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Abstract

This study attempts to bring new perspectives on the *death of distance* hypothesis by examining to what extent the intensification of ICT has contributed to attenuate the effect of distance on international trade issues. Our analysis is based on an extended gravity model constituted of 2827 country pairs observed from 2002 to 2012. The model is estimated by using the Hausman-Taylor instrumental variable approach to deal with specificities of the panel gravity models that cannot be treated in classical fixed-effect or random-effect models. The estimations confirm significant beneficial effects of ICT regarding trade costs reduction. We found that bilateral trade costs are significantly low between countries that have a more densified communication network. And this effect appears to be strongly heterogeneous regarding the distance. In particular, we found that the impact of ICT on trade costs is greater when the distance between the trading partners is more important. We also found that the elasticity of trade costs to distance decreases as the level of ICT increases. These results appear robust to various sensitivity and robustness checks and are consistent with other studies. Finally, the results obtained in this study suggest the existence of strong *distance-neutralizing* effect of ICT.

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Introduction

The recent upheavals in information and communications modes brought by the Internet and cellular technology coupled with progress in transport technologies have led many observers to argue that geographic distance will no longer be a major concern for international transactions. This vision marked the birth of the "*death of distance*" hypothesis (see Cairncross, 1997; Friedman, 2005). However, despite the optimistic nature of this assertion, its empirical foundations have been questioned in numerous studies. For example, Brun, Carrère, Guillaumont and de Melo (2005), using bilateral trade data for 130 countries from 1962 to 1996, found that the (negative) elasticity of trade to distance has been increasing significantly over time. Also Disdier and Head (2008), adopting a meta-analysis on 1,467 estimated gravity equations in 103 papers, observed that the magnitude of the coefficient associated of distance in these equations has been slightly on the rise since 1950. These results have even led some commentators to point out that distance is, in fact, not "dying" but "thriving"(Lendle et al., 2012), suggesting thus that the distance has not yet finished delivering its secrets.

However, several attempts have been made to shed light on this paradox. For many authors, the information friction inherent to distance is the main explanation of the trade reducing-effect of distance (Rauch, 1999; Chaney, 2011; Allen, 2011). Allen (2011) shows, for example, that almost 93 percent of the relation between trade flows and distance are attributed to information frictions rather than transportation costs. In such a context, one of the questions one may legitimately ask is, if the relationship between distance and trade is established through information frictions what then was the role played by the recent boom in information and communication technologies? Does questioning of the death of distance hypothesis mean that ICT development has failed in reducing information frictions? These questions constitute the motivation of this article in which we attempt, through empirical analysis, to bring about answers.

The work takes part in the international trade problematic which we approach regarding trade costs. The main reason underlying this choice is that, although trade costs (especially tariffs) have significantly declined in many countries in the past decades, there are number of evidence that recall that trade costs remain abnormally high. For example, one of the well-known estimations is that of Anderson and Van Wincoop (2004) who show that, in a typical developed country, trade costs can be as high as 170% ad valorem. The situation is likely to be worse in developing countries which are characterized by poor infrastructures and dysfunctional transport and logistic services.

In this study, instead of focusing on trade volumes, we choose to look directly at the trade costs that determine them. This choice was motivated by the idea that trade cost is as informative as trade volume. Therefore, by focusing on the first indicator one should be able to provide some keys to the understanding of international trade.

The work is organized as follows. In the first section, we conduct a literature review in which we inventory the main theoretical and empirical works on trade cost problematics about to distance and the development of ICT. In the second section, we present the key hypotheses and the empirical framework which can allow one to test them. In the third section, we present the data, the variables and descriptive statistics. The fourth section is devoted to estimations and the discussion of results. The last section is dedicated to the conclusion of the study.

1. Literature review

Prominent works have already been done on the international trade costs issues during recent the years, particularly on the role of geographic distance (Hummels, 1999; Limao and Venables, 2001; Micco and Pérez, 2001; Fink et al., 2002; Kumar and Hoffmann, 2002). In most of these studies, geographic distance has been identified as a key determinant of trade given its positive influence on trade costs. The trade-depressing effect of distance is largely explained by the fact that remoteness between countries exacerbates trade costs through, not only, high transportation costs but also costs generated by asymmetrical, incomplete and insufficient information during transaction process (information costs). For this reason, the development of ICT infrastructure is regarded as a mean to improve the efficiency of the transactional processes. This argument is supported by both theoretical predictions and empirical evidences (see Malone et al., 1987; Rauch, 1999; Jensen, 2007, Aker, 2010, Goyal, 2010; Chaney, 2011; Allen, 2011).

On the theoretical side, author such as Malone et al.(1987) argue that ICT lowers transaction costs by allowing information to be communicated in real-time and at much lower costs. For Benjamin and Wigand (1995), ICT helps to reduce transaction costs by reducing the producers/retailers coordination and intermediation costs. Yadav (2014) signals that in presence of well-developed ICT infrastructure, the fixed costs associated to searching for international clients and suppliers to establish trade networks are significantly reduced. Based on these arguments, one can thus expect that ICT development contributes in increasing information flows between trading partners by breaking down barriers to information. It can reduce information related costs such as search costs, advertising costs, distribution costs and costs associated to delays and uncertainties of delivery (Liu and Nath, 2013).

From empirical point of view, several evidences attest the beneficial impact of ICT on the trade through information costs reduction (Limao and Venables, 2001; Freund and Weinhold, 2002, Fink et al.,2002 ; Freund and Weinhold, 2004 ; Fink et al., 2005; Clarke and Wallsten, 2006; Francois and Machim, 2007; Vemuri and Siddiqi, 2009; Demirkan et al., 2009; Choi, 2010; Mattes et al., 2012). For example, Fink et al. (2005) using telephone call costs data in a gravity model found that high information cost has negative and significant effect on bilateral trade flows. Similarly, Limao and Venables (2001), Francois and Machim (2007) and Nordas and Piermartini (2004), who respectively use telecommunication indicators such as the number of mainlines and mobile telephones, conclude that improvement in information and communication infrastructures have a positive effect on bilateral trade. On the other hand, the fact that internet has become, undeniably, one of the major communication channels, has led many authors to broaden their interest in its potential role in international trade (Freund and Weinhold, 2002 Freund and Weinhold, 2004; Tang, 2006; Clarke and Wallsten, 2006; Demirkan et al., 2009; Liu and Nath, 2013; Kurihara and Fukushima, 2013; Yadav, 2014; etc..). Most of these studies confirm the existence of the significant and positive effect of internet on trade. For example, Freund and Weinhold (2004) who have paved the way on this issue, show that, between two trading countries, a 10% increase in the relative number of web hosts in one country leads approximately to 1% increase in bilateral trade.

In this article, we use a broadened concept of ICT that includes both telephone and internet dimensions. The goal is to be able to comprehensively capture all the effects that can pass through any individual dimension.

2. Hypotheses and empirical model

The empirical methodology developed in this paper aims to test two main hypotheses. First, we postulate that, regardless the importance of distance, trade costs should significantly decrease as the ICT level increases. In this hypothesis we suppose the existence of a direct effect of ICT development on trade costs. This hypothesis is supported by the idea that, for a given level of the ICT, the marginal cost of communicating at any greater distance is substantially equal to zero (see Cairncros, 1997). Secondly, we postulate that the development of the ICT capacity between two trading countries is associated with the diminishing importance of distance on their bilateral trade costs. We suppose that the marginal effect of ICT on trade costs will increase as distance increases while the marginal effect of distance on trade costs will decrease as ICT increases.

In order to test these hypotheses, we build a conceptual framework allowing to capture both the direct and the moderating effects of ICT but also the direct and the amplifying effects of distance. The model is an extended version of the standard gravity model in which a single node is used to form a country dyad. Thus, the gravity model used in this work is presented in a dyadic form (i.e. one observation for each pair of countries, not two) and expressed in the following econometrical specification:

$$log(costs_{ijt}) = \beta_0 + \beta_1 log(distance_{ij}) + \beta_2 log(ICT_{ijt}) + \beta_3\, log(distance_{ij}) \times log(ICT_{ijt}) + \beta_X X_{ij} + u_{ij} + v_t + e_{ijt} \quad (1)$$

Where $log(costs_{ijt})$ is the logarithm of bilateral trade costs between countries i and j at time t. $log(distance_{ij})$ the log of geographic distance. $log(ICT_{ijt})$ the log of ICT capacity between the two countries at time t. X_{ij} represents the vector of control variables (that we will present later); u_{ij} represents country pair specific effect, v_t the temporal effect and e_{ijt} the idiosyncratic error term. The coefficients $\beta_0, \beta_1, \beta_2,\ \beta_3$ and β_X are parameters to be estimated. Since all the variables in the model are in the dyadic format, the subscripts ij and ji that capture the direction of flow are symmetric and thus represent the same value.

Our main parameters of interest are β_1, β_2 and β_3. They are interpreted as elasticities since trade costs, distance and ICT are in logs. β_1 is expected to be positive ($\beta_1 > 0$) while β_2 and β_3 are expected to be negative ($\beta_2 < 0$ and $\beta_3 \leq 0$). The joint validation of these two latter conditions provides the evidence of a mitigating effect of ICT on distance. Indeed, following equation (1), the total elasticity of trade costs to distance (respectively with ICT) is expressed as follows:

$$\begin{cases} \tilde{\beta}_{distance} = \dfrac{\partial log(costs_{ijt})}{\partial log(distance_{ij})} = \beta_1 + \beta_3 log(\widetilde{ICT}) \\ \\ \tilde{\beta}_{ICT} = \dfrac{\partial log(costs_{ijt})}{\partial log(ICT_{ijt})} = \beta_2 + \beta_3 log(\widetilde{distance}) \end{cases} \quad (2)$$

Where $\tilde{\beta}_{distance}$ and $\tilde{\beta}_{ICT}$ respectively represent the total elasticity of trade costs to distance and ICT. Equation (2) shows that the elasticity of trade costs to distance or ICT can be decomposed into two elements: an unconditional (direct) elasticity and conditional (indirect) one. The unconditional elasticity of trade cost to distance is β_1 while the conditional elasticity is β_3 because it depend on the level of ICT. Since $\beta_1 > 0$ and $\beta_3 \leq 0$, the increase in the level of $\widetilde{ICT}$ leads to a decrease of the magnitude of $\tilde{\beta}_{distance}$. In the same manner, the unconditional elasticity of trade cost to ICT is β_2 while the conditional elasticity is β_3 because it depend on distance. Since $\beta_1 > 0$ and $\beta_3 \leq 0$, the increase in the $\widetilde{distance}$ leads to increase in the magnitude of $\tilde{\beta}_{ICT}$.

3. Data, variables and descriptive statistics

3.1. Trade costs

Droadly defined, trade costs are all costs (other than the marginal cost of producing the good itself) incurred in getting a good to a final user (Anderson and Wincoop, 2004). They include, in addition to policy barriers (tariffs and non-tariff), transportation costs (freight costs and time costs), contract enforcement costs, currencies use costs, legal and regulatory costs, local distribution costs and information costs.

Given the generality of this definition, several definition of trade costs have been proposed categorized as direct or indirect measures. As direct measures, many authors use for examples CIF/FOB ratio. Indeed, most importing countries report trade volume inclusive of freight and insurance (CIF). And most exporting countries report trade flows exclusive of freight and insurance (FOB). Thus the difference between the CIF and the FOB is considered as a good proxy for transport and insurance costs(Harrigan, 1993; Limao and Venables, 2001; Hummels, 2001a; Hummels, 2007). Other direct measures have also been used: tariff or non-tariff costs (Chen, 2004; Head and Mayer, 2000); information costs (Rauch,1999); time costs (Evans and Harrigan, 2005; Hummels, 2001b). However, given the multidimensionality of trade costs, none of these single indicators can reveal the true extent of the trade costs (Chen and Novy, 2011). Also, most of these single indicators are known for having several shortcomings. For example, Hummels (1999) shows that CIF/FOB ratios cannot be considered as good proxies for variation in transport costs since such a variable provides no information about changes over time.

In this article, we follow the long tradition of inferred trade costs methodology which consists in using indirect approaches to aggregate trade costs from trade flows (see Anderson and van Wincoop, 2004; Chen and Novy, 2008, Novy, 2013; Arvis et al., 2013a; Arvis et al., 2013b). The bilateral trade costs used in this paper is extracted from the ESCAP-WB Database providing bilateral trade costs panel data for 2827 country pairs spanning from 1995 to 2012. This database is constructed by Arvis et al.(2013b) according to Novy(2013) methodology in which bilateral trade costs is expressed as follows:

$$\tau_{ij} = \left(\frac{E_{ii}E_{jj}}{E_{ij}E_{ji}}\right)^{\frac{1}{2(\sigma-1)}} - 1 \quad (3)$$

Where τ_{ij} denotes bilateral trade costs between country i and country j (in ad-valorem equivalent). E_{ij} denotes trade flow (exportation) from country i to country j. E_{ij} the trade flow (exportation) from country j to country i. E_{ii} denotes intra-national trade flow for country i (amount of production traded in the local market) while E_{jj} denotes intra-national trade flow for country j. σ is the elasticity of substitution between traded goods.

There are two main advantages associated with this trade costs measure. First, since it allows trade costs to be directly deducted from the observed trade flow, there is no need to assume any particular trade costs function (Novy, 2013). Secondly, contrarily to many other direct costs, this measure allows trade costs to be function of time-varying observables; hence allowing researchers to trace changes in bilateral trade costs over time and to analyze factors contributing to its evolution.

It should be noticed that because of the data availability concerns for some countries on other indicators (especially before 2000), we restrict trade costs data sample to the 2002-2012 period to be able to construct a better correspondence with other data sources. Our final analysis sample includes 2827 country pairs constituted by 178 countries and spanning from 2002 to 2012. The list of countries is presented in Appendix.

3.2. ICT variables

In the literature, ICT development have been apprehended in several approaches: ICT access, ICT use or a combination of the two dimension in the shape of index (see Freund and Weinhold 2002, 2004; Choi 2010; Clarke and Wallsten 2006, Demirkan et al., 2009; Marquez-Ramos et al.,2010; Nor et al., 2011; etc…).

In this paper, we focus primarily on the ICT infrastructure indicators. As recognized by Tang (2006), the development of ICT infrastructure is an initial condition that increases the network capacity in the country, to lower the marginal cost of connecting additional users and consequently to increase the ICT adoption.

To capture the ICT infrastructure dimension, we consider respectively the number of telephone mainlines per 100 inhabitants, the mobile network coverage in proportion to the population, the number of secure Internet servers per million inhabitants, the Internet bandwidth in Megabits per second and per Internet user and the number of personal computers per 100 inhabitants. The first two variables reflect the building of ICT infrastructure while the remaining variables measure the country's technical capability for data transmission and communications. These indicators are extracted from ITU World Telecommunication/ICT Indicators database, except for the number of secure Internet servers that is obtained from the World Economic Forum annual Global Information Technology Reports. However, in the perspective of examining the robustness of our results, we envisage to supplement these infrastructure indicators by the use ones. The ICT use indicators (which indicate the degree of proliferation of ICT use in the country) include mobile phone subscriptions per 100 inhabitants and the number of Internet users per 100 inhabitants. These data are also extracted from the ITU database.

The classification of indicators according to infrastructure and use categories is consistent with the ITU ICT development index (IDI) framework. The classification is based on the idea that the infrastructure level reflect potential access while the use indicators reflect the actual use of

ICT infrastructure. But the classification could not be considered as perfect since some indicators can reflect both access and use (e.g: number of fixed telephone lines or the mobile phone subscriptions).

In the literature, most studies use one indicator at a time to capture the effect of ICT (Freund and Weinhold, 2002, 2004; Demirkan et al.,2009; Kurihara et Fukushima, 2013). Other studies use several indicators, however, by running separate regression for each of the selected variable (Clarke and Wallsten, 2006; Riker, 2014). The limit of such selection approaches come from the fact that none of these ICT indicator is not able to reflect, alone, the real extent of the communication capabilities of a country and there exists a high interdependency between ICT dimensions. For example, wired internet subscription is generally associated with the prior existence of a fixed telephone line and mobile internet service is often accompanied by a subscription to mobile phone services. Thus these selection approaches may leave omitted variable bias in the estimations. For this reason, some authors propose to construct an ICT index by aggregating individual indicators (Francois and Manchin, 2007; Vemuri and Siddiqi, 2009; Mattes et al., 2012) while others use several indicators in the same regression in order to be able to capture the diversity of the ICT capabilities (Timmis, 2012; Chung et al., 2013; Ramli and Ismail, 2014). The latter is the approach that we adopt in this work.

3.3. Distance variables

Various distance measures have also been proposed in the gravity models literature. But the most known and most used measure remain geodesic distance and the weighted distance measures (see Mayer and Zignago, 2011). Geodesic distance is calculated by using the great circle formula with longitude and latitude coordinates of the most important (most populated) city (or the capital city) of each country. The weighted distance proposed by Mayer and Zignago (2006) is calculated by using bilateral distances between the main agglomerations (cities) in the two countries and weighting these inter-city distances by the share of the city in the overall country's population (see Mayer and Zignago, 2006, 2011). Given the multiplicity of distance measures, the natural question that arises is to know what would be the more appropriate in the trade costs analysis. But, as stated by Vemuri and siddiqi (2009), the debate is not necessary since there exists an almost perfect correlation between any pair of distances measure. Indeed we found that the pairwise correlations between the three distance measure are at least 0.99

In this study, we privilege the geodesic distance by following the commonly used approach in the gravity model literature. We use the distance calculated between most populated cities. However the other distance measures are descriptively presented for illustrative purposes. All these distance variables are extracted from the CEPII GeoDist Database.

3.4. Control variables

In order to control other aspects of trade costs that are not directly related to distance and to ICT, other explanatory variables are added to model. These control variables are essentially dummy variables capturing respectively country pair landlockedness, commonality of their official language, whether they are in regional trade agreement, whether they use common currency and whether they have a past colonial link. All these variables have been extracted from CEPII Gravity database. However, it should be noted that CEPII Gravity database provides information only till 2006. Additional information has been gathered from other sources to complete information for the remaining years for time-varying variables such as regional trade agreement (RTA) or common currency variables. The RTA variable was updated using information from the WTO's Regional Trade Agreements Information System (RTA-IS) while the information on common currency status has been updated by looking at countries belonging the major currency union across the world.

Table I below presents the descriptive statistics on the main interest variable of the study.

Table I: Descriptive statistics

	Mean	SD	Min	Max	Growth rate*	N Obs
ICT monadic indicators	*Statistical unit: country-year*					
ICT infrastructure indicators						
Fixed telephone lines (per 100 inhbts)	22.45	19.42	0.00	79.68	3.51	61519
Mobile network coverage (per 100 inhbts)	90.65	19.02	0.00	100	0.56	64213
Secure internet servers (per million inhbts)	176.69	385.25	0.01	3025.1	27.31	64237
Internet bandwidth (MbB/s) per Internet user	48277.96	526992.1	0.00	9617645	42.05	68060
Personal computers (per 100 inhbts)	18.55	23.03	0.00	97.6	10.54	44504
ICT use indicators						
Mobile phone subscriptions (per 100 inhbts)	69.59	47.01	0.00	209.6	21.40	61641
Internet users (per 100 inhbts)	29.23	26.49	0.00	95	17.30	61372
Bilateral trade costs indicator	*Statistical unit: dyad-year*					
Total trade cost (ad-valorem equivalent, %)	269.71	154.51	0.23	2299.741	-1.34	68112
Distance indicators	*Statistical unit: dyad*					
Distance (most populated cities, km)	6877.86	4376.35	60.77	19812.04		7085
Distance (between capitals, km)	6856.18	4375.17	60.77	19812.04		7085
Distance (cities pop. weighted distance, km)	6868.67	4383.05	60.77	19650.13		7085
Contiguity (%)	3.51					6664
Traditional variables in gravity model	*Statistical unit: dyad*					
Landlocked (%)	33.95					7343
Common official language (%)	15.33					6664
Regional trade agreement (%)	16.25					6664
Common currency (%)	2.20					6664
Past colonial relation (%)	2.38					6664

* Mean average annual growth rate (in %) from 2002 to 2012

3.5 Construction of the dyadic values of the variables

All the ICT indicators presented in Table I are in *monadic* format since they are measured at individual country level. These monadic values have to be transformed in dyadic ones to be able to represent the extent of bilateral communication possibilities.

In the literature, it is customa use, for each country pair, the product of their monadic ICT indicators (e.g Freund and Weinhold 2004; Timmis, 2012; Kurihara and Fukushima, 2013). The advantage of the product of the monadic indicator is that it allows to capture the network-effect in the ICT development. Taking for example the case of two hypothetical countries, one with 2,000 internet servers, and the other with 3,000 internet servers. According to the network theory, the number of connection possibilities between these two countries is 6,000. Also, if there exist 3 million phones in the first country and 5 million in the second country, then the number of phone call possibilities between the two countries is 15 million. One can easily notice that these 15 million phone calls need not to be simultaneous since all international phone call transactions are not necessarily realized at the same time. They are delayed in the time. Hence, the real communication capacity between two countries is the product of their individual capacity. This argumentation is thus contrary to that of Vemuri and Siddiqi (2009) who advance the simultaneity argument to justify the use of the minimum value to capture the communication possibilities between the two countries. In final, to capture the network effect in the communication possibility between countries, a dyadic indicator is derived as the cross-product of the monadic indicators of each pair of countries. In this definition the variable ICT_{ijt} in equation (1) is calculated as follows:

$$ICT_{ijt} = ICT_{it} \times ICT_{jt} \tag{4}$$

Where ICT_{ijt} is the dyadic ICT indicator between country i and country j at time t while ICT_{it} and ICT_{jt} represent respectively the monadic ICT indicator in country i and j at time t. This formula is, thus, applied for each of the five ICT infrastructure variables presented in table I.

However, given the high interdependency between these indicators, a certain number of precautions should be taken in order to avoid redundancy and multicollinearity problems. In this regard, we perform a correlation analysis and multicollinearity test using the Variance Inflation Factor (VIF) indices. The results of these tests are shown in Table II below.

Table II : Correlations and multicollinearity diagnostics

	(1)	(2)	(3)	(4)	VIF	VIF*
(1) fixed_phone_lines_ij	1.00				[4.89]	[3.47]
(2) mobile_network_coverage_ij	-0.51(0.00)	1.00			[1.41]	[1.24]
(3) secure_internet_servers_ij	-0.77(0.00)	0.40(0.00)	1.00		[5.77]	[4.63]
(4) internet_bandwidth_ij	-0.53(0.00)	0.24(0.00)	0.74(0.00)	1.00	[2.41]	[1.92]
(5) personal_computers_ij	-0.87(0.00)	0.48(0.00)	0.87(0.00)	0.61(0.00)	[6.97]	----

Pearson correlation coefficients; pvalues in parentheses ; Variance Inflation Factors in brackets

The high and strong correlations between indicators combined with the high values of VIF on some variables lead us to suspect the multicollinearity problem. According to a commonly used rule of thumb, a VIF of 10 or higher denotes severe multicollinearity while a value between 5 and 10 is moderate multicollinearity. Given the highest correlations and the highest VIF observed on *personal_computers_ij*, we decide to exclude this variable from the list and re-run the diagnostic tests. As we can see from the last column of Table II, the VIF obtained after this exclusion (VIF*) decrease consequently and are all less than 5. The analyses will then be focused on these remaining ICT infrastructure variables. They are used in the regressions after taking them in logarithm.

4. Estimations strategy

Our empirical strategy is based on the use of a panel gravity model allowing to control all unobservable heterogeneities that potentially bias the results. As we can see from equation (1), the unobserved heterogeneities are captured by u_{ij} and v_t representing respectively the country pair and the time-specific effects. However, neither the classical fixed-effect estimator nor the random-effect one can be used to estimate the model (1). Indeed, since the fixed-effect estimator (obtained by the within transformation) removes all time-invariant variables such as distance, landlockedness, common language, etc…, the coefficients of these variables cannot be identified. Although the random-effect estimator (GLS) allows to determine the coefficients of the time-invariant variables, this estimator is known to be inconsistent when there exists a correlation between the explanatory variables and the specific bilateral effects u_{ij}. The usual approach to overcome these limits is to use the Hausman-Taylor estimator. Proposed by Hausman and Taylor (1981), this estimator is an instrumental variable estimator that allows not only to control for the potential correlation between explanatory variables and the specific effects but also allows to identify the parameter of the time-invariant variables.

The Hausman-Taylor has been used in number of gravity model studies such as Brun et al.(2005), Carrère and Grigouriou (2008). It has been used more specially by Vemuri and Siddiqi (2009) to analyze the impact of internet on trade flow. We follow the same estimation approach by assuming three conditions. First, the temporal effects are supposed as fixed and are captured by the time dummies in the regressions. Second, the country pair effects are supposed as random. Third, the ICT variables are supposed potentially correlated to error term e_{ijt} i.e. $Cov(ICT_{ijt}, e_{ijt}) \neq 0$. The latter condition refers to the endogeneity problem which is widely recognized in the literature (Clarke and Wallsten, 2006, Vemuri and Siddiqi, 2009). Finally, the merit of the Hausman-Taylor estimator is to be able to correct this potential endogeneity while controlling for the unobserved heterogeneities. We follow the same estimation approach in this study.

5. Results

The results are presented in Table III below. The column (1) corresponds to the results of our base estimation obtained without any interaction between ICT variables and the distance. The columns (2), (3), (4) and (5) correspond to the estimations of equation (1) by applying the hierarchical model estimation approach consisting in sequentially including regressors to see their individual contribution. This approach also allows observing the sensitivity of the results after their inclusion. In this spirit, columns (2), (3) and (4) correspond to the results of the estimation of equation (1) by sequentially including interaction terms for each ICT indicator with distance. Column (5) represents the results of the final estimation in which all interaction terms are jointly included. This column constitutes our reference column since it presents the results of the full model (see Table III below).

Table III : Estimation results ; dependent variable log of total trade cost

	(1)	(2)	(3)	(4)	(5)
log(distance_ij)	0.424**	0.472**	0.756**	0.809**	0.812**
	(0.013)	(0.020)	(0.088)	(0.088)	(0.088)
fixed_phone_lines_ij	-0.069**	-0.072**	-0.070**	-0.108**	-0.117**
	(0.021)	(0.021)	(0.021)	(0.021)	(0.022)
fixed_phone_lines_ij × log(distance_ij)		-0.008**	-0.008**	-0.013**	-0.014**
		(0.002)	(0.002)	(0.002)	(0.002)
mobile_network_coverage_ij	-0.001	-0.001	-0.271**	-0.335**	-0.344**
	(0.006)	(0.006)	(0.083)	(0.083)	(0.083)
mobile_network_coverage_ij ×log(distance_ij)			-0.031**	-0.039**	-0.040**
			(0.010)	(0.010)	(0.010)
secure_internet_servers_ij	-0.023**	-0.022**	-0.023**	-0.083**	-0.068**
	(0.001)	(0.001)	(0.001)	(0.004)	(0.007)
secure_internet_servers_ij × log(distance_ij)				-0.007**	-0.005**
				(0.000)	(0.001)
internet_bandwidth_ij	-0.001*	-0.001*	-0.001*	-0.002**	-0.015**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.005)
internet_bandwidth_ij × log(distance_ij)					-0.002**
					(0.001)
landlocked_ij	0.285**	0.287**	0.288**	0.287**	0.288**
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
common_official_language_ij	-0.019**	-0.020**	-0.021**	-0.021**	-0.022**
	(0.001)	(0.001)	(0.005)	(0.005)	(0.008)
regional_trade_agreement_ij	-0.064**	-0.064**	-0.064**	-0.047**	-0.046**
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
common_currency_ij	-0.182**	-0.183**	-0.178**	-0.163**	-0.162**
	(0.053)	(0.054)	(0.054)	(0.054)	(0.054)
past_colonial_relation_ij	-0.418**	-0.425**	-0.428**	-0.420**	-0.422**
	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)
Constant	6.430**	6.015**	3.553**	3.110**	3.085**
	(0.135)	(0.184)	(0.770)	(0.769)	(0.769)
Times dummies	yes	yes	yes	yes	yes
sigma_u	0.591	0.593	0.594	0.593	0.593
sigma_e	0.163	0.163	0.163	0.163	0.163
Wald chi2	5873.6	5867.5	5869.2	6105.2	6107.1
Prob > chi2	0.000	0.000	0.000	0.000	0.000
Observations	5066	5066	5066	5066	5066
Number of dyads	9315	9315	9315	9315	9315

Robust heteroscedasticity-consistent standard errors in parentheses,
Significance levels ** $p<0.01$, * $p<0.05$

Before moving to the discussion of the results concerning our hypotheses, a brief discussion is first done on the results obtained from the control variables. As one can see from the bottom part of Table III, the coefficients on the control variables appear, in most cases, significant and with expected sign. We found that trade costs increase significantly when, at least, one of the two trading partners is landlocked. In contrast, cultural, political and economic factors such as common official language, regional trade agreements, common currency and past colonial relationships all exert negative and significant effects on trade costs. The results tend to suggest that trade costs are significantly low between countries sharing strong cultural and economic ties.

Concerning the results on our main interest variables, we found that the elasticity of trade costs is about 0.8; which means that a 10 percent increase in distance between two trading partners increases trade costs by about 8%. This result appears statistically quite robust given the significance level of the coefficient.

On the effects of ICT variables, as we expected, the results show that ICT development contributes significantly to reduce bilateral trade costs. All the ICT variables included in the regressions have expected signs and significance. In the column (5) which corresponds to the results of the full model, it appears that a 10 percent increase in bilateral fixed phone capability decreases trade costs by about 1.1%. It also appears that a 10 percent increase in bilateral mobile network coverage possibility decreases trade costs by almost 3.4%. On the internet side, we found that enhancement of internet connection capability through the number of secure servers or the bandwidth capacity significantly reduces trade costs. The elasticity of trade costs to these two ICT infrastructure indicators are respectively -0.068 and -0.015.

Concerning the existence of a mitigating effect of ICT, one can see from Table III that all the interaction terms linking ICT variables to distance appear negative and significant. These results have a double interpretation. First, they indicate that the impact of ICT on trade costs are greater when the trading distance is important (i.e. when countries are more distant from one another). Indeed, in the light of equation (2), given that the direct and indirect elasticity of trade cost with respect of ICT have the same sign (negative), then the total elasticity of trade cost increases with distance. In this sense, the distance appears as an amplifying factor for the effects of ICT. Second, the significance of the interaction terms also means that ICT play a mitigating role on the effects of distance on trade costs. Indeed, given that the direct and indirect elasticity of trade costs to the distance are of opposite signs (see equation (2)), the total elasticity of trade costs to distance diminishes when the level of ICT increases. These results tend therefore to confirm our second hypothesis.

6. Sensitivity analysis

We conduct two sensitivity tests to examine the credibility of the results of the base estimations. In the first test, we replace the distance variable by the border contiguity variable. This variable is a binary variable that takes 1 if the country pair shares common border and 0 otherwise. This variable has also been extracted from the CEPII Gravity database. The main idea behind the first sensitivity test is the following. If it turns out that the effect of ICT is important for more distant countries than for less distant countries, then the significances of the interaction terms would disappear for countries sharing common borders. That is to say that, for adjacent countries, the effect of ICT on trade costs should only be limited to the direct elasticity. The results of this test are presented in Table IV below.

Table IV : Sensitivity analysis, distance replaced by border contiguity
Dependent variable is log of total trade cost

	(1)	(2)	(3)	(4)	(5)
contiguity	-0.896**	-0.833**	-0.994**	-1.105**	-1.105**
	(0.041)	(0.063)	(0.362)	(0.362)	(0.362)
fixed_phone_lines_ij	-0.005*	-0.004*	-0.004*	-0.005*	-0.005*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
fixed_phone_lines_ij × contiguity		0.014	0.014	0.007	0.009
		(0.011)	(0.011)	(0.011)	(0.011)
mobile_network_coverage_ij	-0.112**	-0.101**	-0.113**	-0.120**	-0.120**
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
mobile_network_coverage_ij × contiguity			0.018	0.031	0.033
			(0.040)	(0.040)	(0.041)
secure_internet_servers_ij	-0.023**	-0.023**	-0.023**	-0.023**	-0.023**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
secure_internet_servers_ij × contiguity				0.024	0.021
				(0.034)	(0.034)
internet_bandwidth_ij	-0.001*	-0.001*	-0.001*	-0.002*	-0.014**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
internet_bandwidth_ij × contiguity					0.001
					(0.002)
Control variables	yes	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes	yes
sigma_u	0.641	0.641	0.641	0.640	0.640
sigma_e	0.163	0.163	0.163	0.163	0.163
Wald chi2	5069.3	5072.1	5072.1	5169.7	5170.2
Prob > chi2	0.000	0.000	0.000	0.000	0.000
Observations	5066	5066	5066	5066	5066
Number of dyads	9315	9315	9315	9315	9315

Robust heteroscedasticity-consistent standard errors in parentheses ;
Significance levels ** p<0.01, * p<0.05

The first interesting aspect of this sensitivity analysis is the negative and significant association between contiguity and trade costs. It appears that trade costs are significantly low between countries sharing common border. In column (5) for example, the semi-elasticity of the trade cost with regard to contiguity is almost -1.10, indicating that trade costs are 1.10% lower when countries are contiguous. However, beyond the strong significance of the contiguity variable, no noticeable significance is observed on the interaction terms involving contiguity and ICT variables. These results tend therefore to reinforce the initial results.

The second sensitivity test we conduct is to compare the magnitude of the coefficients of ICT by stratifying sample into quintiles of distance. This test is based on the following idea. If it turns out that the effect of ICT is important for more distant countries than for less distant countries, then the coefficients that will be obtained for the top distance quintile sub-sample must be significantly higher than the coefficients obtained for the lowest quintile sub-sample. To examine this hypothesis, we divide the initial sample according to distance quintiles. Then we retain the two "more remote" subsamples namely the first quintile sub-sample (lowest quintile or the quintile corresponding to the bottom 20% of country pairs) and the fifth quintile sub-sample (highest quintile or the quintile corresponding to the top 20% of country pairs). The intermediate quintiles have been discarded to eliminate the possible non-monotonous effects of

ICT that may potentially due to the intermediate values of distance. The first quintile contains all country pairs for which distance is less than 2,640.1 Km while the fifth quintile contains all country pairs for which distance is greater than or equal to 10,681.5 km. The estimation results based on these two groups are presented in Table V below.

Table V : Sensitivity analysis, regressions for close and more remote countries
Dependent variable is log of total trade cost

	Lowest quintile (Distance < 2640.1 km)	Highest quintile (Distance >=10681.5 km)
fixed_phone_lines_ij	-0.062**	-0.081**
	(0.004)	(0.004)
mobile_network_coverage_ij	-0.035*	-0.127**
	(0.016)	(0.012)
secure_internet_servers_ij	-0.005**	-0.021**
	(0.003)	(0.002)
internet_bandwidth_ij	-0.015**	-0.019**
	(0.002)	(0.002)
Control variables	yes	yes
Time dummies	yes	yes
sigma_u	0.728	0.538
sigma_e	0.161	0.154
Wald chi2	1729.3	946.63
Prob > chi2	0.000	0.000
Observations	10319	10062
Number of dyads	1859	1769

Robust heteroscedasticity-consistent standard errors in parentheses,
Significance levels ** p<0.01, * p<0.05

As it appears in Table V, the magnitude of the coefficients on the ICT variables is markedly higher for the top distance quintile sub-sample than for the bottom distance quintile sub-sample. Considering, for example, the variable *fixed_phone_lines*, the coefficient is -0.062 for countries whose distance is less than 2640.1km (lowest quintile) while it is about -0.081 for those whose distance is greater than 10681.5 km (highest quintile). The difference of magnitude of the coefficient is also striking for the other ICT variables (see Table V). In final, all these sensitivity tests tend to consolidate our first results by supporting that the effects of ICT are significantly important for more distant countries.

7. Robustness check

In addition to sensibility tests, we also conduct some robustness checks to appreciate the solidity of the results. The first test is to replace the ICT infrastructure (access) variables by the ICT use variables. Two ICT use variables have been selected for this purpose: the number of mobile phone subscription per 100 inhabitants and the number of internet users per 100 inhabitants. The results obtained from these estimations are shown in the first three columns of Table VI below.

Our second robustness test consists to use a principal component analysis (PCA) to aggregate the access and use indicators in a unique ICT index. This index is then included in the regression as the aggregated ICT variable, replacing, therefore, the individual ICT indicators. Such an approach has been used by other authors such as Vemuri and Siddiqi (2009) who use factor analysis to build a synthetic ICT index. In our case, we perform a PCA on the logarithms of dyadic values of seven ICT variables presented in Table I. The first component of this ACP (capturing 75.06 percent of the total variance) is then used to predict an ICT index which we call *ICT_capability_index*. Results obtained by using this variable are shown in column (4) of Table VI.

Tableau VI : Robustness check : ICT use and ICT index as explanatory variables

Dependent variable is log of total trade cost

	(1)	(2)	(3)	(4)
log(distance_ij)	0.387**	0.386**	0.381**	0.416**
	(0.013)	(0.013)	(0.013)	(0.013)
mobile_phone_ij	-0.002*	-0.004*	-0.053**	
	(0.001)	(0.002)	(0.008)	
mobile_phone × log(distance_ij)		-0.005**	-0.006**	
		(0.001)	(0.001)	
internet_usersper_ij	-0.023**	-0.023**	-0.106**	
	(0.001)	(0.001)	(0.010)	
internet_users_ij × log(distance_ij)			-0.010**	
			(0.001)	
ICT_capability_index_ij				-0.139**
				(0.009)
ICT_capability_index_ij × log(distance_ij)				-0.011**
				(0.001)
Time dummies	yes	yes	yes	yes
sigma_u	0.598	0.598	0.598	0.589
sigma_e	0.167	0.167	0.167	0.163
Wald chi2	5169.8	5170.0	5238.1	5740.8
Prob > chi2	0.000	0.000	0.000	0.000
Observations	57043	57043	57043	50644
Number of dyads	11202	11202	11202	9315

Robust heteroscedasticity-consistent standard errors in parentheses,
Significance levels ** p<0.01, * p<0.05

As we can see from Table VI, the replacement of the ICT infrastructure variables by the ICT use indicators (or the estimations of the equations by considering an aggregate ICT index) do not modify the nature of the results and provide additional empirical arguments on the robustness of the results. They reinforce the idea that the ICT development has undeniably a significant beneficial effect regarding trade costs reduction.

Conclusion

Based on an unbalanced panel data on 2827 country pairs (178 countries) observed from 2002 to 2012, this study aimed to investigate the role of ICT development in mitigating the effects of distance on trade costs. For this purpose, two main hypotheses have been examined. In the first hypothesis, we suppose that the impact of ICT on trade costs increases with distance while in the second, we suppose that the effect of distance on trade costs decreases as the level of ICT increases. These hypotheses have been tested by estimating a panel gravity model using the

Hausman-Taylor estimator which is an estimator that allows dealing with the well-known specificities of the gravity panel models (unobserved heterogeneities, time-invariability of some regressors and potential endogeneity).

The results of the estimations testify the predominance of the role of geographic distance on international trade issues. For example, we found that a 10 percent increase in distance is associated with 8 percent increase in trade costs. Given the multiplicity of the implications directly associated with distance (high transport costs, high time costs, high information costs as well as uncertainties and risks), the question of its neutralization remains a serious policy challenge. Although significant roles have already been played by the increasing sophistication of transport technologies, everything suggests that distance continues to "survive". However, given the significant beneficial effects of ICT in terms of trade cost reduction especially on the dimensions directly related to distance, the actual proliferation of ICT tools seems to hold all its promises. To main results obtained in this study support this argument. On one hand, it appears that the elasticity of trade costs to distance diminishes significantly when the level of ICT increases attesting the existence of a distance-mitigating effect of ICT. On the other hand, the estimations show that the elasticity of trade costs to ICT increases with distance; meaning that the impact of ICT on trade costs is greater when distance between trading partners is more important.

Finally, the results obtained in this study tend to bring new insights into the "*death of distance*" hypothesis by implicitly suggesting that the relationship between trade costs and distance would fade when a certain level of densification of IC networks is achieved. However, such a claim would be valid only if other factors are taken into account such as transport costs, which are intrinsically linked to distance and reduction of which will depend uniquely on the performance of transport technologies. For this reason, the mitigating effect of distance of ICT identified in this study is first regarded as the *distance-neutralizing* effect instead of the *distance-killing* effect.

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Appendix

List of country included in the sample				
Afghanistan	China	Iceland	Moldova	Singapore
Albania	Comoros	India	Mongolia	Slovakia
Algeria	Congo	Indonesia	Montenegro	Slovenia
Andorra	Costa Rica	Iran	Morocco	South Africa
Angola	Côte d'Ivoire	Iraq	Mozambique	Spain
Antigua and	Croatia	Ireland	Namibia	Sri Lanka
Argentina	Cuba	Israel	Nepal	Sudan
Armenia	Cyprus	Italy	Netherlands	Suriname
Australia	Czech Republic	Jamaica	New Zealand	Swaziland
Austria	Democratic Republic of	Japan	Nicaragua	Sweden
Azerbaijan	Denmark	Jordan	Niger	Switzerland
Bahamas	Dominica	Kazakhstan	Nigeria	Syria
Bahrain	Dominican Republic	Kenya	Norway	Tajikistan
Bangladesh	Ecuador	Kiribati	Oman	Tanzania
Barbados	Egypt	Korea,	Pakistan	Thailand
Belarus	El Salvador	Kuwait	Palau	Togo
Belgium	Equatorial Guinea	Kyrgyzstan	Panama	Tonga
Belize	Eritrea	Lao	Papua New Guinea	Trinidad and
Benin	Estonia	Latvia	Paraguay	Tunisia
Bhutan	Ethiopia	Lebanon	Peru	Turkey
Bolivia	Fiji	Lesotho	Philippines	Tuvalu
Bosnia and	Finland	Liberia	Poland	Uganda
Botswana	France	Lithuania	Portugal	Ukraine
Brazil	Gabon	Luxembourg	Qatar	United Arab
Brunei Darussalam	Gambia	Macao	Romania	United Kingdom
Bulgaria	Georgia	Macedonia	Russian Federation	United States
Burkina Faso	Germany	Madagascar	Rwanda	Uruguay
Burundi	Ghana	Malawi	Saint Kitts and Nevis	Uzbekistan
Cambodia	Greece	Malaysia	Saint Lucia	Vanuatu
Cameroon	Grenada	Maldives	Saint Vincent and the	Venezuela
Canada	Guatemala	Mali	Samoa	Viet Nam
Cape Verde	Guinea	Malta	Sao Tome and Principe	Yemen
Central African	Guyana	Mauritania	Saudi Arabia	Zambia
Chad	Honduras	Mauritius	Senegal	Zimbabwe
Chile	Hong Kong	Mexico	Seychelles	
Colombia	Hungary	Micronesia	Sierra Leone	