Applying the gravity approach to sector trade: who bears the trade costs?

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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 show empirically that collecting/using good data on sector-level trade and expenditure is extremely crucial for the quality of econometric estimations. Above all one should strictly adhere to the requirements of the theoretical frameworks in order to obtain unbiased and accurate estimates of the different parameters.

Keywords: Gravity, Trade, Econometrics

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). If the two competing theories provide more justification for using gravity than no theory at all, disentangling the relevant one remains very critical for policy analysis. For instance, the distribution of the benefits of trade liberalization is completely far apart (Head and Ries, 2001). In that perspective, Feenstra et al. (2001) argue that the basic gravity equation can be used to differentiate among these two alternative theories of trade. More precisely, they show that in the firm differentiated-monopolistically paradigm, the elasticity of trade with respect to exporter's GDP is larger than the elasticity of trade with respect to importer's GDP. The opposite is proven with the alternative paradigm. Then authors estimate the traditional empirical version of the gravity model, focusing on the parameters associated to the GDPs. Evenett and Keller (2002) also look for the trade theories which can account for the empirical success of the gravity model. But they do so assuming from the beginning that there is no trade policy. Accordingly, their approach is not useful for all sector trade analysis.

On the other hand, other researches show that the traditional empirical version of the gravity model does not have robust theoretical foundations. In particular, AvW (2003), built on Anderson (1979), show that it does not derive from the nationally differentiated goods perfectly competitive model because it lacks multilateral resistance terms (price indexes) which depend on trade barriers. Accordingly, econometric estimation suffers from an omitted variables bias and, moreover, comparative static exercises are not possible. Authors also argue that the elasticities of trade with respect to the exporter and importer GDP should be equal to one which is at odds with Feenstra et al. (2001) discriminatory criterion. In the same vein, Bergstrand (1989, 1990) demonstrates that the new trade theory conducts to a gravity-type equation supplemented by a multilateral price index as well. Finally, it is worth mentioning that another line of research empirically shows that the gravity model also performs well in the homogeneous good case where bilateral trade flows are not determined theoretically. In particular, Haveman and Hummels (2004) show with simulated data that the success of gravity is mostly statistic in the sense that it reflects the general equilibrium accounting relationship. They further add that the presence of many nil trade flows does not reduce the empirical success of the gravity while they are not allowed in the two main trade paradigms. To sum up, all these researches suggest that the results from basic gravity models are not interpretable and are not useful for policy analysis (Deardorff, 1998). 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; accordingly, it remains difficult to differentiate among the two theories with nested econometric tests.

In this already challenging context for the gravity approach, the purpose of the present paper is to empirically 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. First, 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. For instance, 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 the sector producers in the exporting countries. This fact implies that sector expenditures can not be theoretically equal to sector revenues while this assumption is maintained in the Armington gravity approach. 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. In the first part of the paper we formally show that the theoretically founded AvW-Armington gravity approach is unfeasible at a sector level. We then propose a slight modification to solve this impossibility 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. Depending on the use of fob or cif values of imports, this computation may also omit international transport costs. In this case one ends up estimating a trade equation system without the right measure of the expenditure explanatory variable. 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). We thus have a measurement error issue (under-estimation of sector expenditures) which is a source of econometric endogeneity (as pointed out by 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 impacts the results (see for instance, Egger, 2004 or Baier and Bersgtrand, 2007). Advocated econometric solutions (such as panel data econometrics with the specification of fixed effects or Instrument Variables estimations) are far from ideal but the only available second best solution.[1] Rather than looking for the best econometric remedies, our 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 behaviour parameters, and then estimate the model with the correct and mismeasured expenditures. The procedure is conducted for both theoretical versions of gravity (our modified Armington gravity and the HK version). Our main econometric results are the following. The mis-measurement of sector expenditures significantly impacts the estimated behavioural parameters in the HK gravity version. On the other hand, this does not affect the quality of estimators in our modified Armington gravity version. The difference in results arises from the fact that sector expenditures do not enter in the same manner in the two models. When theoretical constraints in the latter version of gravity are relaxed, estimators are also biased. This suggests that depending on the theory one is willing to adopt, collecting good trade data is highly critical. In all cases, strictly adhering to the requirements of the theory is unavoidable.

The core of this paper is organised in two main sections. The following section is devoted to the Armington gravity approach. We first formally demonstrate that the AvW equations can not 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. Section 3 is devoted to the HK gravity approach. In particular we specify the different assumptions made to develop a sector-level application. We then again move on the illustrative econometric analysis. Finally, section 4 concludes.

[1] Panel data estimation supposes the availability of trade costs data over several years. Moreover AvW (2003) 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 the analysis. Regarding the IV approach, results are well known to be highly dependent on the choice of instruments (Erkel Rousse and Mirza, 2002).

2. The Armington gravity approach to sectoral trade

2a. The basic Armington gravity approach

This approach is nicely explained in AvW (2003, 2004) and therefore we present it very briefly bellow. 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 to be 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:

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

where x_{ij}^k denotes exports from *i* to *j* of product *k*, σ is the elasticity of substitution, N is the number of countries and β_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:

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

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:

$$p_{ij}^k = p_i^k t_{ij}^k \tag{3}$$

where $t_{ij}^k - 1$ is the *ad valorem* tax equivalent of trade costs.

Solving the consumer program we obtain:

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

with the CES price index:

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

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*:

$$Y_i^k = \sum_{j=1}^{N} X_{ij}^k \qquad \forall\, i = 1, N \tag{6}$$

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

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

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

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

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

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

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 ensure the equilibrium on the goods' market.

2b. 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 stands 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, which is often not the case (think about the use of the services of a foreign transport firm). Another way to see that this framework can not 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). Sector-level production and consumption values consistent with (8)-(10) also verify:

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

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 amounts Y_i^k and E_j^k to be different as observed in reality. We propose to assume the volume of production (denoted by $y_i^k = Y_i^k / p_i^k$), but not its value, to be fixed (exogeneous). 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:

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

The producer price is now implicitly determined by:

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

The value of trade to final consumers (in cif terms) is then given by:

$$p_{ij}^k x_{ij}^k = X_{ij}^k = \frac{\frac{t_{ij}^{k\,1-\sigma}}{P_j^{k\,1-\sigma}} E_j^k}{\sum_{l=1}^{N} \frac{t_{il}^{k\,-\sigma}}{P_l^{k\,1-\sigma}} E_l^k} p_i^k y_i^k = \frac{\frac{t_{ij}^{k\,1-\sigma}}{P_j^{k\,1-\sigma}} E_j^k}{\sum_{l=1}^{N} \frac{t_{il}^{k\,-\sigma}}{P_l^{k\,1-\sigma}} E_l^k} Y_i^k = \left(\frac{t_{ij}^k}{P_j^k \tilde{\Pi}_i^k} \right)^{1-\sigma} E_j^k Y_i^k \qquad (8')$$

$$with \quad \tilde{\Pi}_i^k = \left(\sum_{l=1}^{N} \frac{t_{il}^{k\,-\sigma}}{P_l^{k\,1-\sigma}} E_l^k \right)^{\frac{1}{1-\sigma}} \qquad \forall\ i,\ j = 1, N$$

This new theoretically grounded gravity version can be applied to sector trade and is still quite close to the AvW original one (it still can be expressed with two price indexes).

2c. The 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 the best of 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). A more radical solution is to simply replace it by the importer's production value (e.g. Feenstra et al., 2001). Again, this measurement issue does not exist when the analysis is conducted at the macroeconomic level under the assumption of balanced trade. This is typically an empirical issue that we investigate with a Monte Carlo analysis. In this section, we use our modified Armington gravity specification developed for sector trade. The analysis consists of two steps. In the first step, we generate trade flows by fixing the levels of production volumes, expenditures, trade costs, and CES behavioural parameters and solving the system of equations (7')-(8') along with the consumer price index equation (5). More specifically, we assume:

$$N = 30$$

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

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

Without loss of generality, we assume that all distributions parameters are equal to one and we adopt a rather standard elasticity of substitution. Regarding trade costs, i.e. costs non incurred at the production level, we assume that they are observable and are on average equal to 30% (see the introduction). Non observable trade costs are assumed to be nil. Finally we consider a set of 30 countries which gives us 870 trade flows plus 30 internal demands, as well as 30 price indexes and 30 producer prices.

Once we get these data by simulations, we turn to the second step. We add an error term which is a normally distributed random variable with mean zero and variance equal to that of simulated international trade flows: $\varepsilon_{ij}^k \approx N(0,0.97)$. Negative trade values (17 out of 900 observations) are replaced by zero and used along with positive trade demands in estimations. As expected, dropping these 17 nil observations does not alter the results. Then, we estimate the parameters of equation (8') subject to the definition of the consumer price index (5).[2] If we

[2] We also assume that producer prices are observable and exogenous. On one hand, this considerably simplifies the econometrics. On the other, this does not recognize their endogeneity and is likely to bias the result. This

fully respect the theory, then we only estimate one parameter, namely the substitution elasticity σ. The first seven rows in Table 1 report the results of this estimation with three measurements of final expenditures: (i) the true one that we set initially, (ii) one free of trade costs (initial expenditures less trade costs), and (iii) one proxied by the value of importer's production. The mis-measurement of expenditures appears to have no effect on the quality of estimation in the sense that we always get the true substitution elasticity in the 95% confidence interval. On the other hand, if we mis-measure the expenditure either in the numerator or in the exporter's price index appearing in the denominator of equation (8'), then the estimated value of the elasticity of substitution is significantly different from its true value (larger in the first case and lower in the second case). The interpretation of these results is that, since the expenditure appears in both the numerator and the denominator of the trade flows equation, the mis-measurement on both sides does compensate on the ratio. This outcome suggests again that theory must be taken seriously in empirical studies: price indexes 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 (see for instance Baldwin and Taglioni, 2006).

The substantial bearing of the theory is also illustrated with the subsequent estimations where we do not constraint the coefficient on expenditure to be equal to one (both at the numerator and the denominator). Results are reported in the last six rows of Table 1. When the true expenditure variable is used, one correctly estimates the elasticity of substitution and the coefficient on importer's expenditure (5 and 1 respectively). However, the estimated coefficient on expenditure is no longer significantly different from zero when this expenditure is mis-measured. The results of the estimation when both the coefficients on expenditure and production are unconstrained lie in the same vein. We are able to recover the true value of parameters only using the correct measure of expenditures. To sum up, the overall message of this section is that mismeasuring sector-level expenditure does not bias the estimator of the substitution elasticity provided that the theoretical restrictions of our modified Armington gravity version are fully respected. Relaxing some of these restrictions, in particular those regarding the price indexes, leads to a significant bias.

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assumption is nevertheless adopted in all estimations in order to be able to compare them without a great prejudice. Treating producer prices as endogenous is left for another research.

3. The Helpman-Krugman gravity approach to sector trade

3a. 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, Helpman and Krugman, 1985). According to our knowledge, this second version of gravity has only been derived at the aggregate level. Below we present it at the sector level and then show that, contrary to the Armington gravity, 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, ad valorem equivalents of trade costs, as well as 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:

$$U_j^k = \left(\sum_{i=1}^{N} n_i^k x_{ij}^{k\frac{\sigma-1}{\sigma}} \right)^{\sigma/\sigma-1} \tag{12}$$

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*.[3] The budget constraint is now given by:

$$E_j^k = \sum_{i}^{N} n_i^k p_i^k t_{ij}^k x_{ij}^k \tag{13}$$

The resulting demand (trade) equations are then:

$$X_{ij}^k = n_i^k \left(\frac{p_i^k t_{ij}^k}{P_j^k} \right)^{1-\sigma} E_j^k \qquad \forall\, i,\ j = 1,\ N \tag{14}$$

with the CES price index $$P_j^k = \left(\sum_{i=1}^{N} n_i^k \left(p_i^k t_{ij}^k \right)^{1-\sigma} \right)^{1/1-\sigma} \qquad \forall\ j = 1,\ N \tag{15}$$

On the supply side, a monopolistically competitive framework with symmetric firms using the same increasing returns production technology is assumed. This representative firm

[3] Hence, the total export of good *k* varieties by *i* to *j* in volume terms is equal to $n_i^k x_{ij}^k$.

maximizes profits subject to the workhorse linear technology function defined on a single input variable (labour):

$$l_i^k = \alpha^k + \varphi^k y_i^k \quad \forall i = 1, N \tag{16}$$

where l_i^k represents labour used by the representative firm in country *i*, y_i^k is the firm output (in volume terms), and α^k and φ^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 markup over the marginal cost of production (determined by wages w_i^k):

$$p_i^k = \frac{\sigma}{\sigma - 1} \varphi^k w_i^k \qquad \forall\, i = 1, N \tag{17}$$

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:

$$y_i^k = \frac{\alpha^k}{\varphi^k}(\sigma - 1) = q \qquad \forall\, i = 1, N \tag{18}$$

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:

$$n_i^k = \frac{L_i^k}{l_i^k} = \frac{L_i^k}{\alpha^k + \varphi^k q} = \frac{Y_i^k}{w_i^k\left(\alpha^k + \varphi^k q\right)} \quad \forall i = 1, N \tag{19}$$

Substituting the above expression in the demand equation (14) and using equation (17) for p_i^k yields the gravity equation:

$$X_{ij}^k = \frac{{p_i^k}^{-\sigma}\ {t_{ij}^k}^{1-\sigma}\ Y_i^k\ E_j^k}{\sum_l {p_l^k}^{-\sigma}\ {t_{lj}^k}^{1-\sigma}\ Y_l^k} = \frac{{w_i^k}^{-\sigma}\ {t_{ij}^k}^{1-\sigma}\ Y_i^k\ E_j^k}{\sum_l {w_l^k}^{-\sigma}\ {t_{lj}^k}^{1-\sigma}\ Y_l^k} = \frac{{w_i^k}^{1-\sigma}\ {t_{ij}^k}^{1-\sigma}\ L_i^k\ E_j^k}{\sum_l {w_l^k}^{1-\sigma}\ {t_{lj}^k}^{1-\sigma}\ L_l^k} \quad \forall i,\ j = 1, N \tag{20}$$

Traditional gravity explanatory variables appear in the first right hand term of (20). However, in this framework both producer prices (or wages obtained from equation (17)) and the value of sector production are endogenous. Note, that in this case the gravity equation can also be written as a function of prices or wages and exogenous variables (sector-level endowments, expenditures, and trade costs). Wages are implicitly determined by the market equilibrium conditions:

$$q = \sum_{j=1}^{N} \left(\frac{p_i^k\left(w_i^k\right) t_{ij}^k}{P_j^k\left(w_i^k\right)} \right)^{1-\sigma} \left(t_{ij}^k\right)^{-1} E_j^k \qquad \forall\, i,\ j = 1, N \tag{21}$$

By fixing the level of the production factor, L_i^k, the HK version of gravity can be readily applied to sector-level trade. One should note at least one major difference between the trade equation (20) and the one from our modified Armington version (equation (8')): once we posit producer prices (or wages), the sector expenditure appears only in the numerator and no longer in the denominator (price index). We now turn again to the empirical issue of (in)correctly measured expenditures.

3b. 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. In the first step, we make the following assumptions:

$$N = 30$$

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

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

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 *2c*. We add a normally distributed error term to our simulated trade flows, replace negative values by zero, and finally estimate equation (20) with different measures of expenditures: (i) the true expenditure, (ii) the value of expenditure less trade costs, and (iii) the importer's production.[4]

Estimation results are reported in the upper part of Table 2. When all theoretical constraints of the model are imposed, one can correctly estimate the elasticity of substitution only if 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. Supplementary results displayed in Table 2 show that relaxing some or all constraints on the value and the relationship between the parameters of the model always result in an unbiased estimator of the substitution elasticity. However, this is achieved to the detriment of the precision of other structural parameters.

[4] As in section 2c, we assume that producer prices (or equivalently wages) are observable and exogenous.

4. Concluding comments

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) using simulated data and different measures of importer's expenditure. We find that collecting good sector-level trade and expenditure data is crucial for the quality of estimated parameters. The mis-measurement of sector expenditures significantly affects the value of the estimated behavioural parameters in the HK gravity version. This is also the case in our modified Armington version of gravity if all theoretical constraints are not imposed. Therefore, strictly confirming to the requirements of the theory is a fundamental condition for the accurate estimation of gravity model parameters.

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

Measure of expenditure	R^2	Parameter σ Mean	Std. Err.	[95% Conf. Interval]	Coefficient on E_j Mean	Std. Err.	[95% Conf. Interval]	Coefficient on Y_i Mean	Std. Err.	[95% Conf. Interval]
Model with all theoretical constraints										
True	0.911	4.94	0.08	(4.77; 5.10)						
Trade cost free	0.910	4.96	0.08	(4.80; 5.13)						
Production	0.897	4.90	0.09	(4.72; 5.08)						
Trade cost free (except the price index)	0.881	5.78	0.11	(5.56; 6.00)						
Production (except the price index)	0.868	5.68	0.11	(5.45; 5.90)						
Trade cost free in the price index	0.875	4.23	0.09	(4.06; 4.40)						
Production in the price index	0.874	4.18	0.09	(4.01; 4.35)						
Model without constraints on expenditure										
True	0.911	4.95	0.08	(4.79; 5.11)	0.86	0.07	(0.71; 1.01)			
Trade cost free	0.906	4.95	0.09	(4.78; 5.12)	0.04	0.00	(0.03; 0.04)			
Production	0.905	4.99	0.09	(4.81; 5.16)	-0.22	0.03	(-0.27; -0.16)			
Model without constraints on expenditure and production										
True	0.911	4.92	0.09	(4.74; 5.11)	0.84	0.09	(0.67; 1.01)	1.00	0.00	(0.99; 1.01)
Trade cost free	0.906	4.90	0.09	(4.71; 5.08)	0.03	0.00	(0.03; 0.04)	1.00	0.00	(0.99; 1.01)
Production	0.906	4.91	0.10	(4.72; 5.10)	-0.13	0.01	(-0.15; -0.10)	1.00	0.00	(0.99; 1.01)

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^2	Parameter σ Mean	Std. Err.	[95% Conf. Interval]	Coefficient on Ej Mean	Std. Err.	[95% Conf. Interval]	Coefficient on Yi Mean	Std. Err.	[95% Conf. Interval]
Model with all theoretical constraints										
True	0.926	4.91	0.08	(4.75; 5.07)						
Trade cost free	0.896	5.61	0.11	(5.39; 5.83)						
Production	0.808	6.30	0.17	(5.97; 6.63)						
Model without constraints on expenditure										
True	0.926	4.91	0.09	(4.74; 5.08)	1.00	0.002	(0.99; 1.01)			
Trade cost free	0.926	4.90	0.09	(4.72; 5.07)	1.05	0.002	(1.04; 1.05)			
Production	0.900	4.86	0.10	(4.66; 5.06)	1.10	0.003	(1.09; 1.11)			
Model without constraints on expenditure and production										
True	0.926	4.91	0.09	(4.74; 5.08)	1.00	0.002	(0.99; 1.01)	1.02	0.07	(0.88; 1.16)
Trade cost free	0.926	4.91	0.09	(4.74; 5.08)	1.05	0.002	(1.04; 1.05)	1.03	0.08	(0.88; 1.18)
Production	0.900	4.89	0.10	(4.69; 5.08)	1.10	0.003	(1.09; 1.11)	0.93	0.08	(0.77; 1.08)