Gravity, log of gravity and the "distance puzzle"*

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Abstract

In the international trade literature, a non intuitive result appears in the traditional log linear estimates of gravity equations: the absolute value of the elasticity of trade with respect to bilateral distance is estimated to have drastically increased over time, whereas its non-decrease is refered to as the "distance puzzle" or "missing globalization puzzle". In order to analyse the sensitivity of this "puzzle" to the econometric specification, theoretical gravity equations are estimated for each year over 1948-2006 using the traditional log linear least squares and several non-linear estimators, including Poisson Pseudo-Maximum Likelihood (PPML), following Santos Silva and Tenreyro (2006).

There are four main results. First, the elasticity of trade with respect to bilateral distance is quasi flat over time. However, it has not declined in absolute value, since 1970, contrary to the finding by Coe, Subramanian and Tamirisa (2007). Second, the increasing gap between traditional log linear and PPML estimates of the distance coefficient is mainly driven by the increasing heterogeneity of trade flows while dropping zero flows has very limited impact on the estimated elasticity. Third, controlling for free trade agreements alter the overall diagnosis only marginaly. Fourth, the most efficient estimator seems to be between non linear least squares and PPML.

JEL Codes: F10, F15, C13, C21, C23

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1 Introduction

Despite globalization, the role of distance in shaping world trade across trading partners does not seem to have diminished over time. Indeed, the elasticity of international trade with respect to distance is generally found to be stable, or even increasing in absolute value, a stylized fact framed as the "distance puzzle" by Buch, Kleinert and Toubal (2004) or the "missing globalization puzzle" by Coe, Subramanian and Tamirisa (2007). The latter argue that taking into account the zero trade flows using a non-linear estimator of gravity equation in levels, rather than the common practice of using a linear estimator based on the logarithm of flows, enables to resolve the puzzle: they find that the (absolute value of the) elasticity of trade to distance significantly decreased from roughly 0.5 in 1975 to 0.3 in 2000. In order to simplify the text, the current paper will always discuss the evolutions through time of various elasticities in absolute values since there is no ambiguity about their sign.

It is not clear in the first place why a stable elasticity would represent a puzzle. The rather vague presumption seems to be that the expansion of world trade associated with a fall in distance-related trade costs means that distance is having a lesser impact on the structure of trade. Noting that the elasticity of trade to distance is the product of the elasticity of trade to trade costs and of the elasticity of trade costs to distance, there are at least three reasons to be sceptical about this presumption. First, in a careful formalisation of gravity equation, Anderson and van Wincoop (2003) show that trade is actually a homogenous function of degree zero in trade costs due to the multilateral resistance terms. Therefore, even though a general decrease in tariffs spurs international relative to domestic trade, a uniform decrease in transport costs might not lead to increased trade.

Second, an overall decrease in transport costs does not necessarily imply a lower distance elasticity of trade. For example, if trade costs, $\tau_{ijt}$, between countries $i$ and $j$ in year $t$ is a function of the bilateral distance $d_{ij}$ such as $a_t \cdot d_{ij}^{\gamma_t}$, distance can become irrelevant over time through either a decrease in $a_t$ or in $\gamma_t$, but a uniform decrease in distance-related transport costs would be associated with a fall in $a_t$ with no implication for the elasticity $\gamma_t$ (Buch et al.

\[\text{Indeed, according to the meta-analysis of 103 papers carried out by Disdier and Head (2008), trade decreases with distance by roughly the same amount today than thirty years ago, with an increase in the (absolute value of) the elasticity of trade with respect to distance since the late eighties.}\]
In fact, the elasticity of bilateral trade costs to distance measures a relative rather than level effect. That is, a decrease through time in the elasticity of trade costs to distance means that trade costs decrease relatively more or increase relatively less for longer than for shorter distances: \( \Delta \gamma_t = \left( \frac{\Delta \tau_{ijt}}{\tau_{ijt}} - \frac{\Delta \tau_{ikt}}{\tau_{ikt}} \right) / \left( \log d_{ij} - \log d_{ik} \right) \) (Boulhol and de Serres, 2008). None of these two possibilities seem to find a clear empirical support\(^2\).

Third, the elasticity of trade with respect to trade costs might rather have increased. In usual theoretical model (e.g. Anderson and van Wincoop), this elasticity is positively related to the elasticity of substitution between varieties, and it is often believed that globalization is associated with an increase in the degree of substitutability between varieties, thereby inducing an increase in the elasticity of trade to distance.

All in all, this idea that a non-decreasing elasticity represents a puzzle seems somehow related to the "world-is-getting-flatter" hypothesis that Leamer (2007) questions, pointing out that trade remains mostly a neighbourhood phenomenon. However, beyond the semantical debate about whether we are facing a puzzle, the analysis of how the elasticity of trade to bilateral distance has evolved in past decades is of course interesting in its own right. In that respect, the most important contribution of Coe et al. consists in highlighting how a nonlinear estimation of gravity equations that are specified in levels could lead to a radically different conclusion than that obtained from a linear estimation of the same equations in log.

Nevertheless, there is scope for improving the analysis of the "distance puzzle". Santos Silva and Tenreyro (2006) show that heteroskedasticity in trade levels is such that it biases the main parameters of interests in the gravity equation, including the distance elasticity. They propose a Poisson Pseudo-Maximum Likelihood (PPML) estimator and argue that it is likely to be much more efficient than the non-linear least squares (NLS) estimator. However, their study covers a single year (1990) only. With this in mind, the Coe et al.'s assessment could be revisited in several directions. First, their main result is established using NLS. They do conduct a robustness check using a Pseudo-Maximum Likelihood, but it is not totally clear which one they use. Second, their sample is restricted to 73 countries and start in 1975 only. Third,

\(^2\)Even the presumption that transport costs have declined relative to the price of the goods being transported, i.e. mostly manufacturing goods, is far from obvious according to recent studies that provide direct measures of costs over different routes and modes of transportation (Hummels, 2007; Golub and Tomasik, 2008).
their bilateral dependent variable is the sum of exports and imports, which is considered the
"silver medal mistake" by Baldwin and Taglioni (2006). Fourth, the data they use for Free
Trade Agreements (FTAs) are not well defined. However, because FTAs have mainly promoted
regional integration, they are de facto inversely related to distance. Therefore, not properly
controlling for FTAs might provide an inaccurate picture of the evolutions at stake. The
current paper addresses methodological issues related to the estimation of gravity equations
and analyses carefully the sensitivity of the results to the treatment of FTAs. The main results
are the following.

Methodology. The Poisson hypothesis cannot be rejected in any (post-1952) year. Second,
the most efficient estimator might, however, be in between NLS and PPML, i.e. consistent
with the variance of trade flows being about proportional to the square root of the conditional
mean. Third, there remains a serious puzzle / inconsistency with respect to the whole method-
ology based on the class of PML estimators relying on the proportionality of the conditional
variance to a power of the conditional mean. Indeed, the gamma-PML estimates which should
be consistent, albeit inefficient, under the proportionality assumption is significantly different
from the Poisson-PML ones, being actually closer to the biased OLS of the log specification.
Fourth, there are some limitations on the type of estimators one can used. For example, the
negative binomial PML estimator is not appropriate because it artificially depends on the unit
chosen to measure the value of trade flows. This limitation also applies to some of the tests
suggested by Santos Silva and Tenreyro that should therefore be amended. Fifth, weighted least
squares of the log specification that uses observed flows as weights leads to similar estimates
as PPML on the level specification. Sixth, given the high level of serial correlation of trade
flows, a "first-differencing" type of data transformation ought to be preferred over a "within"
type transformation.

Empirics. Based on PPML and without controlling for FTAs, the distance elasticity of
trade has been broadly stable within a (minus) 0.60-0.75 range since 1950, even though it has
increased from the bottom to the top of that range since the late eighties. The gap between
this PPML elasticity and that estimated based on the log specification has steadily increased
over time; this trend is shown to be related to the growing heterogeneity of trade flows since the
seventies. This result is consistent with the explanation proposed by Santos Silva and Tenreyro for the bias of the log specification that they highlight for one single year. Taking into account the influence of FTAs to analyse the "distance puzzle" raises some intricate issues, as shown by Baier and Bergstrand (2007). However, the influence of FTAs appears somehow limited. In all carried out robustness checks, including panel estimates, the inclusion of FTAs does alter the diagnosis of a broad stability of the elasticity, although within a lower 0.50-0.65 range, still leading to a clear rejection of the rising elasticity obtained in usual log specification. Compared with Baier and Bergstrand, all parameters related to determinants of trade costs are allowed to vary over time, using a panel specification. The effect of FTAs is then around 0.3 with few variations over time, which means that two countries which share an agreement trade about 35% more than two countries which do not. The other most notable change relates to the effect of colonial linkages which is estimated to have basically vanished over time from a very high level in the fifties. However, the main difference compared with the situation where FTAs are excluded refers to an estimated increase between 1970 and 1995, which might be more in line with the results of Coe et al.

The rest of the paper is organised as follows. Section 2 discusses the main empirical issues when estimating gravity equations to analyse the "distance puzzle". Section 3 presents the data and specifications, while Section 4 is devoted to the cross section results obtained when FTAs are not included in the list of explanatory variables. Section 5 focuses on the impact of accounting for FTAs, in both cross section and panel estimates. Section 6 briefly discusses the estimated trends in the other determinants of trade than distance, Section 7 concludes.

2 The empirics of gravity equations

2.1 Microfoundations of gravity equations

There have been major advances in the formalisation of bilateral trade flows since the mid-nineties, as the traditional specifications of gravity equations were largely a-theoretic. In an effort to lay out the microfoundations of gravity equations, Deardoff (1998) shows that not only the bilateral distance between two countries, but also their geographical positions relative to all
other countries, matter for the level of bilateral trade flows. Consequently, Wei (1996) and many researchers since then have added a remoteness indicator to the list of explanatory variables, approximating remoteness by the weighted average of distances from all trading partners, with trading partners’ GDP as the weights.

The decisive methodological contribution of Anderson and van Wincoop (2003) consists in deriving an operational gravity model in which "multilateral resistance", that depends on all bilateral trade costs, is a determinant of bilateral trade flows. The absence of the multilateral resistance terms in traditional gravity estimations leads to biased estimates of some key parameters, such as the effect of a common border, as these missing terms are correlated to traditional explanatory variables. In Anderson and van Wincoop, the nominal value of exports from $i$ to $j$, $x_{ij}$, depends on the total income, $Y_i$, of each country, world income, $Y_W$, the bilateral trade cost, $\tau_{ij}$, the elasticity of substitution between all goods, $\sigma$, and the multilateral resistance, $P_i$, of each country, according to:

$$x_{ij} = \frac{Y_i Y_j}{Y_W} \left( \frac{\tau_{ij} P_i P_j}{P_i P_j} \right)^{1-\sigma}$$  \hspace{1cm} (1)

where the $P_i$ terms are related to each other according to:

$$P_j^{1-\sigma} = \sum_i P_i^{\sigma-1} \tau_{ij}^{1-\sigma} \frac{Y_i}{Y_W} \quad \forall j$$  \hspace{1cm} (2)

From this specification, Anderson and van Wincoop draw two implications that are especially relevant for the current study. First, the remoteness variables as commonly approximated are disconnected from the theory. Second, given a specification of trade costs, replacing the multilateral resistance terms by country fixed effect leads to consistent estimates of the gravity equation (1) in log form by ordinary least squares. Even though this fixed-effect estimator is less efficient than the nonlinear least-squares estimator that uses information on the full structure of the model, i.e. (1) and (2), it has the huge advantage of simplicity.

2.2 Log of gravity: consistency, efficiency and competing estimators

In turn, Santos Silva and Tenreyro (2006) highlight another typical bias of gravity equations that are estimated in log form, on top of the sample selection bias that results from the implicit
exclusion of zero trade flows. Starting from a stochastic version of the gravity equation in levels such as (1), the log-linear specification generates biases as a consequence of Jensen’s inequality ($E(\ln x) \neq \ln E(x)$), because the expected value of the logarithm of trade flows depends on higher moments, including the variance. Formally,

$$x_{ij} = \exp(Z_{ij}\beta)u_{ij}, \quad E(u|Z) = 1$$ (3)

$$\text{Var}(u|Z) \neq 0 \Rightarrow E(\ln u|Z) \neq 0$$ (4)

where the Z explanatory variables include importer and exporter fixed effects, (log of) bilateral distances and other control variables influencing the trade costs. Since it is very likely that the variance of the residuals depends on explanatory variables such as importer and exporter characteristics (that cover observed ones like GDP), estimators using the log specification bias the parameters of interest.\footnote{Indeed, in that case, the conditional variance depends on Z, and the bias is not limited to the constant (see the last paragraph of this sub-section).} Actually, the magnitude of the bias depends on the structure of the variance of the residuals, and heteroskedasticity in the trade level equation could become a serious concern for inferences one can make from estimates based on the log-linear specification.

This problem can be overcome by estimating the level equation (3) using a nonlinear estimator. Santos Silva and Tenreyro (2006) propose the Poisson Pseudo-Maximum Likelihood estimator (PPML), assuming that the variance of $x$ is proportional to its conditional expectancy, which is likely to make this estimator more efficient than the simple non-linear least squares (NLS). Indeed, it is unrealistic to assume that the variance of estimated trade flows is the same for small/remote and large/central countries, as implicit with NLS. Besides, whatever the specific choice of a non-linear estimator, a level specification allows for the inclusion of zero trade flows, even though Santos Silva and Tenreyro show ex post, i.e. based on the empirical analysis, that including the zero flows does not make a material difference.

A natural extension consists in assuming other distributions than Poisson. This would include Gamma distribution according to which the variance is proportional to the square of the conditional mean, and more generally any power of it. Some authors have also used the negative binomial distribution (e.g. Head, Mayer and Ries, 2008), but this is inappropriate
when applied to trade flows because such an estimator artificially depends on the choice of the nominal unit of the dependent variable. Indeed, the assumption of the negative binomial distribution is:

\[ \text{Var}(x|Z) = E(x|Z) + \eta^2 E^2(x|Z) \]  

(5)

where \( \eta \) is a scalar to be estimated. The problem arises because the ratio between the expectancy of \( x_{ij} \) and its square can be made either infinitely small or large depending on the unit choice. Formally, if the unit is changed such that the empirical analysis is conducted on \( X = \kappa x \), assuming that \( \tilde{x} \) follows a negative binomial distribution implies that:

\[ \text{Var}(X|Z) = E(X|Z) + \eta^2 E^2(X|Z) = \kappa E(x|Z) + \kappa^2 \eta^2 E^2(x|Z) \]

Hence, when \( \kappa \to 0 \), \( \text{Var}(X|Z) \approx \kappa E(x|Z) = E(X|Z) \), and the negative binomial PML estimator tends towards PPML. Conversely, when \( \kappa \to \infty \), \( \text{Var}(X|Z) \approx \kappa^2 \eta^2 E(x|Z) = \eta^2 E^2(X|Z) \), and the negative binomial PML estimator tends towards gamma-PML.

In order to discriminate between the various \( a \ priori \) legitimate PML estimators, Manning and Mullahy (2001) suggest that if \( \text{Var}(x_{ij}|Z) = \lambda_0 E(x_{ij}|Z)^{\lambda_1} \), the choice of the appropriate estimator can be based on an estimation of \( \lambda_1 \). As pointed out by Santos Silva and Tenreyro, it is asymptotically valid to estimate \( \lambda_1 \) from:

\[ (x_{ij} - \bar{x}_{ij})^2 = \lambda_0 \bar{x}_{ij}^{\lambda_1} + \zeta_{ij} \]  

(6)

where \( \bar{x}_{ij} \) is the value of \( E(x_{ij}|Z) \) estimated from an initially consistent estimator like PPML.\(^4\)

A final comment refers back to the estimation of gravity equations in logarithm. A Taylor series that is limited to the second moment around the conditional mean gives:

\[
\log x_{ij} \approx \log E(x_{ij}|Z) + \frac{x_{ij} - E(x_{ij}|Z)}{E(x_{ij}|Z)} - \frac{1}{2} \frac{(x_{ij} - E(x_{ij}|Z))^2}{E^2(x_{ij}|Z)}
\]

\(^4\)Santos Silva and Tenreyro actually suggest testing the adequacy of a particular value of \( \lambda_1 \) from a Taylor expansion of (6), which they apply in the empirical part of their paper. Unfortunately, this procedure is subject to the same problem as for the negative binomial estimator: it artificially depends on the unit choice of trade flows, and could therefore be misleading.
And therefore,

\[ E(\log x_{ij}|Z) \approx \log E(x_{ij}|Z) - \frac{1}{2} \frac{\text{Var}(x_{ij}|Z)}{E^2(x_{ij}|Z)} \]  
(7)

\[ \text{Var}(\log x_{ij}|Z) \approx \frac{\text{Var}(x_{ij}|Z)}{E^2(x_{ij}|Z)} \]  
(8)

On top of the possible selection bias due to the elimination of zero trade flows, these equations summarize two issues with the log of gravity. Equation (7) highlights the bias that is stressed by Santos Silva and Tenreyro. Beyond that bias, equation (8) shows that assuming that errors of the log specification are i.i.d., as implicit when estimating with OLS, is consistent with the conditional variance of the flow being proportional to the square of the conditional mean, i.e. with the Gamma distribution. Therefore, if the true distribution is Gamma, estimating the log level equation using OLS only biases the intercept (ignoring the sample selection bias, see eq. 7), and not the other parameters of interest such as the distance coefficient. In other words, the magnitude of the biases (except the constant) of the gravity equation that is estimated using the log-linear specification depends on how far the distribution of trade flows is from the Gamma distribution. If, however, the true distribution is Poisson, (7) and (8) become, where \( \alpha \) is constant:

\[ E(\log x_{ij}|Z) \approx \log E(x_{ij}|Z) - \frac{\alpha}{E(x_{ij}|Z)} \]  

\[ \text{Var}(\log x_{ij}|Z) \approx \frac{2\alpha}{E(x_{ij}|Z)} \]

In that case, the bias would be very severe for small flows. Moreover, OLS estimates of the log specification would ignore that the variance of the log is very large for small flows; in other words, it would give far too much weight to small flows. Ignoring the bias, the efficient weighted least squares (WLS) is obtained by weighting each observation by the inverse of the variance, i.e. in that case by the conditional mean. This WLS estimator of the log specification might be appealing because it reduces the bias mechanically, as low weights are given to observations that contribute the most to the bias.\(^5\)

\(^5\)In contrast, unbiased NLS of the trade level specification might be inefficient because they do not give enough weights to small flows. It has been checked that iterative weighted NLS of the level equation, where weights are the inverses of the conditional mean, converges to PPML estimates.
2.3 Panel estimates and the distance puzzle

Cross section estimates of gravity equation might be biased due to the endogeneity of FTAs. Instrumental variables approaches have failed to estimate them properly because of finding an instrument for FTA that does not influence trade by another channel is extremely difficult. Panel specifications of gravity equations make it possible to control for a battery of fixed effects. Multilateral resistance terms in panel data require including origin and destination country dummies for each year. Baier and Bergstrand (2007) argue that country pair idiosyncrasies should also be accounted for via the so-called "dyadic fixed effects" to eliminate the bias due to the endogeneity of free trade agreements (FTAs). Properly controlling for the influence of FTAs might indeed be important for the estimate of the evolution of the elasticity of trade with respect to distance since FTAs are often agreements between neighbouring countries, hence an obvious correlation between FTAs and distances. Indeed, Berthelon and Freund (2008) refer to regionalism as the most obvious explanation for the persistence of distance as a determinant of trade flows. However, when introducing dyadic fixed effects, the level of the distance elasticity is lost, and only the changes through time can be estimated. It is clear also that introducing the $i*j$, $i*t$, $j*t$ fixed effects in a non-linear specification represents a numerical challenge that will call for some empirical (and acceptable) trade-offs. By comparison, Baier and Bergstrand use a specification in logs with elasticities with respect to distance, border, colonial link, etc. that are constant through time.$^6$

3 Data and econometric specification

3.1 Data

Trade flow data come from the IMF Direction Of Trade Statistics (DOTS) database.$^7$ This choice is guided by two motivations. First, it provides data for a long period, starting in 1948, which is important to study properly the distance puzzle, and for 204 "countries".$^8$ Second, $^6$They also reduce the number of fixed effects keeping only one over five years of their sample.

$^7$We are thankful to Thierry Mayer who provides trade flows from IMF DOT statistics and necessary programs for definitions of FTAs.

$^8$The list of countries is available on appendix.
DOTS includes zeros and differentiates them from missing values, avoiding some necessary but doubtful assumptions when otherwise. Figure 1 plots the number of zero and non-zero trade flows through time, thereby illustrating the risk of selection bias using log linear OLS. Indeed, despite the decreasing share of zero trade flows from 81% in 1948 to 29% in 2006, they still represent an important proportion. The sample of strictly positive trade flows, used for comparison of the different estimators, has about 3,500 flows in 1948 and 22,000 in 2006.

The geographic variables, distance between countries, common border, common language and colonial linkage dummies, are taken from the CEPII database. The free trade agreement (FTA) data is broadly the same as the one used in Baier and Bergstrand (2007). Specifically, the database used by these authors has been corrected and improved by Fontagné and Zignago (2007) in their re-estimation of the impact of FTAs. The proportion of the value of world trade covered by FTAs goes from 7% in 1958 to 31% in 2006.

Finally, it proved useful to work also with the largest perfectly balanced panel to account for the increasing number of trade flows as well as for the change in the sample over time. Hence, the balanced panel consists of the same 2550 pairs of countries between 1952 and 2006 covering 90 countries and 92% of world trade in 1952, 83% in 1986 and 66% in 2006. In particular, by drastically reducing the number of dyadic fixed effects, the construction of the balanced panel enables us to estimate the FTA effect in panel.

### 3.2 Specification

Following the discussion in section 2, the gravity equation is estimated in level including importer and exporter fixed effects. Although the Poisson-PML is the central estimates, non-linear least squares and Gamma-PML estimators are also computed. Moreover, the most efficient power of the conditional mean is estimated according to equation (6), which enables to test the Poisson assumption.


10 We have only updated the different FTAs within European countries. In total, 47 FTAs are covered including those between existing FTAs.

11 The first FTA in the database is the European Economic Community. Its treaty was signed on March 25th, 1957, so it begins in 1958 in the database.

12 Years before 1952 are deleted because the estimated value of $\lambda_1$ by equation (6) is quite too high compared with next years validating PPML.
Formally, the following equation is estimated for each year:

$$x_{ij} = \exp(\alpha_0 + \gamma \ln d_{ij} + \alpha_1 B_{ij} + \alpha_2 L_{ij} + \alpha_3 C_{ij} + \alpha_4 FTA_{ij} + FX_i + FM_j)u_{ij}$$ \quad (9)$$

with \( Var(x_{ij}|Z) = \lambda_0 E(x_{ij}|Z)^{\lambda_1} \). The choice of the appropriate estimator can be based on the estimation of \( \lambda_1 \).

\( x_{ij} \) is the nominal US$ value of export from \( i \) to \( j \), \( FX_i \) and \( FM_j \) are the fixed effects for exporting and importing countries, respectively. \( B_{ij} \), \( L_{ij} \) and \( C_{ij} \) are the traditional control covariates: common border, common official language and colonial linkage dummies, respectively. \( u_{ij} \) are the multiplicative error terms of the non-linear estimates. The log version is also estimated using ordinary and weighted least squares estimators, where the weights are the observed bilateral trade flows (subsection 2.2).

FTAs (FTA\(_{ij}\)) are generally considered important determinants of trade flows. In order to separate the various factors influencing the analysis of the distance puzzle, the gravity equations are first estimated without controlling for FTAs. Because these first results might be subject to the omitted variable biases, the analysis focuses, in a second step, on the effect of controlling for FTAs. Finally, following the discussion in sub-section 2.3, a panel specification including dyadic fixed effect is estimated:

$$x_{ijt} = \exp(\gamma_t \ln d_{ijt} + \alpha_{1t} B_{ijt} + \alpha_{2t} L_{ijt} + \alpha_{3t} C_{ijt} + \alpha_{4t} FTA_{ijt} + FX_{it} + FM_{jt} + Dyadic_{ij})u_{ijt}$$ \quad (10)$$

4 Cross section results without controlling for FTAs

This section presents the results obtained without controlling for free-trade agreements. The focus is on the elasticity of trade with respect to bilateral distance, the other parameters of interests in the gravity equation being discussed in greater detail in Section 6. As a benchmark, estimates using the PPML are presented in sub-section 4.1 while sub-section 4.2 shows why this benchmark is actually the baseline.
4.1 Baseline (PPML)

The gravity equation as specified in equation (9) is estimated for each year by PPML. Table 1 presents the results for six specific years between 1955 and 2005. Based on this estimator, the elasticity of trade to distance has been broadly stable over the period within a (0.60, 0.75) range. This range is tight compared with those found in the distance puzzle debate based on log specifications. The estimated robust standard error has steadily declined from 0.040 to 0.025 indicating an improvement over time in the precision of the estimate.

Figure 2 presents the evolution of the trade elasticity to distance, estimated using either OLS in logs or PPML in levels, along with confidence intervals. The PPML estimates are not sensitive to whether the zero trade flows are included or not (confidence intervals are also similar), a result also found by Santos Silva and Tenreyro, and Coe et al. using NLS. Based on the log-linear specification, the elasticity would have steadily increased from 0.70 to 1.60, which characterizes the distance puzzle. As a result, the difference between "PPML" and "log-linear" elasticities has dramatically increased over time.

This increasing difference seems to be due to the growing heterogeneity of flows and induced heteroskedasticity, consistent with the idea introduced by Santos Silva and Tenreyro in their cross-section analysis. The intuition behind such a link is illustrated in two ways. First, Figure 3 replicates Figure 2 and adds the elasticity estimated from the smaller albeit more homogenous balanced panel. While the PPML estimate is not sensitive to the choice of the sample, the reduced heterogeneity in the balanced panel leads to a lower estimated elasticity in the log-linear specification compared with that for the whole sample, the more so far the more recent years. Second, two measures of dispersion and one of heteroskedasticity were computed. The measures of dispersion are the interquartile ratio (ratio of 3rd to 1st quartile) of trade flows, and the coefficient of variation (standard deviation divided by mean). They are computed on the sample on which the log-linear specification is based, i.e. without zeros (again, the inclusion of zero flows has minor effects on the PPML estimates). The measure of heteroskedasticity related to the bias of the log-linear estimator is the Fisher statistics of regressing $\ln \hat{u}$ on the (log of) explanatory variables (equation 4), where $\hat{u}$ is the PPML estimated residual.

Figure 4 represents these three indicators in addition to the difference in the distance elas-
ticity between PPML and log-linear OLS. Over the period, the q3 / q1 ratio has increased by a factor of 12. This is due to the tremendous increase in small non-zero flows, as q1 decreased from $2 millions (year base = 2000, deflated by US GDP deflator) in the 1950s to $0.1 million since the mid-1990s. Within the same period, the average flow increased from $100 M to $400 M, and the standard deviation increased even faster as the coefficient of variation rose from 4 to 10. Since the small non-zero flows carry a disproportionate weight in log, the increase in its share is likely to contribute heavily to the widening of the gap between the PPML and the log-linear elasticities. The fact that the F-stat indicator has been multiplied by 6 over the period implies that the log of u, and therefore the variance of u, is increasingly related to the explanatory variables, which aggravates the log-linear OLS bias.\footnote{Equation 3 and 7 imply that $E(\log u|Z) \approx -\frac{1}{2} Var(u|Z)$.}

4.2 Which pseudo-maximum likelihood estimator?

This part investigates whether the assessment of the distance puzzle is sensitive to the choice of the non-linear estimator among the class that verifies $\text{Var}(x_{ij}|Z) = \lambda_0 E(x_{ij}|Z)^{\lambda_1}$, all of them being consistent under (5). This includes the non-linear least squares (NLS, $\lambda_1 = 0$), the PPML ($\lambda_1 = 1$) and the gamma-PML (GPML, $\lambda_1 = 2$).\footnote{For $\lambda_1 = 0$, NLS or maximum likelihood leads to estimates almost identical.} As discussed in Section 2, the cleanest way consists in estimating equation (6). Figure 5 plots the estimated $\hat{\lambda}_1$ with confidence interval, using PPML to estimate $\hat{x}_{ij}$. The average estimate over the period is 1.04 with an average estimated standard error of 0.28. PPML is never rejected as optimal, whereas NLS and GPML always are at 95% confidence level (except for a few years for GPML). This test clearly discriminates in favour of PPML.

Figure 6 nevertheless compares the NLS and PPML estimates of the distance elasticity. The level and evolution of the estimated elasticity is similar between the two estimators, even though the variations are greater with NLS (and the elasticity unrealistically low at the beginning of the period). On average with NLS the estimated standard error is twice as large as with PPML. The main difference is that the elasticity is estimated to have fallen since the mid-1980s with NLS, while it is broadly stable with PPML.

The significant difference between PPML and GPML estimated elasticity is striking, as
illustrated by Figure 7. Actually, the trend in the GPML elasticity looks very similar to the log-linear OLS one, which is problematic: even though both GPML and log-linear OLS give a high weight to small flows, which might be a source of poor efficiency (and bias for log), the GPML should be consistent under (3). However, it is significantly different from PPML, another consistent estimator under (3): this is the main remaining puzzle of the whole approach.

Since this might question the validity of the $\lambda_1$ test, $\lambda_1$ is re-estimated using either NLS or GPML as the initial estimator of $\tilde{x}_{ij}$. Results are reported in Table 2. Based on the GPML initial estimate, $\lambda_1$ is estimated at around 0.50 (with an unrealistically high degree of precision), and when using NLS has a starting point, $\lambda_1$ is estimated at around 0.40. This means that, even when the starting point is GPML, GPML appears as being very inefficient. In addition, the optimal PML estimator would be right in between NLS and PPML, both leading to a similar assessment of the "distance puzzle". All in all, this sugests that the optimal estimator is between NLS and PPML, with a preference for PPML based on figure 5.

Figure 7 also adds the negative binomial estimator for different unit values of the trade flows in order to illustrate the theoretical result established in sub-section 2.2: this estimator is indeed sensitive to the unit choice, converging at the limits either to the PPML or the GPML, which makes it inadequate to estimate gravity equations.

Finally, as PPML seems to be the preferred estimator, one is tempted, following the discussion in sub-section 2.2, to compute the WLS estimator of the log specification, where the weights are the trade flows; first, the observed flows and, then, the iterated estimated ones. Both WLS linear estimates are amazingly close to the PPML ones, as shown in Figure 8. This highlights that using WLS to improve efficiency is also powerful to reduce, and even eliminate, the bias of the OLS log specification, which gives far too much weight to the small flows.

5 Results with FTAs, and panel specification

Sub-section 5.1 discusses whether the baseline obtained in section 4 without controlling for FTAs is sensitive to different values of the FTA parameter is constraint in cross sections. Sub-
section 5.2 analyses the "distance puzzle" using panel data. Sub-section 5.3 compares our results with those of Coe et al..

5.1 Sensitivity to the effect of FTAs in cross section

Accounting for FTAs has a small impact on the assessment of the "distance puzzle". The sensitivity of the distance elasticity of trade to the FTA parameter is shown in figure 9, the parameter being equal to 0, 0.3 or 0.6 using PPML in cross section, while results where the FTA parameter is freely estimated in cross section are in appendix. These values are based on the different estimates of the effect of FTAs in the panel approach (sub-section 5.4). Naturally, the first case (parameter = 0) corresponds to the results presented in the previous section, as for example in Figure 6. As expected, because FTAs are negatively correlated with distance, taking into account the effect of FTAs reduces the absolute value of the estimated distance coefficient, although the difference is never greater than 0.12.

Whether the FTA parameter is constrained to 0, 0.3 or 0.6 does not make any difference in the evolution of the elasticity of trade to distance until 1972. From 1973, the gap between the different estimates increases, as does the coverage of trade flows by FTAs (right scale). 16 When the FTA parameter is constrained to 0.3, for example, the estimated distance coefficient remains stable around 0.65 (average standard error around 0.03) and within a 0.60-0.70 range. From the mid-eighties the evolution is hump-shaped with a recent increase (in absolute value) from 0.60 to 0.70 between 1994 and 2006.

In sum, the main difference between these three estimates lies in the end point value for the elasticity. It is 0.76, 0.71 and 0.66 in 2006 when the FTA parameter is constrained to 0, 0.3 and 0.6 respectively. The shape of the evolution is affected accordingly, but without changing the broad assessment of a stable elasticity over the whole period. In particular, these differences are small compared with the magnitude of the bias identified by Santos Silva and Tenreyro.

161973 is an important year for FTAs: the United Kingdom, Denmark and Ireland join the European Union. An agreement between the EU and the European Free Trade Association is created, as well as the Carribbean Community.
5.2 Panel analysis of the distance puzzle

Following section 2.3, the panel estimation of gravity equations requires both time-varying importer and exporter fixed effects as well as "dyadic fixed effects" in order to account for bilateral heterogeneity. All these fixed effects generate computational difficulties. As a result, the estimation of equation (10) has been carried out using 5-year averaging\(^{17}\). Also, working on the perfectly balanced panel dataset presented in section 3 (covering 90 countries) allows to drastically reduce the number of fixed effects (dyadic and time-and-country ones).

With dyadic fixed effects, only the evolution through time can be estimated, the levels of the parameters that are fixed through time, such as geographic characteristics, being wiped out. However, unlike Baier and Bergstrand, elasticities are here allowed to vary through time. The estimation of equation (10) in PPML is the mirror of the within estimator in linear regressions. Figure 10 shows that the evolution of the trade elasticity to distance is similar to that obtained in the cross section analysis. Indeed, the PPML estimator in panel leads to a total increase of 0.17 in the (absolute value of the) trade elasticity to distance from the first period (1952-1956) to the last one (2002-2006), with small variations. (The cross section estimates with an FTA parameter constrained to 0.3 yield a total increase of 0.9).

Depending on the autocorrelation level of the residuals, the within transformation might not be the most efficient (Woolridge, 2001, chapter 10). As robustness checks, two other panel estimators, that mirrors first-differencing, have been implemented to deal with the dyadic fixed effects. The first uses \(x_{ijt}/x_{ijt-1}\) as the dependent variable\(^{18}\)

\[
\frac{x_{ijt}}{x_{ijt-1}} = \exp(\Delta\gamma_t \ln d_{ij} + \Delta\alpha_{1t} B_{ij} + \Delta\alpha_{2t} L_{ij} + \Delta\alpha_{3t} C_{ij} + \Delta(\alpha_{4t} FTA_{ijt}) + \Delta F X_{it} + \Delta F M_{jt}) v_{ijt}
\]

(11)

where \(v_{ijt} = u_{ijt}/u_{ijt-1}\).

Due to heteroskedasticity, this specification is estimated efficiently by nonlinear WLS where the weights are the inverse of the variance of \(x_{ijt}/x_{ijt-1}\). Appendix Z shows that when \(x_{ijt}\)

\(^{17}\)To be consistent with the gravity specification in levels such as (9) or (10), the geometric mean of trade flows is used as the dependant variable. To limit the number of fixed effects, Baier and Bergstrand reduce their sample by keeping only one year for each five-year periods.

\(^{18}\)The balanced panel does not include zero flows which are eliminated by this transformation. The analysis in section 4 has shown that zero flows do not matter anyway.
is Poisson then $Var(x_{ijt}/x_{ijt-1})$ is proportional to the inverse of $E(x_{ijt-1})$. Hence, the ratio $x_{ijt}/x_{ijt-1}$ is weighted by $x_{ijt-1}$.$^{10}$

The second alternative estimator, following the results established at the end of section 4, consists in a linear WLS of equation (11) specified in logs

$$\log\left(\frac{x_{ijt}}{x_{ijt-1}}\right) = \Delta \gamma_t \ln d_{ij} + \Delta \alpha_{1t} B_{ij} + \Delta \alpha_{2t} L_{ij} + \Delta \alpha_{3t} C_{ij} + \Delta (\alpha_{4t} FTA_{ijt}) + \Delta FX_{it} + \Delta FM_{jt} + \epsilon_{ijt}$$

(12)

Appendix Z shows that the efficient estimator uses the harmonic mean of trade flows over subsequent periods as weights.

As shown also in Figure 10, the broad picture remains the same based on these estimates, supporting the view of an overall stability of the trade elasticity to distance through time—a small increase in absolute terms to be precise (except with the nonlinear WLS estimator). Using the tests for serial correlation of the residuals (Wooldridge, equation 10.71) enables to discriminate between within and first difference estimators, depending on whether the autocorrelation parameter of $\log v_{ijt}$ is close to 0 and 1. Based on this test, the WLS estimators should be preferred over PPML.$^{20}$ Although the choice of the parameter has basically no impact on the assessment of the distance puzzle, some other parameters are affected, as shown in section 6.

5.3 Comparison with Coe et al.

The main result that this study shares with Coe et al. is that the elasticity of trade with respect to bilateral distance does not seem to have increased since the 1970s in contrast with the usual results obtained from the log-linear specification. There are, however, two main differences. First, the average level of the elasticity is about 0.40 in Coe et al., way below our 0.68 over the same period. The choice of the NLS vs PPML estimator, as the baseline, cannot explain the difference, notwithstanding the possible lower efficiency of NLS based on the above results: the difference in the point estimate is very small based on our results; in Coe et al., the

$^{10}$Ideally one would like to use an iterated WLS, but only the ratios are estimated, not the level of flows. Fortunately, results in section 4 indicate that WLS and iterated WLS estimates are very close to each other.

$^{20}$This estimator is estimated to be very close to 0 in both nonlinear WLS, and log linear WLS (eq. 11 and 12 respectively).
PML estimates, which seem to be PPML, that they report in their table 5 give a similar order of magnitude as their NLS. Actually, for 1990, Santos Silva and Tenreyro estimate a PPML distance elasticity of 0.78 compared with 0.65 in our case while Coe et al. report 0.33 with NLS and about 0.45 with PML. Second, the estimated distance elasticity has even decreased in Coe et al., by about 0.20 between 1975 and 2000, while it is the same in both years based on our analysis.

Although it is difficult to know for sure, here are the possible explanations that drive such differences. First, their sample is more restricted, being limited to 73 countries. Second, their dependent variable is the sum of bilateral import and export, which is highly problematic according to Baldwin and Taglioni (2006) (the gravity equation explains uni-directional bilateral trade, sum or average must be done with reference to theory to be done properly). Finally, there might be some collinearity issues in their results as the reported levels of and changes in the common border and Free-trade agreements parameters (their tables 3 to 5) are often very surprising. Besides, it is not totally clear which Free-trade agreement variable is used.

6 Other trade determinants

6.1 The particular case of the FTA parameter

Although Baier and Bergstrand countrain the elasticities to be constant over time, the panel approach allows for time-varying elasticities, as needed for the analysis of the "distance puzzle". However, for comparison purposes, estimates of equations 10 and 11 are also reported holding the FTA parameter \( \alpha_{4t} \) to be constant over time, and Figure 11 presents the evolution of the FTA parameter across the different estimators. Holding the FTA parameter constant leads to an estimate of 0.52 and 0.27 using equations 10 and 11 respectively while Baier and Bergstrand obtain 0.49 and 0.36, respectively, using a specification of trade flows in logarithm. While the "first difference" transformation generates only small variations of the FTA parameter through time, the estimated coefficient using the "within" transformation varies from 0.27 to 0.74 between 1952 and 1975, and steadily decreases to 0.50. However, the tests for the serial correlation of residuals (section 5.2) discriminate in favour of the "first difference" transformation. A point
estimate of 0.27 means that two countries which share a FTA trade about 35% more than two
countries which do not.\footnote{\textit{exp}(0.3) − 1.}

6.2 Contiguity, common language and colonial linkages dummies

Because the dummies for contiguity, common official language and colonial linkages do not vary
through time, only the changes of the corresponding coefficients can be estimated in a panel
specification. Figures [12] [13] and [14] present these evolutions using the three panel estimates,
as well as those obtained using procedures PPML in cross sections. The latter is particularly
useful as it provides estimates of the parameters in levels. For the first period (1952-1956),
point estimates for common border, common official language and colonial linkages dummies
are 0.48, 0.14 and 1.11, respectively, with estimated robust standard errors of 0.14, 0.13 and
0.15.

All estimators point to a notable decrease in the effect of colonial linkages over the years,
especially pronounced until the mid-eighties, even though the amplitude varies importantly
across estimators. Based on cross section, the effect sharply decrease from 1.1 to about 0 on
the whole period, while the decrease is "only" 0.51 with PPML in panel and 0.89 with the
nonlinear "first difference" panel estimator.

END OF THIS SECTION AND CONCLUSION ARE IN CONSTRUCTION BY THE
TIME OF THE SUBMISSION.

7 Conclusion
References


Head, K., Mayer, T. and Ries, J. (2008), ‘How remote is the offshoring threat?’, *forthcoming in European Economic Review*.


Leamer, E. (2007), ‘A flat world, a level playing field, a small world after all, or none of the above? review of thomas l. friedman’, *Journal of Economic Literature* **45**.


A Crude introduction of FTA

The gravity equations are estimated using the PPML estimator with a distinct FTA parameter for each year (but common to all FTAs). The evolution of the elasticity of trade with respect to distance in this particular case can be seen in figure 15 and the (free) FTA coefficient in figure 16. Despite a high FTA effect in 1972 (0.57 with a standard error of 0.08), the gap between estimated elasticities of trade to distance with and without FTA is not large because few countries share a FTA. Since 1973 and the abrupt fall due to the integration of three new members in the European Economic Community, the link between FTA coefficient and the trade elasticity to distance seems more obvious. Indeed, the FTA coefficient and the trade elasticity to distance increase slowly between 1973 and 1985, then grow abruptly until 1988. From this peak, both coefficients decrease following proximate trends.

It is difficult to explain at first sight the hump between 1986 and 1993. So we decide to work with disaggregated FTAs. Therefore regressions are no longer implemented with a variable FTA but with as many dummies as free trade agreements. The first result is that there is practically no aggregation bias on the distance coefficient. Indeed, the evolutions of the trade elasticities with respect to distance with disaggregated FTAs and with only one dummy are quite similar. Each FTA are then removed one by one to see if one could be responsible of the hump. The results are again quite striking. As shown in figure 15, removing the agreement between the European Economic Community and the European Free Trade Agreement signed between the two institution in 1973 (accompanying the transition of Great-Britain and Denmark from the EFTA to the CEE) is enough to delete half of the hump. Then, in order to avoid omitted variable bias, the coefficient associated to the dummy corresponding to this FTA is constraint to 0.5. As depicted in figure 15, this leads to very small change comparing with the initial situation. This is because the presence of the dummy corresponding to the agreement between the EU and the EFTA not only plays naturally a role on the distance coefficient but also change the values of the estimated effects of the EU and the EFTA. Figure 16 also presents the evolution of the FTA parameter when the agreement between the EU and the EFTA is

\[22\] The comparison with log linear estimates confirms the underestimation of FTA coefficient with the traditional log linear method being often not significant since 1973.

\[23\] There is elsewhere no aggregation bias on the other coefficients of the control covariates.
removed, and the evolution of the parameter corresponding to this FTA when it is included.

Despite this particular results, we do not search more explanation for the moment. Indeed, Baier and Bergstrand emphasize that endogeneity biases the estimates of the parameters of FTA in cross-section regressions. This bias could be different in some years than in others.

B Other trade determinants in cross section

PPML yields a very different pattern of the evolution of the trade elasticity to distance since World War Two compared to traditional estimates. This section look at the other covariates used as control in the estimated gravity equations, that is to say the dummies for contiguity, common official language and colonial linkages. Equation (9) is estimated for each year in cross section when the FTA parameter is constrained to 0.3.

In figure [17] the prediction of PPML and log-linear techniques are quite similar regarding to the measure of the impact of a common border on international trade. The coefficient associated is about 0.3 from 1948 to 1985, that is to say that during this period, two countries having a common border trade about 35% more than two countries who do not have a common border. Then the coefficient increases with the two specification (even if there is a bigger variation of the parameter when it is estimated with traditional log-linear technique) to about 0.7 in the beginning of the nineties (two contiguity countries trade more than one hundred percent more). This result is a bit surprising and seems to be overvalued with log-linear estimation. It could confirm the importance of regionalism as an important determinant of international trade.

The picture presented in figure [18] is different. Indeed, besides the fact that log-linear method predicts a dramatical continuous progression of the impact of the common official language dummy, PPML seems to be more reasonable. Even if the two methods lead to similar result until 1968, Poisson regression then predicts a decreasing effect of having a common official language on international trade. This result is more coherent to what could be expected with the generalization of English as the language of international business. In 2006, PPML predicts an 0.2 impact (about 22% trade more) when log-linear predicts an 0.95 effect which correspond to a supplement of 159% of trade between two countries which share a common official language with regard with two countries which do not.
The evolution of the effect of having colonial linkages is depicted in figure [19]. It seems that PPML yields again to more realistic results. The two methods confirm the declining importance of colonial links as an international trade determinant, which seems to be reasonable. Nevertheless, the log linear estimation shows a late beginning of this decrease and keep a very high level at the end of the period (about 0.95 that is to say 159% of trade more in 2006) which seems again to be quite too much. On the contrary, PPML estimation starts a continuous and quasi linear decrease in 1953 and the coefficient has become stable to 0.2 since 1983. Considering this is more reasonable, two countries who have colonial linkages trade 22% more on average.

C Tables

Table 1: Gravity equations estimated with PPML

<table>
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<tr>
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<td>Log distance</td>
<td>(-0.59^{***})</td>
<td>(-0.61^{***})</td>
<td>(-0.69^{***})</td>
<td>(-0.70^{***})</td>
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<td>Contiguity</td>
<td>(0.41^{***})</td>
<td>(0.35^{***})</td>
<td>(0.27^{***})</td>
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<td>(0.65^{***})</td>
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<td>Language</td>
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<td>(0.39^{***})</td>
<td>(0.30^{***})</td>
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<td>Colony</td>
<td>(1.12^{***})</td>
<td>(0.83^{***})</td>
<td>(0.49^{***})</td>
<td>(0.08)</td>
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<td>7049</td>
<td>11123</td>
<td>12391</td>
<td>19973</td>
<td>22201</td>
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Table 2: Estimated \(\lambda_1\) from (6) with the different non-linear estimators as starting points

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<td>PPML</td>
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<td>1.10</td>
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### Table 3: List of countries in the balanced sample

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E Figures

Figure 1: Descriptive statistics on trade flows

Figure 2: Evolution of trade elasticity to geographic distance: PPML vs log linear estimates
Figure 3: Evolution of trade elasticity to geographic distance: sample analysis

![Figure 3](image)

To the right scale, the Fisher statistics and the quartile ratio are divided by 2 and 25, respectively.

Figure 4: Illustration of the heteroskedasticity issue

![Figure 4](image)
Figure 5: Estimated $\lambda_1$ since 1952

Years before 1952 are deleted because $\lambda_1$ point estimates are both too high and very poorly estimated.

Figure 6: NLS vs PPML
Figure 7: Which PML estimator?

Figure 8: Log-linear WLS and PPML
Figure 9: Trade elasticity to distance based on different values of the FTA parameter

Figure 10: Evolution of the elasticity of trade to distance from the first period (1952-1956)
Figure 11: Trade elasticity to FTAs, panel estimates

Figure 12: Evolution of the trade elasticity to a common border from the first period (1952-1956)
Figure 13: Evolution of the trade elasticity to a common official language from the first period (1952-1956)

Figure 14: Evolution of the trade elasticity to colonial linkages from the first period (1952-1956)
Figure 15: Trade elasticity to distance with time-varying FTAs' parameter

Figure 16: Trade elasticity to FTAs
Figure 17: Trade elasticity to a common border

Figure 18: Trade elasticity to a common official language
Figure 19: Trade elasticity to colonial linkages