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# Distance and Border Effects in International Trade: A Comparison of Estimation Methods

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**Abstract**
This paper compares various estimation techniques used to determine the impact of distance and borders on international trade. The results consistently confirm the significantly negative distance effect, while the border effect, measured by evaluating whether intra-continental trade exceeds inter-continental trade, appears to be ambiguous and dependent on the estimation method. In addition, also the size of both effects varies substantially across estimation methods. Finally, the authors generally find that the estimations are in line with the respective weighting schemes of each estimation method.

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# 1 Introduction

*"There is very little that economists fully understand about global trade but there is one thing that we do know – commerce declines dramatically with the distance"* (Leamer, 2007).The negative impact of distance on trade is indeed one of the most robust findings in international economics (see e.g., Leamer 1993; Frankel 1997a; Disdier and Head, 2008). Trade is not only reduced by distance, but also by international borders (see e.g., McCallum, 1995; Wei, 1996; Anderson and van Wincoop, 2003; Obstfeld and Rogoff, 2001; Coughlin and Novy, 2012). Adjacent countries trade more than non-adjacent ones (see e.g., Leamer 1993; Helliwell, 1997), leading to the so-called adjacency or contingency effect. Consequently intra-national/continental trade exceeds inter-national/continental trade.

These well-established empirical results appear in the estimates of the so-called gravity equation based on various kinds of trade models, either assuming perfect competition (e.g., Anderson, 1979; Deardoff, 1995; Eaton and Kortum, 2002), monopolistic competition (e.g., Bergstrand, 1989, 1990) or a demand system with translog preferences (Novy, 2013).

The importance of distance and borders as determinants of trade flows may be explained by the variety of barriers to trade they reflect. Distance and border effects account not only for the geographical barriers between two trading partners, but also for various costs traders may incur when transporting a good to its final consumer (see e.g., Anderson and van Wincoop, 2004, for surveys on the relationship between physical distance and trade costs). Moreover, as argued by Blum and Golfarb (2006), distance may also capture consumers' tastes, since it reduces trade even in online products where trade costs should be zero.

Theoretical work argues that the magnitude of the distance effect should be equal to one. Empirical evidence by and large confirms this theoretical prediction. In general, according to the meta-analysis by Disdier and Head (2008), based on 1,467 estimates from 103 papers, the size of the distance effect is close to 0.9. However, the estimated magnitude of the distance effect varies depending on the countries or periods studied. In addition, because of increasing globalization and advances in transport technology, the world is shrinking. Therefore, one may expect that the distance coefficient decreases over time. Empirical studies measuring the evolution of trade elasticity with respect to distance are, however, not conclusive. Some authors find little change in the trade elasticity to distance (see e.g., Leamer 1993). Also Disdier and Head (2008) argue that the distance effect is rather constant after a rise around mid twentieth century. Frankel (1997a), Soloaga and Winters (2001), Berthelon and Freund (2008), among others, obtain evidence for an increasing distance effect, whereas Boisso and Ferrantino (1993), Eichengreen and Irwin (1998), Brun et al. (2005), Felbermayr and Kohler (2006), Coe et al. (2007), amongst others, observe a negative evolution in the distance effect over time. There are several possible explanations for these contradictory results. For example, Brun et al. (2005) argue that infrastructure is responsible for the decline of the distance effect. According to Felbermayr and Kohler (2006), the non-decreasing distance effect found in previous studies, can be explained by the fact that these studies do not take into account the extensive margin of trade. Finally, Berthelon and Freund (2008) show that the increase of the overall distance coefficient is due to the changes of distance coefficients across industries. They explore two possible reasons for these changes. First, in some industries, goods have become more substituable. Second, trade costs have changed too. The author argues that the first phenomenon is the most important one.

The empirical literature on border effects was inspired by the seminal work of McCallum (1995), who shows that Canadian provinces trade up to 22 times more with each other than with US states (the so-called *"home bias"*). This finding was confirmed, for a longer time period by Helliwell (1996) and Helliwell and McCallum (1995). Similarly, Wei (1996) finds that OECD countries buy about 2.5 times more from themselves than from identical foreign countries[1] Helliwell (1997) points to an even larger border effect, but it is approximately halved by for countries sharing a common border and common language. Following a similar approach as Wei (1996) and Helliwell (1997), Nitsch (2000) finds that domestic trade within a European Union country is seven to ten times larger than trade with another European Union country.[2] Finally, note that most of these studies observe a trade increasing effect for adjacent countries.

These findings, and in particular the finding by McCallum (1995), were revisited by Anderson and van Wincoop (2003) who show that the spectacularly high border effects come from omitting the multilateral resistance term in McCallum's specification and from the small size of the Canadian economy. Moreover, although most studies following McCallum (1995) include a multilateral resistance term in the form of a remoteness variable, they still do not account for national border barriers. Thus, Anderson and van Wincoop (2003) show that the inclusion of the multilateral resistance term

[1] Wei (1996) assumes that a country's purchases from itself equal the difference between its production and exports. In his analysis, he assumes that the internal distance equals half of the distance from the country's economic centre to the border of the nearest neighbour.

[2] Note that Helliwell (1996, 1997), Wei (1996) and Nitsch (2000) employ the method of seemingly unrelated regressions (SUR).

considerably reduces McCallum's ratio of inter-provincial trade to province-state trade (from 16.4 to 10.7). Moreover, when using US data instead of Canadian data, they find that trade between states exceeds trade between states and provinces only by a factor 15. Finally, they also find that borders reduce trade between the US and Canada by 44 per cent and among other industrialized countries by 29 per cent.

Interestingly, as demonstrated by Wolf (2000), the home bias exists not only at the international level, but also at the intranational level. According to this author, trade between US states is about three times lower than trade within states.[3] Adjacent states trade 2.6 times more with each other. In addition, the distance coefficient is similar to the coefficients found for international trade. Hillberry and Hummels (2003) explain the finding of Wolf (2000) by the importance of wholesale activities for intra-state trade.

More recently, Coughlin and Novy (2012) compare international borders with domestic borders. More precisely, they compare trade between and within individual US states with trade between states and foreign countries. They find that a state's border is a larger trade barrier than an international US border. One of possible explanation is related to Hillberry and Hummels (2008) who find that trade within the US is heavily concentrated at the local level. Trade within a single ZIP code is on average three times higher than trade with partners outside the ZIP code. Hillberry and Hummels (2008) explain their finding by co-location of producers in supply chains to exploit informational spillovers, minimize transportation costs and facilitate just-in-time production. According to Coughlin and Novy (2012), producers also concentrate in order to benefit from external economies of scale in the presence of intermediate goods and associated agglomeration effects (see e.g., Rossi-Hansberg, 2005), as well as from the hub-and-spoke distribution systems and wholesale shipments (see, Hillberry and Hummels, 2003). It means that the domestic border effect reflects the local concentration of economic activity rather than trade barriers associated with crossing a state border.

From this literature review it appears that the sensitivity of the distance and border effectrs in trade have been tested for various countries, regions and periods. So far, the sensitivity of these effects to the applied estimation methods has not been tested yet in a consistent manner. This paper aims to fill this gap. The remainder of the paper is organized as follows. In the next section we discuss the main econometric approaches mainly or recently followed in the gravity literature. In the third section we present the data and our empiriical approach. Section 4 discusses the results from applying various econometric techniques measuring distance and border effects. Section 5

[3]Note that he does not take into account the multilateral resistance term.

presents some robustness checks. Section 6 concludes.

# 2 The Econometrics of Gravity

While the earliest implementation of the gravity model in international trade was just an intuitive copy of its counterpart in physics, most models of international trade now derive an aggregate bilateral demand system that can be written as a form of the original gravity equation. Following the notation of Head and Mayer (2014), we write the general gravity model as:

$$X_{ij} = GS_iM_j\phi_{ij} \tag{1}$$

where $X_{ij}$ denotes nominal exports from country $i$ to $j$, $G$ is a gravity constant, $S_i$ and $M_j$ are the capabilities of exporter and importer respectively, and $\phi_{ij}$ is a function of the impact of trade barriers to bilateral trade flows, with $0 \leq \phi_{ij} \leq 1$. Using homothetic budget shares and general equilibrium market clearing conditions for the exporter, one can derive a structural basis for eq.1, so that:

$$X_{ij} = \frac{Y_i}{P_i}\frac{X_j}{\Pi_j}\phi_{ij} \tag{2}$$

where $Y_i$ is gross output of exporter $i$, $X_j$ is the total consumption value of goods in $j$, $P_i$ and $\Pi_j$ are multilateral trade resistance terms (MTR).[4] Subsequently in most empiric applications, $Y_i$ and $X_j$ are proxied by exporter's GDP and importer's GDP respectively.

The bulk of theory in the gravity literature is related to static and cross-sectional models. At the same time most empirics are performed in a panel setting, and this for two main reasons: i) there is plenty of panel data available at the country level and even at the sector or product level; and ii) using time-invariant regressors (such as distance and borders) can infer causation of the model with respect to predicted trade flows.[5] However, even in panel settings almost all the estimated models are still static, not dynamic.[6]

[4] In Anderson and van Wincoop (2003), the authors enforce $X_i = Y_i$ (balanced trade) and $\phi_{ij} = \phi_{ji}$ (symmetric trade costs), which leads to $P_i = \Pi_j$ as a unique solution to their system of market clearing conditions.

[5] At the same time, observations of individuals (countries in our case here) are not independent over time. This introduces spurious correlation and generates standard errors that are too small. That's why (at least with large $N$ and small $T$) we should cluster observations at the highest level of aggregation, i.e. the country-pair level since we observe bilateral flows.

[6] There is some work on dynamic panel models in international trade, for instance Harris

## 2.1 From OLS to NLS...

The general functional form of the empirical gravity model is given by

$$\mathbf{Y} = exp(\mathbf{X}\beta)\eta \tag{3}$$

where $\mathbf{X}$ is a vector of regressors with elements $x_{ij}$, $\beta$ is a vector of coefficients to be estimated, and $\eta$ is a vector of idiosyncratic error terms with random noise so that $E(\eta_{ij}|\mathbf{X}) = 1$.[7] Clearly, eq.3 can accomodate both eq.1 and eq.2. Traditional estimation of the gravity model log-linearizes the model and uses OLS to estimate the parameters of interest, $\beta$:

$$\mathbf{y} = \mathbf{X}\beta + \varepsilon \tag{4}$$

where $\mathbf{y} = ln(\mathbf{Y})$ and $\varepsilon = \eta exp(\mathbf{X}\beta)$. This linear transformation is often applied in empirical trade research, but it causes three issues. The first two issues are pointed at by Santos Silva and Tenreyro (2006), the third one is new, and constitutes the focus of this paper. i) The validity of the model depends on the orthogonality of $\eta$ with respect to the regressors - which is violated with heteroscedastic errors; ii) the estimation runs on only positive values, as $ln(0)$ is undefined, which leads to the exclusion of zero-trade flows in estimating bilateral trade; iii) the specified loss function that minimizes the objective implies how observations are weighted in estimating the parameters of interest. Let's elaborate a bit on each of these.

1. *Heteroscedasticity* One cause of heterogeneity is omitted variable bias. If the model is misspecified due to omitted variables or the exclusion of a (non)-linear combination of regressors which are correlated with the error term, this leads to a non-homogeneous pattern of the residuals of the model (see also robustness tests). When estimating eq.4, one assumes that there is no information in the noise, or equivalently $Y|\mathbf{X} \sim N(\cdot)$, where $N(\mu, \sigma)$ is the Normal distribution with a given mean $\mu = \mathbf{X}\beta$ and standard deviation $\sigma$ and $ln\eta \sim N(0, \sigma)$. However, when the error term is heteroscedastic, the variance of the error term is not constant ($\sigma_i \neq \sigma, \forall i$). Heteroscedasticity does not affect the unbiasedness of the OLS estimator, but it affects the efficiency, since it does not minimize the variance. It also affects the estimated $p$-values

and Matyas (2004), Harris, Kostenko, Matyas and Timol (2009) and Baltagi et al. (2014).

[7] Here $exp(\cdot)$ is the exponential function, $E(\cdot)$ stands for the expectations operator, and $\mathbf{X}$ is a vector of variables with appropriate length clear from the context.

and to a lesser extent confidence intervals and prediction intervals. The estimated standard errors are biased and the bias can go either way. If heteroscedasticity is moderate, we can transform the estimation equation or use robust methods to correct for the standard errors such as White's (1980) standard errors if we consider the estimation equation correctly specified. Also, Weighted Least Squares can be used to offset the heteroscedasticity problem and produce an efficient estimator. However, deriving the correct weighting matrix through iteration can be a tedious task (see below).

2. *Positive values*

   Running the estimation procedure only on positive values can bias the estimated coefficients, as zero trade flows can contain valuable information. Santos Silva and Tenreyro (2006) advocate a Poisson Pseudo Maximum Likelihood (PPML) estimator to deal with both heteroscedasticity and zero-trade flows simultaneously, and we will describe the PPML below. However, PPML does not directly account for structural zeros, as derived from models with fixed costs of exporting (see Melitz, 2003; Helpman et al., 2008) or models of Bertrand competition as in Eaton and Kortum (2002). Some patches have been proposed such as selection models with a 2-stage estimation procedure, where the first stage estimates the amount of zeros in the system, and the second stage subsequently estimates the bilaterel trade values. While Helpman et al. (2008) use a selection model that is derived from theory and accounts for firm heterogeneity, alternatives such as Zero Inflated models deliver biased results as the gravity model does not relate to count models, only the first-order conditions of the PPML coincide with those of the Poisson model.[8]

3. *Loss function*

   The specified loss function of any estimation procedure to be minimized affects how estimates for $\beta$ are obtained. The loss function used in OLS is the least squared errors function, which puts larger weight on larger observed errors. The objective to minimize is that of the Sum of

[8] Since the Helpman et al. (2008) procedure can only be performed on a small subset of countries (in order to be computationally able to use fixed effects), we do not present the results of those estimations here. In addition, since the count data alternatives of Negative Binomial and Zero Inflated models are biased, we do not go into further details on their estimation in this paper.

Squared Residuals (SSR)

$$\hat{\beta} = \arg\min_{\beta} SSR(\beta) = \arg\min_{\beta} \sum (\mathbf{y} - \mathbf{X}\beta)^2 \tag{5}$$

where $\hat{\beta}$ is the estimate of $\beta$ that minimizes the objective function. The first-order conditions are $\frac{\partial SSR(\beta)}{\partial \beta} = -2\mathbf{X'y} + 2\mathbf{X'X}\beta = 0$, or $\beta = (\mathbf{X'X})^{-\mathbf{1}}\mathbf{Xy}$, where $\mathbf{X'}$ is the transpose of $\mathbf{X}$.[9] There is a unique minimum if $\mathbf{X}$ has full rank. In the linear model and under normality of the error terms, the first-order conditions with respect to $\beta$ of the objective to be optimized under Least Squares and Maximum Likelihood (ML) coincide. In the linear model with normally distributed errors, the log-likelihood function $\ell(\beta|\mathbf{X}) = -\frac{n}{2}ln(2\pi) - \frac{n}{2}ln(\sigma^2) - \frac{1}{2\sigma^2}(\mathbf{y} - \mathbf{X}\beta)'(\mathbf{y} - \mathbf{X}\beta)$ is the objective function to be maximized. The first-order conditions write $\frac{\partial \ell}{\partial \beta} = (\mathbf{X'X})^{-\mathbf{1}}\mathbf{Xy} = \hat{\beta}_{OLS}$.

Instead of log-linearizing equation 3, we can estimate the coefficients from the model in the original exponential function. Using non-linear least squares (NLS) and optimizing SSR, the objective to estimate parameters of the model becomes:

$$\hat{\beta} = \arg\min_{\beta} SSR(\beta) = \arg\min_{\beta} \sum [\mathbf{Y} - exp(\mathbf{X}\beta)]^{\mathbf{2}} \tag{6}$$

with a system of first-order conditions:

$$\frac{\partial \hat{\beta}}{\partial \beta} = \sum [\mathbf{Y} - exp(\mathbf{X}\beta)] exp(\mathbf{X}\beta)\mathbf{X} = 0 \tag{7}$$

The first factor $(\mathbf{Y} - exp(\mathbf{X}\beta))$ is the model to be estimated, minimizing the errors, and the factor $exp(\mathbf{X}\beta)\mathbf{X}$ represents weights to each observation in minimizing those errors. Some authors (Frankel and Wei, 1993; Frankel, 1997b; Anderson and van Wincoop, 2003) have proposed using the NLS method in estimating the gravity equation: the function gives more weight to observations where $exp(\mathbf{X}\beta)$ is large, so that countries with larger $S_i$ and $M_j$ for instance, get more weight.[10] There is economic intuition for this weighting scheme, as countries with higher GDP tend to report more accurately and therefore get more weight in estimating the model. However, Santos Silva and Tenreyro (2006) state that i) this does not address

[9]From the second-order conditions, this is a minimum: $\frac{\partial^2 SSR(\beta)}{\partial \beta^2} = 2\mathbf{X'X} \geq 0$.

[10]This is not only GDP, but also other variables that might be used in this dimension such as the MTR, and also the distance function.

the heteroscedasticity problem and ii) these observations also have the most variance so more noise is added in the model, which brings down the efficiency of the estimation, leading to larger standard errors. Generally, the estimator could be fully efficient if one calculates the appropriate weights. This is largely the optimization method Anderson and van Wincoop (2003) propose in their gravity model as in eq.2. Its computational problem is that the weights have to be calculated together with the MTR for each country pair relative to all other pairs (general equilibrium), making this method very cumbersome. To deal with this issue, alternative, non-parametric methods have been proposed (e.g. Robinson, 1987). However, empirical researchers enjoy easily implementable methods and have continued to use OLS with a "twist", or alternatively the PPML method.

## 2.2 ... from NLS to FE...

The "twist" comes from not having to calculate the NLS procedure, but instead accounting for the non-linear MTR by using exporter and importer fixed effects in the estimation, which can be implemented in an OLS estimation and subsequently gives consistent estimates. Also Anderson and van Wincoop (2003) use the fixed effects approach in one of their procedures, and it is the standard procedure for most empirical researchers using the gravity model.[11]

One drawback of the easily implementable fixed effects approach is that the system of structural non-linear market clearing conditions of Anderson and van Wincoop (2003) is evaded, and general equilibrium comparative statics are not possible (Baier and Bergstrand, 2009). Additionally - and often more practically - using fixed effects renders identification of variables of interest in those dimensions impossible. One way to accommodate both problems is to approximate the non-linear system by a first-order Taylor approximation, as proposed by Baier and Bergstrand (2009). This allows to approximately account for MTR, while having the dimensions of identification free as the researcher sees fit. The model is then specified as follows:

$$x_{ij} = \beta_0 + \beta_1 y_i + \beta_2 y_j + \beta_3 lnDist^*_{ij} + \beta_4 Border^* + ... + \varepsilon_{ij} \tag{8}$$

where:
$lnDist^*_{ij} = lnDist_{ij} - \sum_j \theta_j lnDist_{ij} - \sum_i \theta_i lnDist_{ij} + \sum_i \sum_j \theta_i \theta_j lnDist_{ij}$ is a

[11]The interested reader can find a version of the NLS approach in Anderson and van Wincoop (2003) on the companion website of Head and Mayer (2014), where the authors call it SILS, or Structural Iterated Least Squares: https://sites.google.com/site/hiegravity/stata-programs.

first-order Taylor approximation of the non-linear $lnDist_{ij}$ and $\theta_i$ is country $i$'s GDP share in world GDP. Note that the Taylor approximation has to be performed for each bilateral variable of the distance function separately.[12] Below, we will present results on both the fixed effects approach and the Baier and Bergstrand method in this paper which both use the OLS procedure, instead of the NLS method, due to their practical use and thus easing comparison across most used estimation methods.

## 2.3 ... and from FE to PPML and GPML

Another approach is to simplify the first-order conditions in order to ease estimation and so to approximate the objective, hence the name "pseudo" (or quasi). Since the first-order conditions determine the values of the maximum/minimum, one can start from there, rather than from the objective function to be optimized.

Santos Silva and Tenreyro (2006) propose to replace the weighting factor of the NLS by an assumption on its behavior. Here we set $exp(\mathbf{X}\beta)\mathbf{X} \equiv \mathbf{X}$, assuming that weights are proportional to the value of their observations.[13] This satisfies the Poisson model assumption of the conditional mean being proportional to the conditional variance. This is the only assumption taken from the Poisson model, but it happens to coincide with the first-order conditions of the Poisson ML. This implies that there are no distributional assumptions (the dependent variable does not have to be Poisson distributed) and there is no relationship to other count data models. If this assumption does not hold in reality however, standard errors are too small and significance is overestimated. The Poisson model is given by:

$$Pr(\mathbf{Y} = k|\mathbf{x}) = \frac{exp(-\lambda)\lambda^k}{k!} \qquad for\ \mathbf{Y} \geq 0 \tag{9}$$

$$\tag{10}$$

where $\lambda = exp(\mathbf{X}\beta)$. The ML estimation is given by:

$$\hat{\beta} = \arg\max_{\beta} \sum[-exp(\mathbf{X}\beta) + \mathbf{Y}(\mathbf{X}\beta) - ln(\mathbf{Y}!)] \tag{11}$$

with first-order conditions:

[12]To evade potential endogeneity and following Baier and Bergstrand (2009), we use simple averages for $\theta_i \equiv 1/N$, where $N$ is the number of countries in the sample.

[13]Note that weights are attached to the residuals of country pairs.

$$\frac{\partial \hat{\beta}}{\partial \beta} = \sum [\mathbf{Y} - exp(\mathbf{X}\beta)]\mathbf{X} = 0 \tag{12}$$

Notice the difference with eq.7: each observation is given the same weight now, $x_i$, rather than emphasizing those for which $exp(\mathbf{X}\beta)$ is large as in NLS. These are not the real first-order conditions of the log likelihood function of the original problem in eq.7, and therefore are "pseudo", but they are easier to calculate as the second factor is simplified. Furthermore, Gourieroux et al. (1984) show that these estimators are consistent and asymptotically normal. They are not proven to be efficient, but without *ex ante* info about the pattern of heteroskedasticity it is not unnatural to give equal weights to observations. Note that the starting point of the analysis is NLS. Therefore, no distributional assumptions are made on the model parameters, nor is there any other relationship to other count models such as Negative Binomial and Zero-Inflated models.

Another PML is the Gamma PML given by:

$$Pr(\mathbf{Y}) = \left(\frac{\mathbf{Y}}{Z}\right)^{k-1} \frac{exp\left(\frac{-\mathbf{Y}}{z}\right)}{z\Gamma(k)} \qquad for\ \mathbf{Y} \geq 0 \tag{13}$$

where $z > 0$ is the scale parameter, $k$ is a slope parameter and $\Gamma(.)$ is the Gamma distribution. In the PPML, we assumed equidispersion, so that the variance of the model is proportional to the mean: $V(\mathbf{Y}|\mathbf{x}) \propto E(\mathbf{Y}|\mathbf{x})$. In the GPML, we assume that the dispersion grows as the observations grow, following $V(\mathbf{Y}|\mathbf{x}) \propto E(\mathbf{Y}|\mathbf{x})^2$, so that the standard deviation is proportional to the mean. This leads again to a higher weighting of large deviations as in OLS and NLS. Both PPML and GPML return consistent estimates, and depending on the variance proportionality, one is more efficient. The first-order conditions are now given by:

$$\frac{\partial \hat{\beta}}{\partial \beta} = \sum (\mathbf{Y} - exp(\mathbf{X}\beta))exp(-\mathbf{X}\beta)\mathbf{X} = 0 \tag{14}$$

which is very close to the first-order conditions of NLS.[14] Under log-normality of the error term, GPML and OLS or NLS give very similar results (Head and

[14] See also Head and Mayer (2014), who compare first-order conditions of OLS, Poisson true ML and Gamma true ML. Their takeaway is that GPML resembles the first-order conditions of OLS, where GPML looks at percent deviations of the errors versus OLS that looks at log deviations. Here we compare the NLS to the GPML directly. Taking logs of the NLS leads us to the OLS comparison in Head and Mayer (2014).

Mayer, 2014), while the PPML and GPML only converge under large enough sample size, given the asymptotic consistency of both estimators. Table 1 compares our estimation procedures and their relationship to dealing with heteroscedasticity, zeros and the weighting scheme in minizing the loss function. No two methods are the same compared across these characteristics, hence advocating the use of a combined estimation recipe.

Table 1: Characteristics estimation procedures

| | OLS/ML | LSDV/BB | PPML | GPML |
|---|---|---|---|---|
| Heteroscedasticity | Biased standard errors | Unbiased | Unbiased | Unbiased |
| Zeros | Dropped | Dropped | In | In |
| Deviations/weight | More on large | More on large | Equal weight | More on small |

# 3 Data and Empirical Approach

In order to compare the impact of various estimation techniques on the distance and border effects in international trade, we use an extensive data set that approximately covers global trade. We use the CEPII/BACI database (Gaulier and Zignago, 2010) for creating bilateral trade flows at the country level.[15] This is a cleaned and "mirrored"[16] version of the UN Comtrade database that records product-level trade for almost all countries in the world. We aggregate the product level trade flows to yearly country level trade flows, drop some accounting aggregates and make some countries that splitted or merged during the period consistent over time. We use geographical indicators such as distance, adjacency, colonial ties and continent from the GeoDist database at CEPII as presented by Mayer and Zignago (2011). We use GDP from the World Bank (2012). We use RTA dummies from Jose De Sousa's (2014) website,[17] and we collect WTO accession dates from the WTO website to create a duration database of WTO membership.[18] The resulting database covers the years from 1998 to 2011, has 208 countries or economic entities and 602,784 bilateral trade flows are recorded.

We estimate the gravity specification given by eq.2 using different estimation specifications. We apply both linear and non-linear methods as

[15] http://www.cepii.com/anglaisgraph/bdd/baci.htm

[16] In order to mitigate the potential problem of non-reporting in the data, Gaulier and Zignago (2010) fill in missing export values with the transpose of the trade matrix, leading to an increase of around 10% observed values in the dataset.

[17] http://jdesousa.univ.free.fr/data.htm

[18] http//www.wto.org

presented in Section 2. As is common in the gravity literature, we assume that the distance function is linear in observables: $ln\phi_{ij} = lnDist_{ij} + Adjacency + Language + Colony + RTA$, with the variables labeled as follows: $Dist_{ij}$ is the great circle distance in kilometers between the most populated cities/agglomerations in $i$ and $j$; $Adjacency$ is a dummy variable that takes value 1 if $i$ and $j$ share a common country border and 0 otherwise; $Language$ is a dummy that takes value 1 if both countries share an official language; $Colony$ is a dummy variable that takes value 1 if $i$ and $j$ ever shared a colonial tie; $RTA$ is a dummy that takes value 1 if both countries share any regional trade agreement. Finally, $WTO_i$ and $WTO_j$ represent WTO membership of the exporter and importer respectively. In this paper, we focus on the identification and estimation of distance and border effects, while controlling for other observable bilateral and time invariant effects that are part of the distance function. In doing so, we estimate a series of cross-sectional models to trace the evolution of coefficients over time.[19]

# 4 Results

## 4.1 Comparison of the distance effect across estimation methods

We first analyze the sensitivity of the distance effect to the applied estimation techniques. To that end, we estimate a series of cross-section gravity models, one for each year between 1998 and 2011 and plot the results in Figure 1.

First, all methods confirm the significantly negative distance effect. We also confirm that the estimated coefficients are fairly stable over time. The difference of the coefficients in 1998 and 2011 is statistically insignificant at the 1% level in all the estimation methods. Given the short time span of our data set, we cannot interpret this as evidence that the distance coefficient is stable over time. A longer time span is required for such analysis. Rather, our results indicate that all estimation methods lead to consistent findings regarding the distance effect across years.

Secondly, there is, however, substantial variation in the magnitude of this distance effect across estimation procedures: while the linear procedures OLS, LSDV and BB give results that are close to each other and around -1.1 to -1.2, the estimated coefficient in PPML is much closer to zero, around -0.5 (in line with the findings of Santos Silva and Tenreyro (2006) and subsequent

[19] As stated before, we do not consider dynamic panels in our setup, and so do not estimate panel models. We do robustness checks of the residuals of a static panel setting in our robustness section.)

PPML estimations). The estimated coefficient in GPML in absolute value is much larger, i.e. around -1.7. We also see that the fixed effects estimation (LSDV) and the Baier and Bergstrand (2009) methods almost completely line up, in line with the idea that the first-order Taylor approximation of the MTR is a good approximation, which can be used when one needs identification in the country dimension. Hence, we want to advocate the use of the Baier and Bergstrand (2009) method as a valid alternative to the LSDV method, with additional benefits of speed of computation and additional freedom in dimensions of identification, while it is still being under-used at the moment.[20]

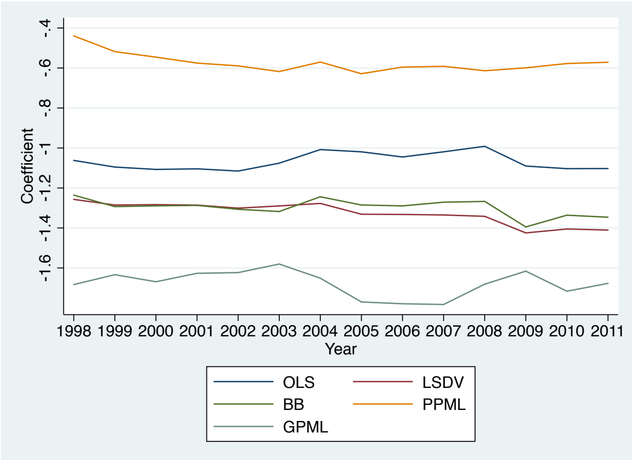
Comparing the estimated size of the distance coefficients, we obtain the following ranking: $GPML > LSDV/BB > PPML$. This is in line with the results by Egger and Staub (2015) who obtain the same ranking of methods for their first quartile of distance coefficients (distance becomes insignificant for methods in other quartiles). This also shows that simulations of structural gravity models as in Head and Mayer (2014) and Egger and Staub (2015), are not good predictors for actual coefficients. The data generating process of the simulations only models the variance function. It means that different estimates of the coefficients do not come from misspecification of the variance function. The simulation approach is hence complementary to our estimation approach in order to compare and assess various estimation techniques.

## 4.2 Border Effects by Continents

Next, we compare the border effect on international trade using various estimation methods. We focus on the border effect by continent, given the global scale of our trade data. We want to test whether intra-continental trade is larger than trade between continents, and whether this border effect is different for each continent. We use dummies for within versus between continents trade: each continent dummy equals 1 if the observed trade flow is an intra-continental one, and zero otherwise. The baseline model is returning the estimation for inter-continental trade, and the dummies adjust for intra-continental trade for each of the five continents we consider in this paper, i.e. Europe, the Americas, Africa, Asia and the Pacific. Note that we control for adjacency when estimating the border effects: this captures the idea that intra-continental trade is larger for countries that also share a common border.

[20] We also ran the 5 specifications on the original data as in Anderson and van Wincoop (2003) and find the same patterns as in our estimations, albeit with a smaller deviation of PPML with respect to the other estimation methods.

Figure 1: Estimation of the distance coefficient cross methods




*Note:* Multiple cross-section estimates across estimation methods. The estimation equation is given by eq.2, controlling for the observable variables in the distance function: ln(GDP) exporter, ln(GDP importer, ln(distance), adjacency, common official language, colonial ties and RTAs. We also control for WTO membership status for the exporter and importer. Exporter and importer fixed effects are used in the LSDV, PPML and GPML models. The coefficients for distance are all significant at the 0,1% level across all years and estimation methods. Standard errors are robust and clustered at the country-pair level.

Table 2 shows the estimated parameters for inter- versus intra-continental trade flows over the pooled period 1998-2011. Note that we observe that the distance coefficient is in line with the cross-sectional estimates as before. Moreover, we see that the adjacency effect is positive, tough insignificant in the BB setting. Furthermore, all the control variables have the expected signs and sizes.

We obtain interesting insights into the border effect by continents. We first focus on the LSDV specification. After correcting for multilateral trade resistance, GDP and bilateral observables, we see that some continents trade relatively more globally than intra-continentally. This is the case for Europe and Asia, with Europe being the most open continent. In other words, these continents are globally more connected, a finding we see in reality. Note that this is not at odds with the well-known fact that e.g. intra-European trade exceeds extra-European trade since it is the effect after controlling for the regular gravity explanations. The Pacific is the most "closed" continent, in the sense that it trades relatively more inside the Pacific than across the globe. When we turn to other estimation methods, results change dramatically depending on the procedure used. Hence contrary to our findings for the distance effect, the border effect appears to be much more sensitive to the selected estimation methody. In the biased OLS setting (not correcting for MTR), most results are insignificant, and Asia is trading relatively more inside Asia. Similar to our findings for the distance effect, also now LSDV and BB line up nicely. Based on both methods, the Americas are more open, while Europe is not. For the non-linear methods of PPML and GPML, we find contradictory coefficients for Europe. It is also interesting to note that this continental border effect is in contrast with the regional flows as in Anderson and van Wincoop (2003). In their findings, the border effect is always negative. Apparently things change in the global context.

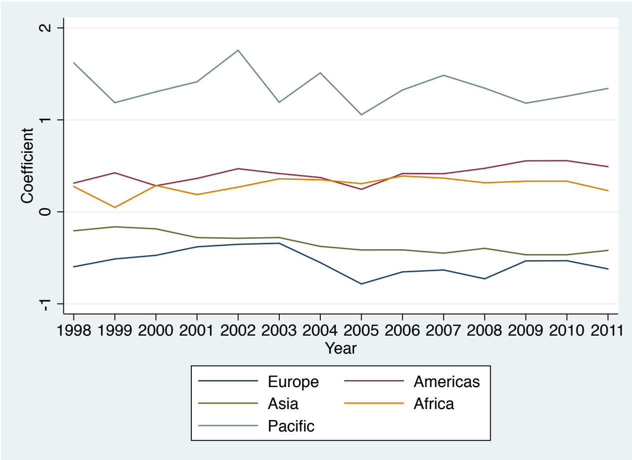
Finally, Figure 2 shows the evolution of the estimated coefficients for the intra-continental predicted trade over the years 1998 to 2011, where we have used the LSDV method as representation.

Table 2: Borders by continents

| | (1)<br>OLS | (2)<br>LSDV | (3)<br>BB | (4)<br>PPML | (5)<br>GPML |
|---|---|---|---|---|---|
| lnGDP(exporter) | 1.092*** | | 1.099*** | | |
| | (0.0198) | | (0.0195) | | |
| lnGDP(importer) | 0.857*** | | 0.864*** | | |
| | (0.0299) | | (0.0298) | | |
| ln(distance) | -1.023*** | -1.298*** | -1.399*** | -0.494*** | -1.385*** |
| | (0.0992) | (0.0848) | (0.109) | (0.0888) | (0.0227) |
| Adjacency | 0.912** | 0.777* | 0.508 | 0.415*** | 1.029*** |
| | (0.221) | (0.293) | (0.241) | (0.110) | (0.0646) |
| Common Language | 0.700*** | 0.702*** | 0.568*** | 0.0751 | 0.654*** |
| | (0.0508) | (0.0625) | (0.0478) | (0.0619) | (0.0350) |
| Colonial Ties | 1.015*** | 0.926*** | 1.026*** | 0.403* | 1.408*** |
| | (0.128) | (0.0573) | (0.135) | (0.193) | (0.0621) |
| RTA | 0.851* | 0.711* | 0.833* | 0.477*** | 0.486*** |
| | (0.243) | (0.206) | (0.233) | (0.0587) | (0.0273) |
| WTO exporter | 0.561** | | 0.528*** | | |
| | (0.110) | | (0.0756) | | |
| WTO importer | 0.289* | | 0.271** | | |
| | (0.0774) | | (0.0420) | | |
| Europe | 0.006 | -0.506* | -0.0539 | 0.440*** | -0.922*** |
| | (0.197) | (0.130) | (0.131) | (0.119) | (0.0478) |
| Americas | 0.343 | 0.410 | -0.494* | 0.675*** | 0.300*** |
| | (0.198) | (0.194) | (0.174) | (0.122) | (0.0780) |
| Asia | 0.240** | -0.350** | -0.237* | -0.100 | -0.121** |
| | (0.0498) | (0.0629) | (0.0904) | (0.151) | (0.0396) |
| Africa | -0.0309 | 0.295* | -0.0793 | 0.669*** | 0.430*** |
| | (0.213) | (0.0904) | (0.147) | (0.0545) | (0.0569) |
| Pacific | 2.495*** | 1.333** | 0.923* | 1.110*** | 1.915*** |
| | (0.237) | (0.202) | (0.270) | (0.173) | (0.191) |
| Constant | -31.28*** | 5.953** | -40.30*** | 11.85*** | 10.73*** |
| | (1.951) | (0.894) | (1.096) | (1.017) | (0.332) |
| adj. $R^2$ | 0.671 | 0.735 | 0.674 | | |
| Country FE | No | Yes | No | Yes | Yes |
| BIC | 1232841.3 | 1324651.3 | 1230787.3 | 6.40034e+10 | 8388126.5 |
| N | 283586 | 319276 | 283586 | 532029 | 532029 |

*Notes:* Model specifications are (1) OLS, (2) Least Squares Dummy Variable, (3) Baier and Bergstrand (2009) Taylor approximation method, (4) Poisson Pseudo-Maximum Likelihood and (5) Gamma Pseudo-Maximum Likelihood. In model (3), all the bilateral variables are first-order Taylor approximated. Country FE depict exporter and importer fixed effects. Adjusted $R^2$ and/or the Bayesian Information Criterion (BIC) are given where possible. Robust and clustered standard errors are between parenthesis, clustered at the continent level. Significance levels: 5% (*), 1% (**) and 0,1%(***).

Figure 2: Evolution of the dummy estimates of continents over time




*Note:* Multiple cross-section estimates across estimation methods. The estimation equation is given by eq.2, controlling for the observable variables in the distance function: ln(GDP) exporter, ln(GDP importer, ln(distance), adjacency, common official language, colonial ties and RTAs. We also control for WTO membership status for the exporter and importer. Exporter and importer fixed effects are used in the LSDV, PPML and GPML models. The coefficients continents dummies are all significant at the 0,1% level across all years and estimation methods. Standard errors are robust and clustered at the country-pair level.

# 5 Robustness Checks

We check for several potential sources of misspecification. First, following the comments in Head and Mayer (2014), we check convergence of the different estimators under different sample sizes. Since the estimated coefficients based on OLS and GPML are close, while the PPML coefficients are lower, Head and Mayer (2014) ague that this might be due to misspecification of the model if the sample size is big enough. We draw random subsamples from our data, of 75, 50 and 25% respectively. Figure 3 shows the estimated coefficients for distance over time by estimation method. Across all sample sizes, PPML consistently delivers lower estimates for distance, and the ranking of the other estimates remains the same. In this setting, we cannot recreate the convergence of all estimates as proposed by Head and Mayer (2014) in their simulation setting, who state that, if sample size is large enough, and absent of misspecification, the estimates of OLS, PPML and GPML should coincide.

Secondly, we draw the residual versus fitted values plot for the LSDV method in Figure 4.[21] Since we deal with so many observations, traditional scatter plots are not very efficient. Instead, we propose to use a local polyno-

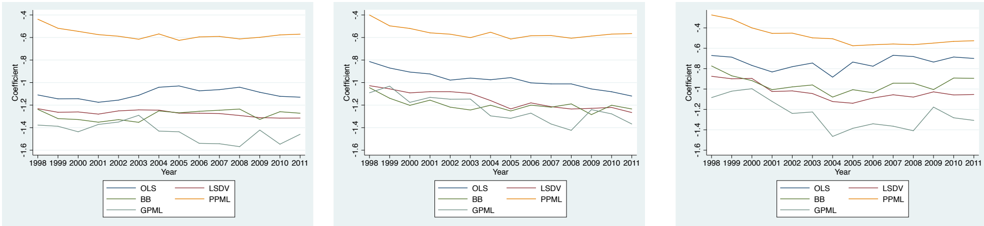
[21] We also run the residual plots for the other estimation methods. Patterns are similar.

mial smoother plot to represent the underlying scatters. The local polynomial has two added advantages for residual analysis: i) the polynomial smoother is an indicator for potential non-linearities or other patterns in the residuals, and ii) the 95% confidence intervals of the smoother are a nice way to depict potential heteroscedasticity: if there are irregularities in the width of the confidence intervals, this indicates non-constant variance of the error terms. We rerun the original specification of Section 4.1, but now for the year 2005 only, to evade potential auto-correlation.[22] There is i) a clear structure in the residuals that resembles a third-degree polynomial and ii) potential heteroscedasticity could show up in the left tail of the distribution of the fitted values. We are confident that heteroscedasticity is not affecting our results in any major way (we also check the pattern of heteroscedasticity using PPML, giving almost identical results), and focus on the non-linear pattern of the residuals. To see where the structure comes from, we plot the residuals against each regressor. The residual plots of all regressors look fine, except the residual plot against distance uncovers the same structure as the residuals versus fitted plot. We should therefore rerun the model with a polynomial approximation for distance: it might be the case that the linear specification of the distance function is just not correct, and we just assumed it following the bulk of the gravity literature. Also, given our global sample, the effect of distance might not be well approximated by a linear relationship, where this might be more appropriate for local sub samples such as Europe. We rerun the model with a second and third order polynomial for distance, which in effect lowers the pattern in the residual plots, but completely disrupts all of the gravity estimates. We also check if there is a non-linear pattern *inside* continents, so to see that the non-linearities do not come from the global sample. We see the same residual pattern recurring for each isolated subsample. We therefore prefer to keep with the main stream of the literature and use the log-linear distance function. However, the correct specification of the distance function is an interesting topic in its own.

Finally, we check for potential multicollinearity between distance and the border effect, since this might also drive misspecification. We find VIF test results for all variables in the model (excluding the fixed effects) between 1 and 1.5, where VIF values of above 5 or 6 might indicate potential multicollinearity problems. We therefore also reject this potential problem.

[22] We also ran the model on the pooled version and the panel version, all giving very similar results.

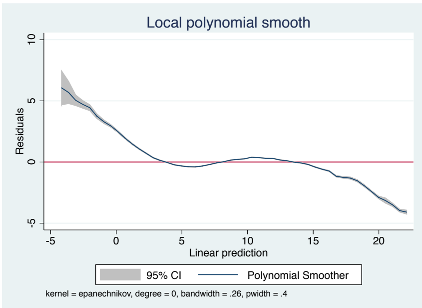
Figure 3: Subsample estimates for distance




(a) Subsample 75% (b) Subsample 50% (c) Subsample 25%

*Note:* Multiple cross-section estimates across estimation methods. Exporter and importer fixed effects are used in all models except OLS and BB. The coefficients for distance are all significant at the 0,1% level across all years and estimation methods. Standard errors are robust and clustered at the country-pair level.

Figure 4: Residual versus fitted plots




*Note:*A local polynomial smoother represents the underlying scatter plot. The gray band indicates the 95% confidence interval, the $y = 0$ line is indicated in red.

# 6 Conclusion

This paper compared the distance and border effects on global bilateral trade flows using various econometric techniques. We clearly confirm the negative distance effect, but its magnitude appears to vary across estimation methods. The distance effect is also constant over time in all methods. The observed variety is in line with the theoretical expectations. Our evidence for the border effect by continents is more ambiguous. Generally speaking, we can confirm that intracontinental trade exceeds intercontinental trade, contolling for various other trade explanations. However, this general finding breaks down using some estimation methods. These results call for caution when including distance and border effects in future empirical trade studies. Our results do not favour particular estimation methods, as they all have their merits and shortcomings. Rather, researchers should be aware of the impact of the selected method on the magniture of the distance effect and on the magnitude, direction and significance of the border effect.

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