes as a reaction to a change in exports caused by a change in the trade barrier t_{ij}. To find out this indirect effect, we first solve from (5) the induced change in the price ratio p_{ij}/P_j from the change in the market share of exports X_{ij}/Y_j resulting, i.a. from a change in t_{ij}. The elasticity of the relative price (p_{ij}/P_j) with respect to the export market share X_{ij}/Y_j can be solved from Equation (5) to be $(1-\sigma)^{-1}$. Next, we take into account that the aggregate price level P_j also changes as p_{ij} changes. This can presented by solving for the elasticity $\varepsilon(P_j,X_{ij})$ from the identity

$$\varepsilon(P_j, X_{ij}) = \varepsilon(P_j, p_{ij})\varepsilon(p_{ij}, X_{ij}) = s_{ij}((1-\sigma)^{-1} + \varepsilon(P_j, X_{ij})), \tag{14}$$

where we have again used the above-mentioned general property in index number theory that $\varepsilon(P_j,p_{ij}) = s_{ij}$.[5] From (14) we can solve for the expression needed in the general equilibrium simulations of changes in trade barriers,

$$\varepsilon(P_j, X_{ij}) = \frac{s_{ij}(1-\sigma)^{-1}}{1-s_{ij}}. \tag{15}$$

This allows us to take into account the indirect effect of a change in t_{ij} on P_j and further to the trade flow, using the gravity model, in addition to the direct effect estimated above. The elasticity in (15) is generally negative, indicating that lower import barriers lead to a lower price level. The changes in the trade barriers also have an impact on the income levels. These can be presented using the identity (see Equation (6) above),

$$dY_i = \sum_{j,i\neq j} dX_{ij} + dX_{ii} = \sum_{j,i\neq j} dX_{ij} + (1-\varepsilon)d\log(P_i)Y_i - \sum_{j,j\neq i} dX_{ji}\ , \tag{16}$$

as the rise in total imports to country i captures the rest of the increase in the total demand in this market not met by supplies of the domestic firms.

Let us now use this framework and the estimated gravity model to analyse the general equilibrium effects of the possibility of the UK joining the EMU. For this simulation, we take the trade equation as estimated in Model 3 in Table 1 and combine it with the price impact as shown in (15) and the income identity in (16). We disaggregate the countries into three groups: the UK, the euro area and the rest of Europe. We allow for the trade barrier to be dismantled from UK exports to the euro area and respectively in exports from the euro area to the UK, if such barriers exist.

The relevant impacts of the trade barriers in the trade between the UK and the euro area are the estimated coefficients (see the definition in (13) above) $\beta_{EMU,EU}$, $\beta_{EMU,EMU}$ and $\beta_{EU,EMU}$. The total initial impact that joining the EMU has on UK exports is then $\beta_{EMU,EMU} - \beta_{EU,EMU}$ and that for the EMU area exports to the UK being $\beta_{EMU,EMU} - \beta_{EMU,EU}$. The estimates of these coefficients are according to our estimation, $\beta_{EU,EMU} = -0.617$ and $\beta_{EMU,EMU} = 0.499$ and $\beta_{EMU,EU} = 0.378$. Thereby the barrier (measured now by its impact on trade, see Equation (12) to see the difference between barrier t_{ij} and its effect on trade, i.e. $t_{ij}^{-\mu}$) on UK exports into the euro area is their difference, i.e. −1.116, which is zero with probability 0.0245. But the reverse barrier existing in the EMU countries' exports into the UK is 0.12, and does not differ significantly from zero. So, the estimation result shows that the impact of the UK joining the EMU would markedly boost the exports of the UK, but not the reverse. In recent studies on the trade impact of the EMU, as in Micco et al. (2004) and Barr et al. (2004), where only the case of symmetric trade barriers is considered, the barrier estimates reached as to the impact of EMU vs. non-EMU membership are much smaller than those reported here. Nevertheless, ours here are by no means lying outside the interval found in the various studies on the effect of common currency on trade, as reported by Rose & Stanley (2004). Anyway, let us consider two cases, first that of abolishing identical barriers in the exports and imports of the UK with the euro area, and second that of

[5] In deriving the last step of Equation (14), we use the identity $p_{ij} = (p_{ij} / P_j)P_j$.

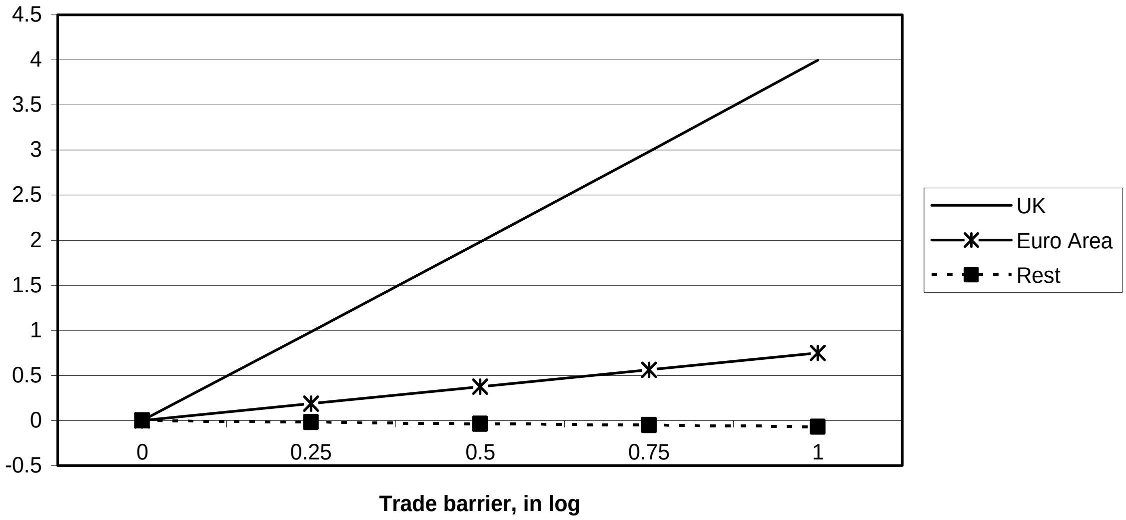
asymmetric barriers, i.e. there being initially one only in UK exports to the EMU but not in reverse trade. Owing to the markedly diverging estimates of the magnitude of these barriers attained in the literature, we also allow the estimate of the size of the existing barrier to vary. We use the value $\varepsilon = 2$ for the price elasticity of demand in Equation (16).

The outcome of the simulations essentially depends on whether or not the price of the domestically produced goods sold to the domestic market also adjusts to the change in the trade barrier, i.e. whether or not the domestic unit cost adjusts to the change in trade policy. Therefore, let us divide the simulations into two stages:

1) The price level P_j only changes as a result of the change in the import prices p_{ij}, $i \neq j$ as shown in Equation (15).
2) The price level P_j also changes as a result of the domestic prices and domestic cost – see Equations (8) and (10).

Let us first consider case 1. In Figure 1 we depict the outcome on real income (nominal GDP deflated by the price index of expenditure) when symmetric barriers are assumed to be dismantled between the UK and the euro area.

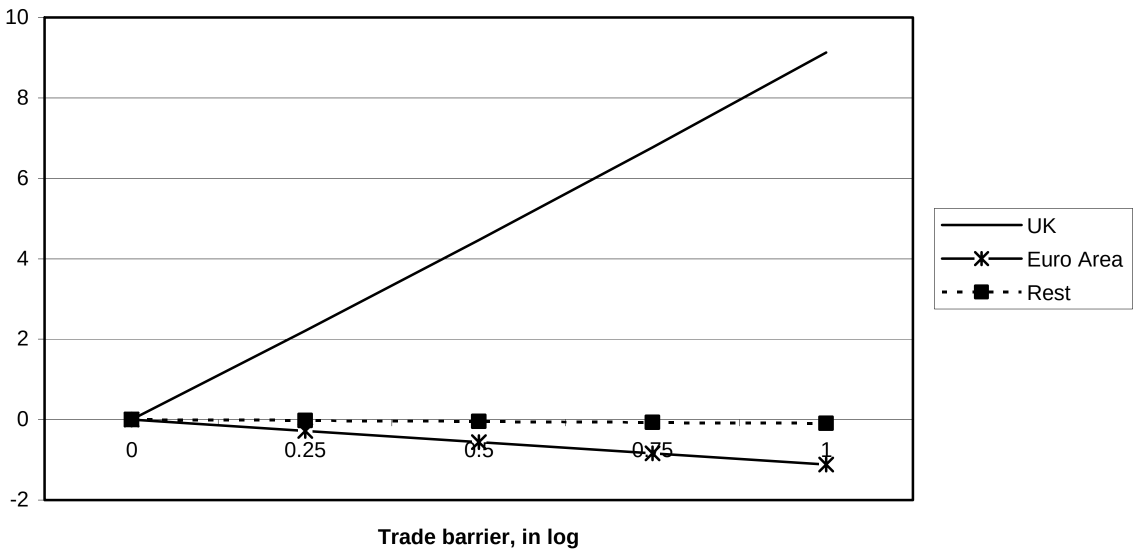
Figure 1. The impact of the UK's entrance into the EMU on real income, percentage deviation from the initial equilibrium, the case of symmetric initial trade barriers existing between the UK and the euro area and that of fixed domestic costs



Both the UK and the euro area gain here from a mutual liberalisation of trade, but the UK gains much more, as is the basic effect of mutual trade liberalisation for a smaller region, being more open with respect to the bigger region, than the reverse. The gains increase with the larger the size of the initial trade barrier that is removed by policy. There is also a slight negative effect, through trade diversion, on those countries remaining outside. In Figure 2, we have the situation of asymmetric barriers so that they only apply presently to UK exports to the euro area, but not to the reverse trade.

In this case, in contrast to the symmetric case, the euro area loses in terms of real income, as the UK captures a larger share of the euro-area market based on its improved market access. The gain to the UK is now very much larger than before, as there is only a small offset through a rise in imports from the euro area to the UK. The rest of Europe is again shown to not be affected by this policy. The issue of symmetry vs. symmetry of trade barriers is thus also an important aspect as to the outcome of integration policies. In our estimated gravity model in Table 1, the equality of these two barriers, i.e. those in exports from the UK to the euro area and in the reverse trade, is strongly rejected.[6]

Figure 2. The impact of the UK's entrance into the EMU on real income, percentage deviation from the initial equilibrium, the case of asymmetric trade barriers (only applying in UK exports to the EMU) and that of fixed domestic costs



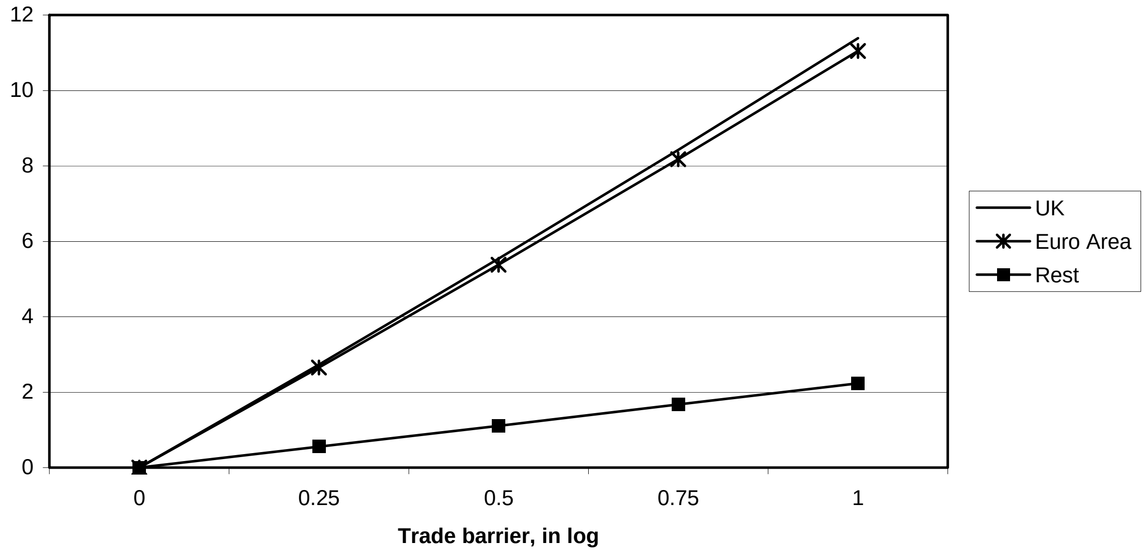
Let us then also allow for the effect through the change in the price of the domestically produced goods sold to the domestic market as a result of a change in the domestic cost level, which further depends on the domestic price level as shown in Equation (10), i.e. we proceed to stage 2 in the simulations. Now we partly come to a different conclusion than that reached above in stage 1, as now both the euro area and the UK gain in the symmetric and asymmetric barrier cases from the EMU membership of the UK. Figure 3 demonstrates the asymmetric case.

The reason for this marked change with respect to the euro area, in contrast to Figure 2, depends on a very large disinflationary effect connected to removing the trade barrier in UK exports to the euro area (6% in the largest case of a unitary barrier), which gives a boost to euro-area competitiveness, exports and real income.[7] The rest of Europe also gains through the same link. In this wider sense, enlargement of the EMU brings gains to all its European partners.

[6] More specifically, we test the equality of the estimates of the coefficients $\beta_{EMU,EU}$ and $\beta_{EU,EMU}$.

[7] The fact that the gains for the UK and the euro area are almost identical is an accident, and depends, i.a., on the elasticity of substitution. If this becomes higher, the gain to the euro area becomes smaller in relative terms, as the price reduction there would be smaller.

Figure 3. The impact of the UK's entrance into the EMU on real income, percentage deviation from the initial equilibrium, the case of asymmetric trade barriers (only applying in UK exports to the EMU), when the price level of the domestically produced goods (i.e. domestic cost) also changes in the domestic market



5. Conclusion

In this paper we have derived a gravity model for trade, explicitly based on monopolistic competition, giving up the property that bilateral trade flows are symmetric. We have also found that this more general specification receives strong empirical support and is also important to the outcome of the trade policy simulations with the aid of the model.

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Appendix

Derivation of the elasticity in Equation (8)

Taking the standard result (7) as a starting point, we can express the elasticity term $\varepsilon(p_{ij}, Q_{ikj})$ in it as follows. Let us first write

$$p_{ij} = \frac{p_{ij}}{P_j}\frac{P_j}{D_j}D_j \ , \tag{A1}$$

and then differentiate both sides logarithmically with respect to Q_{ikj}. Defining h_j as the conjectural variation parameter in the proportional output game, the last term of the differentiation of (A1) gives

$$\frac{d\log D_j}{d\log Q_{ikj}} = \frac{\partial \log D_j}{\partial \log Q_{ikj}} + \frac{d\log Q_j^R}{d\log Q_{ikj}} = s_{ikj} + (1-h_j)s_{ikj} \ , \tag{A2}$$

where Q_j^R is the supply of other firms to the market j and where we have used the basic result of index number theory that $\varepsilon(D_j,Q_{ikj}) = s_{ikj} = X_{ikj}/Y_j$, i.e. the market share of exporter k of country i in the market of country j.

The first term of the logarithmic differentiation of (A1) is, on the basis of (5) and using (A2), equal to $-\sigma^{-1}(1-(s_{ikj}+(1-h_j)s_{ikj}))$. The second term is, using the definition (6), equal to $-(\varepsilon^{-1}+1)(s_{ikj}+(1-h_j)s_{ikj})$. Combining these three terms gives us the elasticity between the export price and the quantity supplied, included in the export supply optimum as

$$\varepsilon(p_{ij}, Q_{ikj}) = -\sigma^{-1} + (-\sigma^{-1} - \varepsilon^{-1})(s_{ikj} + (1-h_j)s_{ikj}) \ . \tag{A3}$$

This is then inserted into (7) and summed over the K_i firms in country i to give Equation (8).

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European Network of Economic Policy Research Institutes
c/o Centre for European Policy Studies
Place du Congrès 1 ▪ 1000 Brussels ▪ Tel: 32(0) 229.39.11 ▪ Fax: 32(0) 219.41.51
Website: http//:www.enepri.org ▪ E-mail: info@enepri.org