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# Applying the gravity approach to sector trade: Who bears the trade costs?

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## **Applying the gravity approach to sector trade: Who bears the trade costs?**

### **Abstract**

Thanks to its empirical success, the gravity approach is widely used to explain trade patterns between countries. In this article we question the simple application of this approach to product/sector-level trade on two grounds. First, we demonstrate that the traditional Armington version of gravity must be altered to properly account for the fact that sector expenditures are not strictly equal to sector productions because some trade costs are incurred outside the sector of interest. Secondly, we test empirically the mis-measurement of the expenditures with both Armington (1969) and Helpman and Krugman (1985) approaches. We estimate trade flows and prices simultaneously with non linear techniques. Underestimated expenditure levels yield biased values of model parameters.

**Keywords:** gravity, trade, econometric simulation

**JEL classifications:** F11, F12, C13, C15

### **Application de l'approche gravitaire au commerce sectoriel : qui supporte les coûts d'échange ?**

### **Résumé**

Grâce à son succès empirique, le modèle gravitaire est couramment employé pour expliquer les flux d'échanges entre les pays. Dans cet article, nous remettons en cause l'application directe de cette approche au niveau sectoriel pour deux raisons. D'abord, nous démontrons que la version traditionnelle gravitaire d'Armington doit être amendée pour expliquer correctement le fait que les dépenses sectorielles ne sont pas strictement égales aux productions sectorielles du fait que certains coûts d'échange sont supportés en dehors du secteur en question. Deuxièmement, à partir des approches d'Armington (1969) et de Helpman and Krugman (1985), nous testons empiriquement le fait de considérer des dépenses mal mesurées. Nous estimons les flux commerciaux et les prix simultanément avec des techniques non linéaires. Nos résultats suggèrent que des niveaux de dépense sous-estimés peuvent biaiser les valeurs des paramètres du modèle.

**Keywords :** gravité, commerce, simulation économétrique

**Classifications JEL :** F11, F12, C13, C15

## **Applying the gravity approach to sector trade: Who bears the trade costs?**

### **1. Introduction**

The gravity equation is one of the greater success stories in empirical economics. In its simplest version, this equation relates bilateral trade flows to the Gross Domestic Products (GDP) of trade partners, the distance separating them, and other factors that portray trade barriers. It has been widely used at the aggregate level or at the product line level for policy analysis, especially to investigate the effects of trading blocks and trade liberalization agreements on bilateral trade. It is also used to identify non tariff trade costs (Anderson and van Wincoop –henceforth AvW, 2004). Despite its empirical success, the gravity approach used to have a poor reputation with the often-asserted lack of theoretical foundations and consequently the inability to interpret results (Baier and Bergstrand, 2001). Moreover, the fact that it performs well in all cases (trade of homogeneous and differentiated products, trade between developed and developing countries) seems puzzling; this again raises the question of the underlying theoretical foundations (Hummels and Levinshon, 1995).

In order to take advantage of these empirical results, some efforts were conducted to show that the basic gravity equation can be derived theoretically as a reduced form from the two dominant paradigms of international trade in final goods, namely from the nationally-differentiated goods perfectly competitive model (often attributed to Armington (1969) and referred to as the old trade theory) and from the firm-differentiated goods monopolistically competitive model with increasing-returns-to-scale technologies (often attributed to Helpman and Krugman (1985) –henceforth HK– and referred to as the new trade theory). However, disentangling the relevant paradigm is critical for policy analysis because the distribution of the benefits of trade liberalization is completely far apart (Head and Ries, 2001). Moreover, AvW (2003) on the old trade theory and Bergstrand (1989, 1990) on the new trade theory show that appropriate price indexes must be specified in the gravity model in order to generate interpretable results. Present efforts are mainly directed to the inclusion of the highly non-linear multilateral price indexes in econometric estimations. Unfortunately the expressions of the multilateral price indexes depend on the underlying theory, hence limiting the usefulness of econometric results from basic gravity models.

In this already challenging context for the basic gravity approach, the purpose of the present paper is to examine two potential issues when it is used for sector trade analysis. The first

issue (all trade costs are not incurred at the sector level) is theoretical and applies only when the Armington trade theory is adopted (which is often the case in practice). The second issue (mis-measurement of sector expenditure) is empirical and relevant to both trade theories. Let's start with the first issue. The Armington gravity approach implicitly assumes that trade costs are supported by the sector producers in the exporting countries (see page 174 and footnote 9 in AvW, 2003). This assumption contradicts the fact that in reality some trade costs are not borne by them. We have in mind two kinds of trade costs. Firstly, international transport costs are not reported in the sector GDP of the exporter, while they are a non negligible part of the total costs faced by consumers in the importing country. For instance, Bergstrand *et al.* (2007) reveal that these international transport costs (computed as the difference between *cif* and *FOB* values of trade) represent nearly 20% of the *cif* value of trade in 2003. Secondly, policy tariffs are obviously not collected by sector producers in the exporting country while they are quite significant in some sectors. AvW (2004) report that average tariffs are low among most developed countries (under 5%) but much higher in other countries (between 10% and 20%). Furthermore, they mention that the variation of tariffs across goods is quite large in all countries, with tariffs on agricultural and food products higher than those on industrial products. A crude approximation suggests that 30% of the trade costs supported by consumers in the importing countries are not incurred by sector producers in the exporting countries. This fact implies that sector expenditures cannot be theoretically equal to sector revenues while this assumption is maintained in the Armington gravity approach.<sup>1</sup> In the first part of the paper we formally show that the theoretically founded Armington gravity approach is unfeasible at a sector level. We then propose a slight modification to solve this issue by assuming that productions by sector are fixed in volume terms rather than in value terms.

The second issue is empirical and applies to our modified version of Armington gravity as well as to the HK gravity version. It refers to the mis-measurement of importers' expenditures in the empirical applications of the gravity. As underlined above, the value of all trade costs must be acknowledged in importers' expenditures. Unfortunately these expenditures are most often (if not always) computed as the sum of production and imports, less exports (*e.g.*, Head and Ries, 2001). Such a computation does not include in particular import tariffs paid by importers. If the *FOB* value of imports is used, this computation also omits international

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<sup>1</sup> On the other hand, under the assumption of balanced trade, expenditures and GDP are equal at the aggregate level and this approach is then theoretically founded.

transport costs. In this case one ends up estimating a trade equation system without the right measure of the expenditure explanatory variable.<sup>2</sup> We thus have a measurement error issue (under-estimation of sector expenditures) which is a source of econometric endogeneity (Wooldridge, 2002, pp. 50-51). The literature on econometric theory in general and on international trade in particular already points out several cases where the endogeneity of regressors severely influences results (see, for instance, Egger, 2004 or Baier and Bergstrand, 2007). Current practice of using panel data econometrics with the specification of fixed effects is far from ideal but the only available second best solution. Moreover, AvW (2003, p.180) emphasize that the fixed effects estimator is less efficient than the nonlinear least squares estimator which uses the entire information on the full structure of the model. They further add that the simple fixed effects estimator is not necessarily more robust to a specification error. Finally, under this approach the effect of trade liberalization on the price index is not acknowledged, which is at odds with the initial objective of identifying trade determinants. Our second objective in this paper is to illustrate how significant is this empirical issue. We do so using Monte Carlo techniques similar to Bergstrand *et al.* (2007). We first simulate trade flows given the level of exogenous variables and behavioural parameters, and then estimate the model with the correct and mis-measured expenditures. The procedure is conducted for both theoretical versions of gravity (our modified Armington gravity and the HK version). The mis-measurement of sector expenditures significantly impacts the estimated behavioural parameters in both approaches. Our findings also suggest that theory must be taken seriously in empirical studies: prices should be estimated simultaneously which is seldom the case. Finally, fixed-effects estimations give unbiased estimates, but they do not provide information about the trade theory behind.

The core of this paper is organised in three main sections. The following section is devoted to the Armington gravity approach. We first formally demonstrate that the AvW equations pertaining to the old trade theory cannot be simply applied to sector-level studies. Then we propose a modified version of the AvW model which solves this unfeasibility and move on the Monte Carlo analysis to reveal the econometric bias. Section 3 is devoted to the HK gravity approach. We first explain why the approach is readily convenient for sector level studies and then again move on the illustrative econometric analysis. In section 4 we present results from the prominent fixed effect econometric approach. Finally section 5 concludes.

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<sup>2</sup> Again, this second issue does not appear when the gravity model is applied at the aggregate level because these trade costs are captured in countries' GDPs/incomes (under the assumption of balanced trade).

## 2. The Armington gravity approach to sector trade

### 2.1. The basic Armington gravity approach

This approach is nicely explained in AvW (2003, 2004) and therefore we present it very briefly below. It is grounded on three main hypotheses. Firstly, bilateral trade is determined in a conditional general equilibrium in the sense that the values of production and demand of country  $i$  for product class  $k$  ( $Y_i^k, E_i^k$ ) are assumed exogenous. Secondly, the preferences of the consumers are identical across countries and are of the Constant Elasticity of Substitution (CES) type. Thirdly, trade costs can be captured by *ad valorem* tax equivalents and are exogenous, *i.e.*, they do not depend of the volume of trade. Formally, the utility function of the representative consumer in the importing country  $j$  is given by:

$$U_j^k = \left( \sum_{i=1}^N (x_{ij}^k / \beta_i^k)^{\sigma-1/\sigma} \right)^{\sigma/\sigma-1} \quad (1)$$

where  $x_{ij}^k$  denotes exports from  $i$  to  $j$  of product  $k$ ,  $\sigma$  is the elasticity of substitution,  $N$  is the number of countries and  $\beta_i^k$  is a positive distribution parameter reflecting the preference for the goods produced in this country. The representative consumer in country  $j$  maximizes his utility subject to the budget constraint:

$$E_j^k = \sum_{i=1}^N p_{ij}^k x_{ij}^k \quad (2)$$

where  $p_{ij}^k$  is the price faced by the consumer for the product  $k$  from country  $i$ . It differs from producer's supply price  $p_i^k$  due to trade costs. Indeed, the third assumption implies:

$$p_{ij}^k = p_i^k t_{ij}^k \quad (3)$$

where  $t_{ij}^k - 1$  is the *ad valorem* tax equivalent of trade costs. Solving the consumer program we obtain:

$$p_{ij}^k x_{ij}^k = p_i^k t_{ij}^k x_{ij}^k = X_{ij}^k = \left( \frac{\beta_i^k p_i^k t_{ij}^k}{P_j^k} \right)^{1-\sigma} E_j^k \quad \forall i, j = 1, N \quad (4)$$

with the CES price index:

$$P_j^k = \left( \sum_{i=1}^N (\beta_i^k p_i^k t_{ij}^k)^{1-\sigma} \right)^{1/(1-\sigma)} \quad \forall i, j = 1, N \quad (5)$$

$X_{ij}^k$  stands for the value of exports of country  $i$  as paid by consumers in country  $j$ .

In order to get a gravity type equation from this demand system, the trick is to solve for producer prices by imposing market-clearing conditions in value terms for all  $i$ :

$$Y_i^k = \sum_{j=1}^N X_{ij}^k \quad \forall i = 1, N \quad (6)$$

From these equilibrium conditions, we get an implicit solution for the producer price and the distribution parameter:

$$\beta_i^k p_i^k = \left( Y_i^k \left( \sum_{j=1}^N \left( \frac{t_{ij}^k}{P_j^k} \right)^{1-\sigma} E_j^k \right)^{-1} \right)^{1/(1-\sigma)} \quad \forall i = 1, N \quad (7)$$

Substituting this expression in the above demand equation (4) yields the gravity equation with two price indexes:

$$X_{ij}^k = \left( \frac{t_{ij}^k}{P_j^k \Pi_i^k} \right)^{1-\sigma} Y_i^k E_j^k \quad \forall i, j = 1, N \quad (8)$$

with

$$\Pi_i^k = \left( \sum_{j=1}^N \left( \frac{t_{ij}^k}{P_j^k} \right)^{1-\sigma} E_j^k \right)^{1/(1-\sigma)} \quad \forall i = 1, N \quad (9)$$

and

$$P_j^k = \left( \sum_{i=1}^N \left( \frac{t_{ij}^k}{\Pi_i^k} \right)^{1-\sigma} Y_i^k \right)^{1/(1-\sigma)} \quad \forall j = 1, N \quad (10)$$

In fact, in the equation system (8)-(10), the values of total supply and total demand, as well as trade costs are predetermined variables, while bilateral trade and producer price are endogenous. The latter ensures the equilibrium on the goods market.

## 2.2. A modified Armington gravity approach for sector-level trade

The framework presented in the previous subsection assumes indeed that all trade costs are incurred by the exporter, and then passed onto the importer. This is reflected by equation (6)

which states that the value of domestic production is equal to the sum of all demands expressed in consumer values. This implies that sector producers in the exporting country support the import tariffs, which is obviously not the case in real life, as well as other international trade costs (think about the use of the services of a foreign transport firm). Another way to see that this framework cannot be adapted to sector trade is to acknowledge, contrary to AvW (2004)'s statement, that many production and expenditure models do not lie behind the set  $\{Y_i^k, E_j^k\}$  that verifies equations (8)-(10). World sector-level production and consumption values consistent with (8)-(10) also verify:

$$Y^k = \sum_{i=1}^N Y_i^k = \sum_{i=1}^N \sum_{j=1}^N X_{ij}^k = \sum_{j=1}^N \sum_{i=1}^N X_{ij}^k = \sum_{j=1}^N E_j^k = E^k \quad (11)$$

Accordingly, the three assumptions necessarily imply that world production is equal to world expenditure and one must relax at least one of these assumptions to allow them to be different as observed in reality. We suggest to assume that the volume of production (denoted by  $y_i^k = Y_i^k / p_i^k$ ), but not its value, is fixed (exogenous). Thus, we keep the initial spirit of a conditional general equilibrium advanced by AvW (2004). But this time, the market-clearing conditions are expressed in quantities:

$$y_i^k = \sum_{j=1}^N X_{ij}^k / p_{ij}^k \quad \forall j = 1, N \quad (6')$$

We multiply both sides of the above expression by  $p_i^k$  and use equations (3) and (4) to obtain:

$$Y_i^k = (\beta_i^k p_i^k)^{1-\sigma} \sum_{j=1}^N (t_{ij}^k)^{-\sigma} (P_j^k)^{\sigma-1} E_j^k \quad \forall j = 1, N \quad (6'')$$

The second part of the right hand expression of (6'') is very similar to the exporter price index  $(\Pi_i^k)^{1-\sigma}$  in section 2.1. (equation (9)). We denote it by  $(\tilde{\Pi}_i^k)^{1-\sigma}$  and derive the producer price:

$$(\beta_i^k p_i^k)^{1-\sigma} = Y_i^k (\tilde{\Pi}_i^k)^{\sigma-1} \quad (7')$$

The consumers' demand (in *cif* terms) is then obtained by combining equations (4) and (7'):

$$X_{ij}^k = \left( \frac{t_{ij}^k}{P_j^k \tilde{\Pi}_i^k} \right)^{1-\sigma} E_j^k Y_i^k \quad \forall i, j = 1, N \quad (8')$$

with 
$$\tilde{\Pi}_i^k = (Y_i^k)^{1-\sigma} (\beta_i^k p_i^k)^{-1} \quad \forall i = 1, N \quad (9')$$

This new theoretically grounded gravity version –given by equations (5), (8'), and (9')– can be applied to sector trade and is quite close to the AvW original model (import demand can still be expressed with two price indexes). Note, that according to our notations the exporter price index can still be written as:

$$\tilde{\Pi}_i^k = \left( \sum_{j=1}^N (t_{ij}^k)^{-\sigma} (P_j^k)^{\sigma-1} E_j^k \right)^{1-\sigma} \quad \forall i = 1, N \quad (9'')$$

Following AvW (2003, 2004), one can interpret  $\tilde{\Pi}_i^k$  from equation (9'') as a demand-weighted average price of products exported by country  $i$  in *cif* terms. Stated differently,  $\tilde{\Pi}_i^k$  is the average price paid by consumers from all countries for goods produced in country  $i$ . Equation (9') shows that this price index is the result of two effects. The first part of equation (9'),  $(Y_i^k)^{1-\sigma}$ , illustrates an ordinary *supply size effect*: the larger the amount of goods produced by a country, the lower the price at which they are sold on the world market. The second part of (9'),  $(\beta_i^k p_i^k)^{-1}$ , denotes a *price effect*: expensive products (high  $p_i^k$ ) are sold mainly to consumers to which they can be shipped at low trade costs, while cheaper products (low  $p_i^k$ ) can be shipped as well to more distant countries and to countries with higher entry barriers. Therefore, the larger the producer price, the lower the average trade costs for these products and the lower the average price paid by consumers.

Trade costs are seldom observed in real life. Instead, they are most frequently instrumented by geographical distance and other bilateral variables. We assume  $t_{ij}^k = (d_{ij}^k)^\delta$  with  $d_{ij}^k$  observable variables. For simplicity, we refer to  $d_{ij}^k$  as *distance*, although it may include as well import tariffs, norms, standards, and other elements. The gravity model given by equations (5), (8'), and (9') can then be rewritten as:

$$\begin{aligned} X_{ij}^k &= d_{ij}^{k\delta(1-\sigma)} E_j^k Y_i^k / (P_j^{k(1-\sigma)} \tilde{\Pi}_i^{k(1-\sigma)}) \\ P_j^{k(1-\sigma)} &= \sum_{i=1}^N (\beta_i^k p_i^k)^{1-\sigma} d_{ij}^{k\delta(1-\sigma)} \quad \forall i, j = 1, N \quad (12) \\ \tilde{\Pi}_i^{k(1-\sigma)} &= Y_i^k / (\beta_i^k p_i^k)^{1-\sigma} \end{aligned}$$

### 2.3. Mis-measurement of final expenditures

Implementing the Armington gravity approach presumes that one is able to accurately observe, for each sector and country included in the study, the *cif* values of trade, trade costs, production (value) and expenditures. If production values are rather easily accessible, other data are much more critical to gather (AvW, 2004). In particular, to our knowledge, sector-level expenditures are always computed as residuals. In theory, a country's expenditure should equal the country's production value less the *fob* value of its exports plus the *cif* value of its imports and tariffs. Due to quality problems, concordance between product nomenclature, consistency between *fob* and *cif* values, difficulties to collect tariffs over several partners/years, one understandable solution may be to simply compute the expenditure as the sum of production and *fob* imports less the value of *fob* exports, and omit tariffs (e.g.,

Head and Ries, 2001):  $E_j^k = \sum_i X_{ij}^k / t_{ij}^k = E_j^k - \sum_i X_{ij}^k (t_{ij}^k - 1) / t_{ij}^k$ . A more radical solution is to

simply replace it by the importer's production value (e.g., Feenstra *et al.*, 2001):  $E_j^k = Y_j^k$ .

This is typically an empirical issue that we investigate with a Monte Carlo analysis.

In this sub-section, we use our modified Armington gravity specification developed for sector trade. The analysis consists of two steps. In the first step, we generate some data satisfying our trade model. We consider a set of thirty countries and fix the levels of their production volumes and expenditures, distances, CES behavioural parameters, and delta:

$$N = 30, \quad i = 1, \dots, 30, \quad j = 1, \dots, 30$$

$$\beta_i^k = 1 \quad \forall i, \quad \sigma = 5, \quad \delta = 1$$

$$E_j^k \approx N(100, 10), \quad y_i^k \approx N(100, 10), \quad d_{ij}^k - 1 \approx N(0.3, 0.1), \quad d_{ii}^k = 1$$

Note, that we do not impose symmetrical trade costs: for  $i \neq j$  we allow for  $d_{ij}^k \neq d_{ji}^k$ . We solve the system (12) and obtain 900 trade flows and 30 producer prices. In the second step, we add a normally distributed zero-mean error term  $\varepsilon_{ij}^k$  to the simulated trade data, and estimate the equation system (12) using non linear least squares.<sup>3</sup> Due to the price homogeneity of the system leading to identification problems, we fix one price  $p_1^k = 1$ . Furthermore, to simplify the econometric estimation, we focus on the estimation of  $\sigma$  and fix

<sup>3</sup> We replace negative trade values by zero. Dropping the few nil observations does not alter the results.

the parameter  $\delta$  at its true value. We replicate the above steps a hundred times and obtain one hundred data sets and estimation results.

Table 1 displays the mean values of the estimated parameters, the associated standard errors, and the 95% confidence intervals. We employ three measures of importers' expenditures: (i) true generated values, (ii) true values less simulated trade costs, and (iii) production values. Note that the second measure corresponds roughly to the computation of sector expenditures as domestic production plus *FOB* imports less *FOB* exports. When all the constraints of the theoretical model are fulfilled, and producer prices are considered exogenous (as in most empirical applications), the substitution elasticity  $\sigma$  is the only estimated parameter. We first use the simulated value of prices and present estimation results in the first three rows of Table 1. In this case the mis-measurement of expenditures in the numerator of the trade equation leads to an overestimation of the elasticity of substitution. When we estimate both  $\sigma$  and  $p_i^k$  in the equation system (12) (the next three rows of Table 1), we obtain a very similar bias. Except for the case when sector expenditures are correctly measured, the true value of  $\sigma$  ( $\sigma = 5$ ) is never even included in the confidence interval. This result emphasizes the importance of using correct expenditure values when estimating a AvW gravity model. Empirical studies rarely impose a unitary elasticity of trade with respect to production and expenditure, as implied by the theoretical model. When we relax this assumption (the last six rows of Table 1), the estimation bias of the substitution elasticity due to the use of wrong expenditure values vanishes. The estimated value of the substitution elasticity is not statistically different from the value used to construct the data ( $\sigma = 5$ ). When trade-costs-free expenditures are used, no estimated coefficient is statistically different from its true value (used for data simulation). By slightly increasing the coefficient on expenditures (from 1.00 to 1.05) we actually decrease the gap between trade-costs-free and true expenditures. Actually, to reach this outcome it is sufficient to relax only the assumption relative to the value of the coefficient on variable  $E_j^k$  (the estimated coefficient on  $Y_i^k$  is equal to one). We obtain very biased estimates of both expenditure and production coefficients when sector productions are used to measure (proxy) sector level expenditures. The relationship between sector-level production and expenditure values is much less systematic in this case. Hence, relaxing the assumption of unitary coefficients does not produce the same results. The deviation of coefficients on  $Y_i^k$  and  $E_j^k$  from unity in this case depends also on the correlation between sector-level expenditure and production values. Note as well that, during the estimation

process, we set  $p_1^k$  as a numerator. The correlation coefficient between estimated prices and their simulated values ranges from 0.38 to 0.40. If we set one producer price ( $p_1^k$ ) equal to its true simulated value, the coefficient of correlation rises to nearly 0.80 (see Tables A1 and A2 of Appendix A.).

**Table 1: Econometric results from the modified Armington (AvW) gravity version for sector-level trade with different measures of expenditure and theoretical constraints**

Measure of expenditure	R <sup>2</sup>	Elasticity of substitution $\sigma$				Coefficient on $E_j$				Coefficient on $Y_i$			
		Mean	Std. Err.	[95% Conf. Interval]	In CI*	Mean	Std. Err.	[95% Conf. Interval]	In CI*	Mean	Std. Err.	[95% Conf. Interval]	In CI*
<i>Model with all theoretical constraints and exogenous prices</i>													
True expenditure	0.86	4.99	0.11	(4.78; 5.21)	97	1.00				1.00			
Trade-cost-free expenditure	0.84	5.69	0.14	(5.42; 5.96)	0	1.00				1.00			
Production	0.82	5.62	0.14	(5.34; 5.90)	0	1.00				1.00			
<i>Model with all theoretical constraints and endogenous prices</i>													
True expenditure	0.87	4.99	0.11	(4.77; 5.21)	96	1.00				1.00			
Trade-cost-free expenditure	0.84	5.69	0.14	(5.41; 5.97)	0	1.00				1.00			
Production	0.83	5.64	0.15	(5.36; 5.93)	0	1.00				1.00			
<i>Model with no constraints on expenditure and production coefficients and exogenous prices</i>													
True expenditure	0.86	4.99	0.12	(4.75; 5.23)	96	0.99	0.11	(0.78; 1.21)	94	1.01	0.11	(0.80; 1.21)	94
Trade-cost-free expenditure	0.86	4.99	0.11	(4.75; 5.23)	96	1.00	0.11	(0.79; 1.21)	95	1.00	0.11	(0.79; 1.21)	95
Production	0.85	4.99	0.13	(4.74; 5.24)	98	1.55	0.14	(1.28; 1.81)	8	0.45	0.14	(0.18; 0.72)	8
<i>Model with no constraints on expenditure and production coefficients and endogenous prices</i>													
True expenditure	0.87	4.99	0.12	(4.75; 5.23)	95	0.98	0.15	(0.69; 1.27)	95	1.02	0.14	(0.74; 1.30)	97
Trade-cost-free expenditure	0.87	4.99	0.12	(4.75; 5.23)	97	1.05	0.14	(0.77; 1.32)	96	1.00	0.14	(0.72; 1.28)	97
Production	0.86	4.99	0.13	(4.74; 5.24)	96	2.10	0.18	(1.74; 2.46)	1	-0.05	0.18	(-0.41; 0.31)	3

Note: \* number of cases out of 100 for which the true value of the estimated coefficient (5 for the elasticity of substitution and 1 for the coefficients on  $Y_i$  and  $E_j$ ) belongs to the estimated 95% confidence interval.

### 3. The Helpman-Krugman gravity approach to sector trade

#### 3.1. The theory

A gravity equation can also be theoretically derived from the firm-differentiated-goods monopolistically-competitive model with increasing-returns-to-scale technologies (Krugman, 1980, HK, 1985). Below we present this model at the sector level and show that, contrary to the Armington gravity model, it does not assume that trade costs are necessarily borne by the producer.

This approach shares many assumptions with the Armington model of trade: preferences are identical across countries and of CES form, trade costs can be captured through *ad valorem* equivalents, and expenditures are exogenous. The main differences lie in the supply side: the number of goods/firms in countries is endogenous and the supply of each good is determined by the profit maximisation subject to increasing-returns-to-scale technologies. Because the number of goods is endogenous, the utility of consumers has not exactly the same expression as before:

$$U_j^k = \left( \sum_{i=1}^N n_i^k x_{ij}^k \frac{\sigma-1}{\sigma} \right)^{\sigma/\sigma-1} \quad (13)$$

where  $n_i^k$  is the number of symmetric firms producing the good  $k$  in country  $i$  and  $x_{ij}^k$  is the quantity of each variety of good  $k$  produced in  $i$  and consumed in country  $j$ .<sup>4</sup> Using a multiplicative price structure as in the AvW model (equation (3)), the budget constraint is now given by:

$$E_j^k = \sum_i^N n_i^k p_i^k t_{ij}^k x_{ij}^k \quad (14)$$

The resulting demand equations are then:

$$n_i^k p_j^k t_{ij}^k x_{ij}^k = X_{ij}^k = n_i^k \left( \frac{p_i^k t_{ij}^k}{P_j^k} \right)^{1-\sigma} E_j^k \quad \forall i, j = 1, N \quad (15)$$

with the CES price indices:

$$P_j^k = \left( \sum_{i=1}^N n_i^k (p_i^k t_{ij}^k)^{1-\sigma} \right)^{1/1-\sigma} \quad \forall j = 1, N \quad (16)$$

<sup>4</sup> Hence, the total export of good  $k$  varieties by  $i$  to  $j$  in volume terms is equal to  $n_i^k x_{ij}^k$ .

On the supply side, a monopolistically competitive framework with symmetric firms using the same increasing-returns production technology is assumed. This representative firm maximizes profits subject to the workhorse linear technology function defined on a single input variable:

$$l_i^k = \alpha^k + \varphi^k y_i^k \quad \forall i = 1, N \quad (17)$$

where  $l_i^k$  represents the labour used by the representative firm in country  $i$ ,  $y_i^k$  is the firm output (in volume terms), and  $\alpha^k$  and  $\varphi^k$  are technological parameters (corresponding respectively to fixed and marginal costs expressed in terms of labour units). The assumption of monopolistic competition permits to write the price equation as a mark-up over the marginal cost of production (determined by wages  $w_i^k$ ):

$$p_i^k = \frac{\sigma}{\sigma - 1} \varphi^k w_i^k \quad \forall i = 1, N \quad (18)$$

Free entry leads to zero economic profits at the equilibrium. The level of production is the same for all firms within the sector and given by:

$$y_i^k = \frac{\alpha^k}{\varphi^k} (\sigma - 1) = q \quad \forall i = 1, N \quad (19)$$

Confronting the demand of labour by firms with the total labour endowment  $L_i^k$  within the sector then determines the number of firms at equilibrium:

$$n_i^k = \frac{L_i^k}{l_i^k} = \frac{L_i^k}{\alpha^k + \varphi^k q} = \frac{Y_i^k}{w_i^k (\alpha^k + \varphi^k q)} \quad \forall i = 1, N \quad (20)$$

Substituting the above expression in the demand equation (15) and using equation (18) for  $p_i^k$  yields the gravity equation:

$$X_{ij}^k = \frac{p_i^{k-\sigma} t_{ij}^{k1-\sigma} Y_i^k E_j^k}{\sum_l p_l^{k-\sigma} t_{lj}^{k1-\sigma} Y_l^k} \quad \forall i, j = 1, N \quad (21)$$

Traditional gravity explanatory variables appear in the right hand side of equation (21). In this framework both producer prices and the value of sector productions are endogenous. Note, that the above trade equation can also be written in terms of exporting country's wages and factor (labour) endowments using expressions (18) and (20) respectively. Production prices (wages) are implicitly determined by the market equilibrium conditions:

$$p_i^k n_i^k q = \sum_j p_i^k n_i^k x_{ij}^k$$

or

$$Y_i^k = \sum_j \frac{X_{ij}^k}{t_{ij}^k} = \sum_j \frac{p_i^{k-\sigma} t_{ij}^{k-\sigma} y_i^k E_j^k}{\sum_l p_l^{k-\sigma} t_{lj}^{k-\sigma} y_l^k} \quad \forall i, j = 1, N \quad (22)$$

By fixing the level of the production factor,  $L_i^k$ , the HK version of gravity can be readily applied to sector-level trade. Note that in both HK and modified Armington (AvW) models, the sector expenditure appears only in the numerator of the trade equation. However, in the HK model, prices (wages), as established by the goods market equilibrium conditions (22), are also a function of expenditure values.

As in the previous model, we can express trade costs as a function of the bilateral distance  $t_{ij}^k = d_{ij}^{k\delta}$ . The HK gravity model then rewrites as:

$$\begin{aligned} X_{ij}^k &= p_i^{k-\sigma} d_{ij}^{k\delta(1-\sigma)} Y_i^k E_j^k / P_j^{k(1-\sigma)} \\ P_j^{k(1-\sigma)} &= \sum_i p_i^{k-\sigma} d_{ij}^{k\delta(1-\sigma)} Y_i^k \quad \forall i, j = 1, N \\ Y_i^k &= \sum_j X_{ij}^k / d_{ij}^{k\delta} \end{aligned} \quad (23)$$

We now turn again to the empirical issue of (in)correctly measured expenditures.

### 3.2. The Monte Carlo analysis

As previously, we use Monte Carlo techniques to check if the correct measurement of sector expenditures is critical for obtaining unbiased estimators of the parameters. First, we construct a hundred data sets satisfying the following assumptions:

$$N = 30$$

$$\alpha^k = \varphi^k = 1, \quad \sigma = 5, \quad \delta = 1$$

$$E_j^k \approx N(100, 10), \quad L_i^k \approx N(100, 10), \quad d_{ij}^k - 1 \approx N(0.3, 0.1), \quad d_{ii}^k = 1$$

Like Bergstrand *et al.* (2007), we simplify the supply side by normalising the technological parameters. The other exogenous parameters are identical to the ones adopted in section 2.3. We solve the system (23) and obtain 900 trade flows and 30 importer-specific price indices for each data set. Secondly, we add a normally distributed error term  $\varepsilon_{ij}^k$  to the simulated

trade flows, replace negative values by zero, and finally estimate equation system (23) with different measures of expenditures: (i) true (generated values) expenditures, (ii) true values less trade costs, and (iii) production values.

Estimation results are reported in Table 2 below. Results in the upper part of the table correspond to the case when all the theoretical constraints of the model are imposed and producer prices are considered as exogenous and fixed to their simulated values. The estimated elasticity of substitution is unbiased only when the correct expenditures are employed. In the next three rows, producer prices are endogenous and estimated by the model. Again, the use of incorrect measures of sector expenditures produces an overestimation bias. In both cases one can correctly estimate the elasticity of substitution only by using the true value of sector-level expenditure. If the trade-cost-free expenditure or production is employed instead, the confidence interval of the estimated parameter does not include the true value of the elasticity of substitution. The last set of results displayed in Table 2 shows that relaxing the constraint of unitary coefficients on production and expenditure variables always yields an unbiased estimator of the substitution elasticity. However, this is achieved to the detriment of the precision of other structural parameters. As in the case of the AvW model in section 2.3., a change in the value of expenditure and production coefficients permits to compensate for the difference between true sector-level expenditures and alternative variables (the correlation between estimated and true prices is shown in Tables A3 and A4 of Appendix A.).

**Table 2: Econometric results from the Helpman-Krugman gravity version for sector-level trade with different measures of expenditures and theoretical constraints**

Measure of expenditure	R <sup>2</sup>	Elasticity of substitution $\sigma$				Coefficient on $E_j$				Coefficient on $Y_i$			
		Mean	Std. Err.	[95% Conf. Interval]	In CI*	Mean	Std. Err.	[95% Conf. Interval]	In CI*	Mean	Std. Err.	[95% Conf. Interval]	In CI*
<i>Model with all theoretical constraints and exogenous producer prices (true values)</i>													
True expenditure	0.86	5.01	0.11	(4.78; 5.23)	93	1.00				1.00			
Trade-cost-free expenditure	0.83	5.70	0.14	(5.42; 5.98)	0	1.00				1.00			
Production	0.82	5.63	0.15	(5.34; 5.92)	0	1.00				1.00			
<i>Model with all constraints on expenditure and production and endogenous producer prices</i>													
True expenditure	0.87	4.96	0.12	(4.78; 5.22)	92	1.00				1.00			
Trade-cost-free expenditure	0.79	6.54	0.17	(6.20; 6.87)	0	1.00				1.00			
Production	0.78	6.46	0.18	(6.12; 6.81)	0	1.00				1.00			
<i>Model without constraints on expenditure and production and exogenous producer prices</i>													
True expenditure	0.86	4.90	0.12	(4.66; 5.16)	87	0.94	0.10	(0.74; 1.14)	84	1.06	0.10	(0.86; 1.25)	85
Trade-cost-free expenditure	0.85	4.90	0.12	(4.65; 5.14)	87	0.98	0.10	(0.78; 1.18)	85	1.07	0.10	(0.87; 1.27)	82
Production	0.84	4.86	0.13	(4.60; 5.12)	81	1.47	0.12	(1.25; 1.70)	7	0.57	0.12	(0.34; 0.80)	8
<i>Model without constraints on expenditure and production and endogenous producer prices</i>													
True expenditure	0.87	5.00	0.12	(4.76; 5.24)	94	0.99	0.15	(0.69; 1.28)	94	1.01	0.14	(0.73; 1.29)	92
Trade-cost-free expenditure	0.87	5.00	0.12	(4.76; 5.24)	94	1.05	0.14	(0.77; 1.33)	93	1.00	0.14	(0.72; 1.27)	90
Production	0.86	5.00	0.13	(4.76; 5.25)	92	2.08	0.15	(1.79; 2.37)	0	-0.03	0.15	(-0.33; 0.26)	0

Note: \* number of cases out of 100 for which the true value of the estimated coefficient (5 for the elasticity of substitution, 1 for the coefficient on  $Y_i$ , and 1 for the coefficient on  $E_j$ ) belongs to the estimated 95% confidence interval.

#### 4. Alternative estimation methods

As shown in sections 2.3. and 3.2., we are always able to recover the true value of parameters using the correct measure of expenditures. When we undervalue the level of sector expenditures (by ignoring a large share of trade costs paid by consumers in the importing country) and estimate the model with all theoretical constraints, we obtain upward biased values of the elasticity of substitution. Still, relaxing the assumption of unitary coefficients on  $E_j^k$  and  $Y_i^k$  emerges as a solution to the unavailability of data on true sector-level expenditures for both AvW and HK gravity versions. But this holds only for sufficiently low values of trade costs and requires that the entire trade system (12), respectively (23), be estimated with non linear techniques. Estimation results in Tables 1 and 2 suggest that theory must be taken seriously in empirical studies: producer prices (wages) and price indices should be estimated simultaneously with trade flows and not taken from outside (as, for instance, in Balistreri and Hillberry, 2007) or be captured by country dummies alone (e.g., Baldwin and Taglioni, 2007). This is seldom the case in empirical studies, most of which reduce to estimating the corresponding trade equation alone and ignore the price/wage endogeneity.<sup>5</sup>

Recent empirical works employing the AvW model increasingly implement a fixed-effects estimator. Rather than estimating the entire equation system (12) with non linear techniques, this approach, suggested by AvW themselves, consists in estimating the trade equation alone with importer and exporter fixed effects:

$$X_{ij}^k = d_{ij}^{\delta(1-\sigma)} FM_j^k FE_i^k \quad \forall i, j = 1, N \quad (24)$$

with  $FM_j^k = P_j^{k(\sigma-1)} E_j^k$  and  $FE_i^k = \tilde{\Pi}_i^{k(\sigma-1)} Y_i^k$ . By estimating equation (24) authors intended to avoid the estimation of non linear price indexes in the AvW version of gravity. This method permits at the same time to solve the problem of mis-measuring (missing) sector/product level productions and/or expenditures. Note that this approach can be applied as well to HK-type gravity models. In this case country fixed effects stand for  $FM_j^k = P_j^{k(\sigma-1)} E_j^k$  and  $FE_i^k = n_i^k p_i^{k(1-\sigma)}$ , where  $P_j^k$  is defined by equation (16). Table 3 below displays the estimation results for both models (means of values across the one hundred simulated data sets). For both

<sup>5</sup> Some studies, including Harrigan (1996), address the issue of endogenous wages in a HK trade model with Instrumental Variables estimators. However, the nature of the assumed endogenous relationship in these studies is different from the one implied by the theoretical model.

AvW and HK data sets the fixed-effects technique yields unbiased estimates of  $\sigma$ . Still, the estimated coefficients are both closer to the true value ( $\sigma = 5$ ) and more precise (lower standard error) when non linear least squares are used. This reveals again the importance of respecting the non linear structure of the trade model.

**Table 3: Econometric results from the Fixed-Effects gravity**

Version of gravity	Estimation technique	R <sup>2</sup>	Elasticity of substitution $\sigma$			
			Mean	Std. Err.	[95% Conf. Interval]	In CI*
AvW	Linear country Fixed Effects	0.7	5.25	0.25	(4.76; 5.74)	84
AvW	Non Linear country Fixed	0.8	4.99	0.12	(4.75; 5.23)	95
HK	Linear country Fixed Effects	0.7	5.25	0.25	(4.76; 5.75)	85
HK	Non Linear country Fixed	0.8	5.00	0.12	(4.76; 5.25)	94

Note: \* number of cases out of 100 for which the true value of the estimated elasticity of substitution coefficient ( $\sigma = 5$ ) belongs to the estimated 95% confidence interval.

Despite the appeal of the fixed effects approach, it has two main shortcomings. First, it does not permit to estimate the impact of any country specific variables, such as domestic distribution costs, product quality or environmental norms. As shown by AvW (2004), this type of costs is relatively large, and accounts for an increasing share of total trade costs (as tariffs, transportation and communication costs continue to drop). Secondly, the fixed-effects estimators do not permit to distinguish the trade theory lying behind the estimated trade equation while this is crucial (Head and Ries, 2001). Thus, while the fixed-effects technique permits to correctly estimate the elasticity coefficient, it has no power in telling what exactly country fixed effects stand for.

## **5. Conclusion**

Due to its empirical success, the gravity approach is widely used to explain trade patterns between countries. Two main theoretical frameworks attributed to Armington and to Helpman-Krugman legitimate this approach at the macro-economic level. In this article we question the relevance of this approach to product trade on two grounds. First, we show that the Armington version of gravity builds heavily on the equality between the value of global expenditure and the value of global production, an assumption seldom verified at sector level because at least some trade costs paid by sector consumers are incurred by producers from other sectors. We propose a modified version of the Armington gravity that solves this inconvenience with real data. Secondly, we estimate the two gravity approaches (the modified Armington model and the HK model) with non linear techniques using simulated data and different measures of importer's expenditure. The mis-measurement of sector expenditures significantly affects the value of the estimated behavioural parameters in both approaches. Therefore, collecting good sector-level trade and expenditure data is crucial for the quality of estimated parameters.

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**Appendix A****Table A1: Correlation coefficients of different measures of sector-level expenditures, the modified Armington gravity**

Measure of expenditure	Coefficients of correlation		
	True (generated) expenditure	Trade-cost-free expenditure	Production
True (generated) expenditure	1.00		
Trade-cost-free expenditure	0.99	1.00	
Production	0.05	0.06	1.00

**Table A2: Correlation coefficients of producer prices, the modified Armington gravity**

Producer prices	Coefficient of correlation with true (generated) prices
True (generated) prices	1.00
Estimated prices with true expenditures and $p_I = 1$	0.40
Estimated prices with trade-cost-free expenditures and $p_I = 1$	0.40
Estimated prices with importer productions and $p_I = 1$	0.38
Estimated prices with true expenditures and true $p_I$	0.79
Estimated prices with trade-cost-free expenditures and true $p_I$	0.78
Estimated prices with importer productions and true $p_I$	0.77

Note: Lower correlation coefficients are obtained when the constraints of unitary  $Y_i$  and  $E_j$  coefficients are relaxed.

**Table A3: Correlation coefficients of different measures of sector-level expenditures, the HK gravity**

Measure of expenditure	Coefficients of correlation		
	True (generated) expenditure	Trade-cost-free expenditure	Production
True (generated) expenditure	1.00		
Trade-cost-free expenditure	0.99	1.00	
Production	0.04	0.06	1.00

**Table A4: Correlation coefficients of producer prices, the HK gravity**

Producer prices	Coefficient of correlation with true (generated) prices
True (generated) prices	1.00
Estimated prices with true expenditures and $p_l = 1$	0.29
Estimated prices with trade-cost-free expenditures and $p_l = 1$	0.20
Estimated prices with importer productions and $p_l = 1$	0.18
Estimated prices with true expenditures and true $p_l$	0.80
Estimated prices with trade-cost-free expenditures and true $p_l$	0.46
Estimated prices with importer productions and true $p_l$	0.49

Note: Lower correlation coefficients are obtained when the constraints of unitary  $Y_i$  and  $E_j$  coefficients are relaxed.

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