Elasticity of trade flow to trade barriers: A comparison among emerging estimation techniques

Olper A. [1], Raimondi V. [1]

[1] University of Milano, Department of Agricultural Economics

Abstract—**The objective of this study has been to analyze the sensitivity of trade flow to trade barriers from gravity equations, using different econometric techniques recently highlighted in the literature. Specifically, we compare a benchmark OLS fixed effects specification a la Feenstra (2002), with three emerging estimation methods: the standard Heckman correction for selection bias, to account for zero trade flow; its extension, recently proposed by Helpman et al. (2008), to control for firm heterogeneity; and, finally, the Poisson pseudo-maximum-likelihood (PPML) technique to correct for the presence of heteroskedasticity, first proposed by Santos Silva and Tenreyro (2006). Our gravity model includes trade among 211 exporter and 104 importer countries, in 18 food industry sectors.**

Keywords— **Gravity model, Trade Elasticity, Food trade**

I. INTRODUCTION

The motivation for this study came from the renewed interest in the use of gravity equations to explain bilateral trade flow, an interest largely driven by the sounder theoretical foundation that has emerged in recent years (Anderson and van Wincoop, 2004)[1]. A key potential of the 'gravity theory' is the possibility of identifying substitution elasticity between home and foreign varieties, an elasticity that represents the key behavioural parameter for capturing the general equilibrium response of trade flow to falling trade barriers (see Lai and Trefler, 2004 [2]; Bergstrand et al., 2007 [3]).

However, there is some disagreement on the possibility of identifying such elasticity in gravity models. Some authors stress that the underlying assumptions of the standard CES monopolistic competition model, on which gravity is based, do not hold in the data (see Féménia and Gohin, 2006) [4]. Others suggest that estimation methods matter (e.g. Santos Silva and Tenreyro, 2006) [5]. Finally, Bergstrand et al. (2007) [3] highlight that, while elasticity cannot be directly estimated using a standard approach, it can be retrieved indirectly.

A central point is that it is now quite normal to use theory driven gravity equations to analyze the effect on the bilateral trade flow of different trade barriers, like FTA, tariffs, NTBs, or trade preferences (e.g. Moenius, 2006 [6]; Wilson et al, 2002 [7]; Fontagné et al., 2005 [8]; Kuiper and van Tongeren, 2006 [9]; Olper and Raimondi, 2008 [10]; Disdier et al., 2008 [11], Agostino et al., 2007 [12]; Cipollina and Salvatici, 2007 [13]). However the variety of proposed gravity equation specifications generates a great deal of controversy and uncertainty over the *correct* specification, as recently shown by Schaefer et al. (2008) [14] using Monte Carlo simulation. Finally, a potential shortcoming of the existing literature is that only rarely is there the testing of the sensitivity of the results to the estimation techniques, notwithstanding the fact that the chosen estimation method seems to matter for the final results (see Santos Silva and Tenreyro, 2006 [5]; Helpman et al, 2008 [15]).

Thus, the objective of the present study is to analyze the sensitivity of trade flow to trade barriers from gravity equations, using different econometric techniques recently highlighted in the literature. Specifically, we compare a benchmark OLS fixed effects specification a la Feenstra (2002) [16], with three emerging estimation methods: the standard Heckman correction for selection bias (Heckman, 1979) [17] to account for zero trade flow; its extension to control for firm heterogeneity, recently proposed by Helpman et al. (2008) [15]; and, finally, the Poisson pseudo-maximum-likelihood (PPML) technique first proposed by Santos Silva and Tenreyro (2006) [5] to correct for the presence of heteroskedasticity.

II. EMPIRICAL FRAMEWORK

The standard CES monopolistic competition trade model with iceberg trade costs introduced by Krugman (1980) [18] represents the 'benchmark' from which we derive the gravity-like equation estimated in this paper. Under the assumption of identical and symmetric firms, the bilateral trade flow from j to i yields the following log-linear equation:

$$(1)\quad m_{ij} = \beta_0 + \lambda_j + \chi_i + (1-\sigma)\gamma \ln D_{ij} + (1-\sigma)\ln \tau_{ij} + u_{ij},$$

with λ_j and χ_i the exporter and importer fixed effects to control for the unobserved number of varieties (firms) and the price term of the exporter, and for the expenditure and the unobserved price term of the importer, respectively[1]. D_{ij} is the transport costs proxy by distance between i and j; τ_{ij} is the ad valorem bilateral tariff; $\sigma > 1$ is the elasticity of substitution between home and foreign goods; finally u_{ij} is the i.i.d. error term. Equation (1) represents our benchmark.

When equation (1) is applied at the disaggregated level, the first problem to emerge is the presence of a high number of zero bilateral trade flows. One of the most common methods of dealing with zero trade is the Heckman (1979) [17] two stage selection correction: i) a Probit equation where all the trade flow determinants are regressed on the indicator variable, T_{ij}, equal to 1 when j exports to i and 0 when it does not; ii) an OLS stage with the same regressors as the Probit equation, plus the inverse Mills ratio from the first stage, correcting the biases generated by the sample selection problems.

However, Helpman et al. (2008) [15] recently showed that the standard Heckman correction is a valid estimation technique only in a world without firm-level heterogeneity, where all firms are identically affected by trade costs and other country characteristics. In a model with firm-level heterogeneity, and with fixed as well as variable trade costs, the consistent estimation method is a variant of the Heckman procedure that also corrects for the fraction ω_{ij} of exporting firms.

The probability that country j exports to i as a function of observable variables is

$$(2) \quad \rho_{ij} = \Pr(T_{ij} = 1 | observed\,\mathrm{var}) = \Phi(\gamma_0^* + \xi_j^* + \zeta_i^* - \kappa^* \phi_{ij})$$

where ξ_j and ζ_i are the exporter and importer fixed effects, and ϕ_{ij} is an observed measure of specific country-pair fixed and variable trade costs, like distance, bilateral tariffs and so on. $\Phi(\cdot)$ is the cdf of the unit-normal distribution, and every starred coefficient represents the original coefficient divided by the standard deviation σ_η. Helpman et al. (2008) [15] use the predicted components from equation (2) to construct both the inverse Mills ratio and an estimate of the fraction of firms that export, ω_{ij}, thus correcting for the bias induced by the firm-level heterogeneity.

Let $\hat{\rho}_{ij}$ be the predicted probability of exports from j to i, using the estimates from the Probit equation (2) and let $\hat{z}_{ij}^* = \Phi^{-1}(\hat{\rho}_{ij})$ be the predicted value of the latent variable $z_{ij}^* \equiv z_{ij} / \sigma_n$. Then a consistent estimate of the fraction of exporting firms is $\hat{\omega}_{ij} \equiv \ln\{\exp[\delta(\hat{z}_{ij}^* + \hat{\eta}_{ij}^*] - 1\}$, where $\hat{\eta}_{ij}^*$ is the inverse Mills ratio.

Thus, the second stage least squares regression will be

$$(3) \quad m_{ij} = \beta_0 + \lambda_j + \chi_i + \psi \ln D_{ij} + \theta \ln \tau_{ij} + \hat{\eta}_{ij}^* + \ln\{\exp[\delta(\hat{z}_{ij}^* + \hat{\eta}_{ij}^*)] - 1\} + e_{ij},$$

where the coefficients ψ and θ are now the estimate of the trade effect of transport costs and bilateral tariffs, controlling for sample selection and unobserved firm-level heterogeneity. These parameters should be lower than the analogous coefficients in equation (1) where the trade barrier effect on trade flow confounds the true effect with the indirect effect on the proportion of exporting firms. The last estimation technique considered is the Poisson pseudo-maximum-likelihood (PPML) estimator. For several reasons, this method has met with success in the gravity literature since the important contribution of Santos Silva and Tenreyro (2006) [5]. Indeed these authors suggest that, as a consequence of Jensen's inequality, $E(\ln y) \neq \ln E(y)$. Thus, the standard practice of interpreting the parameters of a log-linearized model estimated by OLS as elasticity can be highly misleading in the presence of heteroskedasticity (Santos Silva and Tenreyro, 2006, 641) [5].

The PPML estimator is very simple to implement with standard econometric programs, and as with this method the gravity equation is estimated in its multiplicative form, thus with the dependent variable in levels, it represents a natural way to also deal with zero trade data.

III. THE DATA

Our gravity model includes trade among 211 exporter and 104 importer countries, of 18 food industry sectors. The number of countries is limited by the availability of importer bilateral tariff data that precludes the possibility of squaring the dataset

We used the UN Comtrade database for bilateral trade at the HS-96 6-digit level, reported by the importer countries, then aggregated at the 4-digit ISIC industry classification. To partially reduce the zero data of one year's observations, we used the average value of trade for the years 2002-03-04. However, more than the 70% of the 239,298 observations in our dataset are of zero trade flow. Some of the zero trade reflects errors, omissions and, rarely, rounding error due to reported low values of trade. However, it appears that most of the zero trade flow between country pairs reflects a true absence of trade (Martin and Pham, 2007) [20].

1. An identical empirical specification can be derived from the model of Anderson and van Wincoop (2003) [19].

Output data come from the UNIDO database and are at the same classification and aggregation level (ISIC rev. 3 code from 1511 to 1600), supplemented by the UNIDO ISIC rev. 2 data in the case of missing values.

Distances are based on bilateral distances between cities weighted by the share of the city in the country's overall population. Data on distances, with the dummies on contiguity, language, colony, and common colonizer, are taken from CEPII (Centre d'Etude Prospectives et d'Informations Internationales).

Bilateral tariff data come from the MAcMap database jointly developed by the ITC (UNCTAD and WTO, Geneva) and CEPII (Paris). It includes ad-valorem, as well as specific components of each bilateral tariff line to six digits of the Harmonized System. Average tariffs are computed starting from the HS 6-digit bilateral tariffs then aggregated at ISIC 4-digit level using import weights based on the reference group method of Bouët et al. (2007) [21].

IV. MAIN RESULTS

We generate two sets of gravity estimates: one pooled over the 18 food industries (Table 1), the others considering each of the 4-digit food sectors separately (Table 2).

Both tables present the same structure: column 1 reports OLS benchmark; the first stage Probit is reported in column 2; the second stage procedure of Heckman and Helpman et al. (Heck_Helpman) is reported in columns 3 and 4 respectively. Finally, column 5 reports the PPML estimates using only the sub-sample of positive trade pairs.[2]

Starting from Table 1, the first point to note is that the tariff coefficients, always statistically significant, are remarkably similar in the OLS and Heckman procedure. The derived elasticity of substitution for food industry products ranges between 2.56 and 2.68, remarkably close to the 2.53 value estimated by Lai and Trefler (2004) [2] using a more complex panel estimation method.

The Probit results (column 2) strongly confirm that the same variables that impact export volumes also affect the probability that country *j* exports to country *i* and these impacts go in the same direction. In particular, the presence of tariffs reduces the probability of registering positive trade flow by more than 50%. In column 4, the Heck_Helpman procedure displays a tariff coefficient that drops to -0.86, suggesting that there is a much smaller effect of tariffs on firm-level trade[3]. The same happens for the coefficient on distance, that drops from -1.36 to -0.46. Also the measured effect of common colonizer is strongly affected, while common language and common border become insignificant. Following the Helpman et al. (2008) [15] conceptual model, these variables show a "great influence on firm's choice of exports location, but not on its exports volume once the exporting decision has been made". At the end, the Poisson results show that tariffs play a smaller role according to OLS estimates when we consider the overall food trade.

Table 1. Results at aggregated level across different methods

	OLS (1)	Probit (2)	Heckman (3)	Heck-Helpman (4)	Poisson (5)
Log (production)i	**-0.049**	**-0.057**	**-0.082**	0.007	**-0.191**
	(0.016)	(0.008)	(0.016)	(0.017)	(0.047)
Log (production)j	**0.643**	**0.199**	**0.745**	**0.431**	**0.810**
	(0.012)	(0.008)	(0.019)	(0.029)	(0.051)
Log Distance	**-1.361**	**-0.772**	**-1.683**	**-0.463**	**-1.065**
	(0.031)	(0.020)	(0.035)	(0.090)	(0.063)
Log (1+tariff)	**-1.561**	**-0.520**	**-1.676**	**-0.861**	**-1.199**
	(0.126)	(0.059)	(0.123)	(0.134)	(0.373)
Common Language	**0.300**	**0.284**	**0.409**	-0.085	0.244
	(0.081)	(0.050)	(0.081)	(0.098)	(0.129)
Common Border	**1.025**	**0.679**	**0.974**	-0.093	**0.511**
	(0.081)	(0.091)	(0.082)	(0.117)	(0.103)
Common Colonizer	**1.615**	**1.109**	**2.281**	**0.538**	**1.604**
	(0.125)	(0.054)	(0.130)	(0.176)	(0.467)
Colonial Relationship	**0.768**	**0.822**	**1.128**		0.220
	(0.095)	(0.082)	(0.100)		(0.174)
Mills ratio			**1.472**	**0.569**	
			(0.079)	(0.092)	
Firm heterogeneity				**1.492**	
				(0.111)	
Constant	**7.606**	**3.950**	**6.695**	**3.351**	**8.552**
	(0.954)	(0.302)	(0.884)	(0.906)	(1.142)
Observations	16095	31563	16095	16095	16095
Adjusted R-squared	0.500	0.460	0.509	0.511	0.748
Linktest p-value	0.000	0.000	0.000	0.000	0.000

Note: Exporter and Importer fixed effects; 3-digit Industry dummies. Marginal effects at simple means reported for Probit. Pseudo R-squared reported for Probit and Poisson. Standard errors are in parentheses. Bold when significant level > 5%.

Table 2 reports only the tariff coefficients when each 4-digit ISIC sector is considered.[4] Results at the product level

2. Poisson estimates using the whole sample present very similar results; the tariff coefficients are always lightly lower than in Poisson with only positive trade.
3. Note that, for the second stage estimation, the Helpman et al. model requires the selection of a valid excluded variable that affects fixed trade costs but does not affect variable trade costs. We selected common colonial ties as an additional cost variable. It has substantial explanatory power for the formation of trading relationships, resulting statistically significant.
4. The specification include the same variables of regressions in Table 1, with exclusion of importer and exporter production.

show that bilateral tariffs generally affect trade flow more, but with strong heterogeneity.

In the OLS estimate, the average magnitude of the tariff coefficients across products is 3.4, thus higher than the previous pooled regression, and ranging from 0.8 (sugar) to 8.2 (fish). When we correct for selection bias (column 3) the product level tariff coefficients decrease, on average, 25% in absolute value, while the introduction of the unobserved firm heterogeneity (column 4) lowers the OLS coefficients of the 45%.

Table 2. Trade elasticity to bilateral tariffs at ISIC 4-digit

Industry of *Isic Rev.3*	OLS (1)	Probit (2)	Heckman (3)	Heck-Helpman (4)	Poisson (5)
Meat	**-2.050**	**-0.517**	**-1.354**	*-0.717*	*-1.404*
1511	(0.400)	(0.178)	(0.395)	(0.402)	(0.811)
Fish	**-8.190**	**-1.281**	**-5.824**	**-2.41**	**-11.54**
1512	(0.915)	(0.512)	(0.920)	(0.953)	(2.229)
Fruit Products	**-3.234**	0.117	**-2.136**	**-2.81**	**-7.695**
1513	(0.538)	(0.356)	(0.540)	(0.539)	(0.980)
Vegetable and Animal Oil	**-3.766**	**-1.057**	**-3.068**	-0.534	0.582
1514	(0.916)	(0.515)	(0.913)	(0.959)	(1.635)
Dairy Products	**-4.011**	-0.123	**-2.97**	**-2.801**	**-3.294**
1520	(0.478)	(0.242)	(0.488)	(0.482)	(0.505)
Grain Mill Products	**-2.700**	**-0.585**	**-2.387**	**-1.411**	**-3.59**
1531	(0.314)	(0.141)	(0.301)	(0.320)	(0.462)
Starch Products	**-3.440**	**-1.020**	**-2.914**	**-1.894**	**-2.834**
1532	(0.454)	(0.289)	(0.457)	(0.501)	(0.560)
Animal Feed	**-3.758**	0.102	**-2.207**	**-2.674**	**-3.007**
1533	(0.974)	(0.457)	(1.012)	(1.015)	(1.307)
Bakery Products	**-4.187**	-0.548	**-4.177**	**-2.995**	**-13.16**
1541	(0.911)	(0.401)	(0.895)	(0.896)	(1.325)
Sugar	**-0.790**	*0.237*	-0.135	*-0.645*	**-2.313**
1542	(0.325)	(0.125)	(0.328)	(0.333)	(0.368)
Cocoa and Chocolate Prod.	**-6.633**	**-0.976**	**-5.948**	**-4.421**	**-13.15**
1543	(0.802)	(0.392)	(0.779)	(0.782)	(1.270)
Macaroni Noodles Couscous	-0.822	-0.418	-0.420	0.0403	**-5.886**
1544	(0.733)	(0.332)	(0.730)	(0.736)	(1.225)
Other Food Products	**-2.533**	-0.452	**-1.74**	-0.825	**-8.079**
1549	(0.826)	(0.371)	(0.827)	(0.827)	(1.374)
Spirits	**-1.401**	0.154	-0.869	**-1.207**	**-2.199**
1551	(0.492)	(0.203)	(0.488)	(0.489)	(0.944)
Wines	**-1.791**	-0.321	**-1.197**	-0.321	**-8.448**
1552	(0.571)	(0.217)	(0.535)	(0.532)	(2.168)
Malt	**-3.916**	**-0.972**	**-4.421**	**-2.928**	**-5.717**
1553	(0.770)	(0.286)	(0.767)	(0.791)	(1.502)
Soft Drinks	**-3.295**	-0.285	**-2.676**	**-2.202**	**-5.113**
1554	(0.949)	(0.329)	(0.920)	(0.919)	(2.420)
Tobacco	**-1.539**	*-0.238*	**-1.739**	**-1.184**	**-4.387**
1600	(0.457)	(0.152)	(0.462)	(0.466)	(1.168)

Note: Exporter and Importer fixed effects. Marginal effects at simple means reported for Probit. Standard errors in parentheses. Number in Bold (Italic) when the significant level higher than 5% (10%). (Obs range from 2,499 to 5,619 and from 9,149 to 15,445 when trade is >0 or not)

This confirms the results previously highlighted in table 1, and suggests that these bias corrections are dominated by the influence of unobserved firm heterogeneity, rather than sample selection, in line with the Helpman et al. (2008) [15] findings. Finally, using PPML (column 5), we often observe remarkable growth in the tariff coefficients, associated with a generalized lower distance elasticity (not reported). For many products the growth of tariff elasticity is more than double the benchmark OLS coefficients. Thus, the PPML results at the product level seem to go in the opposite direction with respect to the aggregated level (see Table 1), suggesting that potential aggregation bias is driving the results.

Table 3. Spearman's rank correlation of tariff elasticity

	OLS	Probit	Heckman	Heck-Helpman	Poisson
OLS	1				
Probit	0.60	1			
	0.01				
Heckman	0.96	0.69	1		
	0.00	*0.00*			
Heck-Helpman	0.75	0.13	0.73	1	
	0.00	*0.60*	*0.00*		
Poisson	0.37	0.23	0.35	0.41	1
	0.13	*0.36*	*0.15*	*0.09*	

Significance levels in *Italic*

Despite the heterogeneity of the coefficients' magnitude, the rank correlation on the different econometric techniques gives some interesting results. Table 3 shows a strong positive rank correlation between OLS and Heckman (0.96); the correlation drops somewhat on passing to the Heck-Helpman (0.75). This evidence confirms the idea that controlling for firm heterogeneity matters the most in the single food industry sector. By contrast, Poisson's results present a weak rank correlation with the other three techniques, suggesting a deeper effect of heteroskedasticity correction at the product level. Now the point is: which is the correct specification ?

To deal with this problem, Santos Silva and Tenreyro performed a heteroskedasticity-robust RESET test showing that only the PPML models pass the test. However, because Martinez-Zarzoso et al. (2007)[22] highlight problem with the Ramsey (1969) [23] Reset test when applied to PPML estimator, we performed the *link test*[5] to check for the correct specification of our econometric approaches (see Marquez-Ramos and Martinez-Zarzoso, 2008 [24]).

The corresponding *p*-value are reported at the bottom of table 1, showing that, in spite of Santos Silva and Tenreyro (2006) [5] findings, all our 'aggregated' gravity models are mis-specificated. Differently, applying the same test at product level (not reported for space constraints), the evidence suggests that the PPML regressions are almost ever mis-specificated, while the others estimation methods normally pass the test. This contrasting evidence, clearly,

5. The *link test* (Pregibon, 1979) considers that, if the model is specified correctly, regressing the dependent variable with the prediction and the prediction squared, this last one would not have any explanatory power. The *linktest* is available in STATA.

call for further research to improve the specification of gravity models both at aggregate and product level.

V. CONCLUSIONS

A key potential from 'gravity theory' is the possibility to identify the elasticity of substitution between home and foreign varieties. However, despite considerable empirical research, we are still far from a consensus on their plausible values, and disagreement exists on the possibility of identifying these parameters in gravity models. At the same time, the different estimation techniques proposed in the literature have generated a great deal of controversy over the correct one, and only rarely is there testing of the sensitivity of the results to the estimation approach .

In this paper we compare a benchmark OLS fixed effects specification a la Feenstra (2002) [16], with three emerging estimation methods: the standard Heckman correction for selection bias (Heckman, 1979) [17], its extension proposed by Helpman et al. (2008) [15], to control for firm heterogeneity; and, finally, the Poisson pseudo-maximum-likelihood (PPML) technique to correct for the presence of heteroskedasticity.

In the OLS and Heckman procedure, the derived 'elasticity of substitution' for the food industry products overall, ranges between 2.56 and 2.68, thus remarkably close to the 2.53 value estimated by Lai and Trefler (2004) [2] using the dynamic panel method. With the Poisson and Helpman procedures the tariff coefficient drops to -1.20 and -0.86, respectively, suggesting in the last that there is a much smaller effect of tariffs on firm-level trade. Differently, when each 4-digit ISIC sector is individually considered, in line with existing evidence, the results show an overall (absolute) increase in the trade elasticity to tariffs. Once again, the selection corrections decrease the estimated elasticity about 25% on average; but this reduction go down to 45% when unobserved firm heterogeneity is checked. Finally, the PPML estimation method often produces notable growth in the (absolute) elasticity parameters. This evidence appears puzzling, and contrasts results obtained at the aggregated level, suggesting a strong effect of heteroskedasticity correction at the product level which that certainly needs further studies.

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- Author: Valentina Raimondi
- Institute: Department of Agricultural Economics
- Address: Via Celoria 2 20133. Milano. Italy
- Email: valentina.raimondi@unimi.it