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Do ICT and technological development facilitate supply chain trade?*

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Abstract

This paper aims to estimate the impact of ICT and technological development of countries on supply chain trade. As proxy measures of supply chain trade, the author applies domestic value added (DVAFX) included in gross-foreign exports, and foreign-value added included in domestic exports (FVA) from the Eora MRIO database while constructing the ICT variable by using confirmatory factor analysis. Furthermore, as a proxy variable for the country's technological development, the author applies the economic complexity index developed by Harvard's Growth Lab, conducting her analysis based on the structural gravity model estimated with the Poisson Pseudo-Maximum Likelihood Estimator (PPML). Together with the standard gravity regressors, the model includes the bilateral position of countries in the supply chain. Our panel dataset covers the 2000-2019 period, including 130 world countries. To control for the potential source of endogeneity, the model includes reporter and partner country fixed effects, yearly fixed effects, and country-pair fixed effects. The results confirm a statistically significant relationship between the country's technological development and supply-chain trade. Technological development enables a country to produce more complex, higher value-added products and thus to be more upstream positioned in the supply chain. The more upstream the country is in the supply chain, the higher the domestic value added is included in its exports.

Key words: *ICT, technology, supply chain trade, trade in value-added, PPML*

JEL classification: *C23, F14, O33*

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1. Introduction

Nowadays, most international trade consists of parts and components usually traded through a supply chain. A supply chain is a network that connects companies with their suppliers to produce and deliver a specific product to the end user, the customer, involving various activities, people, companies, information, and resources. The supply chain also refers to the stages necessary to move a product or service from its initial state to its final destination. Unlike traditional gross trade statistics, supply chain trade is often measured by the value added to the trade products. The logic behind this is that the parts and components are traded across the globe, typically crossing several national borders before becoming the final product. In traditional statistics, trade is counted each time the product crosses the border, leading to double counting and overestimated trade statistics. In the supply chain, only the value added by each country (firm) to the products is counted, and this is a more reliable measure of the global trade value (Saslavsky and Shepherd, 2014). Given the high complexity of supply chains, the many actors involved, and the large amount of information that needs to be shared, it is expected that information and communication technology (ICT) and technology itself can have a significant impact on supply chain trade. ICTs facilitate communication among stakeholders, speed up the documentation and border procedures, shorten trade times, and reduce trade costs. Felipe and Kumar (2012) argue that trade facilitation implies facilitating cross-border trade in goods, efficient physical and telecommunication infrastructure, customs, other trade-related authorities, and logistics services. Therefore, one can agree that ICT can serve as trade facilitation. Recent empirical evidence (Hoekman and Shepherd, 2013; Saslavsky and Shepherd, 2014; Yadav, 2014; Zaninović, 2022) confirms that trade facilitation is more relevant to the supply chain than to traditional trade. However, there is a gap in scholarly work addressing the impact of ICT and technological development on supply chain trade. Most of this work focuses on traditional trade, presented in the second part of this paper, the literature review.

The aim of this paper is to examine the impact of ICT on supply chain trade as measured by domestic value added in gross foreign exports and foreign value added in domestic exports. In addition, this paper also addresses the issue of the impact of a country's technological development on supply chain trade. The surrogate variable used for technological development is the economic complexity index developed by Harvard's Growth Lab. Technology can help countries produce higher value-added products and position countries upstream in the supply chain. Therefore, technologically advanced countries (firms) can be expected to have more domestic value-added content in their exports. This paper explains both the benefits of ICT and technology and the problems that supply chains face today. ICT and technological development have enabled unprecedented cross-border trade in goods and services and removed many practical barriers to cross-border trade.

The remainder of the paper is organized as follows. The second part of the paper reviews the literature on the relationship between ICT, technology, and trade in the supply chain. The econometric model specification is presented in the third part of the paper. The data and variables are described in the fourth part of the paper. The results are presented and discussed in the fifth part. The limitations of the research and concluding remarks are presented in the sixth part.

2. Literature review

The relationship between ICT and international trade is not new in the academic literature, and many scholars have researched the impact of information and communication technology on international trade. However, most studies have mainly focused on traditional gross trade statistics while often neglecting value-added trade statistics. It is partly because value-added trade statistics are relatively new, and partly because the literature on supply chain trade is mainly empirical (Vrh, 2018), although many authors nowadays model value-added trade (Koopman et al., 2010; Noguera, 2012; Antràs and Chor, 2013; Koopman et al., 2014; Timmer et al., 2014; Antràs and Chor, 2018; Antràs and de Gortari, 2020; Antràs, 2020, etc.). In the absence of literature on the relationship between ICT and supply chain trade, Table 1 below provides a summary of the literature on the relationship between ICT and technology and gross international trade.

Table 1: Summary of research on the relationship between ICT, technology, and international trade

Author(s)/year	Research questions	Sample/data	Methods	Results
Clarke (2002)	ICT → X	Eastern Europe and Central Asia, 1999	Gravity model, OLS + treatment effects	ICT→ X↑
Wilson et al. (2003)	TF (e-business usage) → X and M (manuf.)	75 countries, 2000-2001	Gravity model, OLS	TF→ X,M↑
Freund and Weinhold (2004)	Internet→X	56 countries, 1995-1999	Gravity model, OLS, Tobit	TF→ X↑
Fink et al. (2005)	communication costs→ IT	World countries, 1999	Gravity model, OLS	CC→IT↓
Soloaga et al. (2006)	TF (e-business usage) → X and M	Mexico, 2000-2003	Gravity model, Poisson	TF→ X,M↑

Author(s)/year	Research questions	Sample/data	Methods	Results
Demirkan et al. (2009)	ICT→ bilateral trade	175 countries, 2005	Gravity model, OLS	ICT → IT↑
Márquez-Ramos and Martínez-Zarzoso (2010)	technological innovation→ X	bilateral trade data by commodity SITC 4-digit; 13 X, 167 M, 2000	Gravity, OLS, PPML, Harvey	TI→ X↑
Hernandez and Taningco (2010)	TF (telecom. services) → bilateral trade (import data) (BEC) 1 digit	East Asia, 2006-2008	Gravity model, OLS, FE	Tel.(qual)→ M↑
Portugal-Perez and Wilson (2012)	TF (ICT) → export	101 countries, 2004-2007	Gravity model, OLS, PPML	TF (ICT) → X↑
Yadav (2014)	TF (ICT) → total and parts and components	77 countries, 2004-2007	Gravity model, OLS, PPML	TF→ X,M↑
Wang and Choi (2019)	ICT → X; M	BRICS, 2000-2016	Gravity model, POLS, FE, RE	TF → X,M↑

Source: Author's elaboration

The existing literature on the relationship between ICT and international trade shows the positive effects in the case of all ICT measures such as Internet use, ICT technology, or even communication costs. All studies use the gravity model specification as the basis for modelling international trade. As mentioned earlier, supply chain trade modelling is mainly empirical, and a theoretical model does not exist. Noguera (2012) was the first to include value-added trade in the gravity model. Furthermore, he proved that by applying gravity variables the supply chain trade could be explained. Koopman et al. (2014) and Antràs and Chor (2013; 2018) argue that value-added trade modelling should control for a position in the supply chain because the position in the supply chain implies whether a country participates move forward or backward in the supply chain. Position and participation are related to the value added by the country to the products being traded. The position is also closely related to technology because if a country is more technologically advanced, it may be in an upstream position and produce more value added. However, technology could also be an endogenous variable, as Antràs (2020) argues that higher levels of trade in the supply chain led to technology transfer and that countries that trade more are more likely to invest in technology. However, the higher a country's technology level, the more likely it is to affect supply chain trade significantly and positively. This study uses the gravity model and controls for endogeneity by including several fixed-effects dummy variables, which are described in another part of the study.

3. Methodology

Our model specification is based on the gravity theory of international trade, first introduced by Tinbergen (1962). The original gravity model states that trade between countries A and B is proportional to their mass (often measured as the natural logarithm of their gross domestic products) and inversely proportional to the distance between them (often measured as the weighted distance between the capitals of the trading countries). The gravity model is one of the most successful empirical models and is widely used in modelling international trade. Although the original model has only two variables, later models have been extended to include the various socioeconomic variables that affect bilateral trade (Behar and Manners, 2008; Behar and Venables, 2011; Host et al., 2019; Zajc et al., 2016, Bugarčić et al., 2020; Zaninović et al., 2021). Despite their successful predictability, the majority of standard gravitational regressors can be a source of endogeneity problems that lead to bias coefficients. To address endogeneity problems, the literature suggests performing a panel data regression analysis and including reporter and partner country fixed effects, year fixed effects, and country pair fixed effects (Anderson and van Wincoop, 2004; Baldwin and Taglioni, 2006; Baier and Bergstrand, 2007). Including reporter and partner fixed effects also helps control for the multilateral resistance terms (MTS) originally proposed by Anderson and van Wincop (2004).

The traditional gravity equation where both right and left hand side variables are in log form:

$$ln(IT_{ij}) = \beta_0 + \beta_1 ln(gdp_i) + \beta_2 ln(gdp_j) + \beta_3 ln(dist_{ij}) + \varepsilon_{ij} \quad (1)$$

however, estimating the gravity equations with OLS leads to inconsistencies in the presence of heteroscedasticity and also zero trade cannot be accounted for. To solve the problem of zero trade and heteroscedasticity, Santos Silva and Tenreyro (2006) propose to estimate gravity models in multiplicative form.

Therefore, our econometric model for value-added has the following structure:

$$\begin{aligned} SCT_{ijt} = exp\,(&\beta_0 + \beta_1 lngdp_{it} + \beta_2 lngdp_{jt} + \beta_3 rta_{ijt} + \beta_4 lndist_{ij} + \\ &+ \beta_5 contig_{ij} + \beta_6 comlang_{ij} + \beta_7 ict_{it} + \beta_8 ict_{jt} + \beta_9 tech_{it} + \\ &+ \beta_{10} tech_{jt} + \beta_{11} position_{ijt} + \delta_i + \pi_j + \lambda_t + \varphi_{ij} + \varepsilon_{ijt}) \end{aligned} \quad (2)$$

where SCT_{ijt} represents the supply chain trade, measured as domestic value added embodied in gross foreign exports (DVAFX) and foreign value added embodied in gross domestic exports (FVA). DVAFX corresponds to traditional exports while FVA corresponds to traditional imports. The value of trade is expressed in US dollars. The term *i* stands for the reporting country, while the term *j* stands for the partner country. Term *t* stands for the observed year. $\beta_1 - \beta_{11}$ are coefficients of elasticities. $lngdp_{it}$ and $lngdp_{jt}$ are the reporting and partner countries' gross domestic products that are log transformed. rta_{ij} is a free trade agreement dummy variable that has the value one if the trading partners has signed free trade agreement and it has value zero if they don't. $lndistw_{ij}$ is the weighted distance between the capital cities of the trading partners. $contig_{ij}$ is a dummy variable with value one if trading partners share common border and with value zero if they don't. Likewise, variable $comlang_{ij}$ is a dummy variable with value one if countries share common official or first language and with value zero if they don't. The variables ict_{it} and ict_{jt} represent the quality of the ICT infrastructure of trading partners, while the variables $tech_{it}$ and $tech_{jt}$ stands for the technological development of the countries. The quality of the ICT infrastructure of trading partners. $position_{ijt}$ denotes the position of the country *i* in year *t* in the supply chain. Terms $\delta_i + \pi_j + \lambda_t + \varphi_{ij}$ stands for the reporting country fixed effects, partner country fixed effects, yearly fixed effects, and country pair fixed effects.

In the estimation are included country-pair clusters to account for the correlation of error terms within country-pairs. To reduce potential endogeneity issues, all regressors are lagged by one year. The gravity equation is estimated with Poisson Pseudo Maximum Likelihood (PPML) proposed by Santos Silva and Tenreyro (2006), but we also report the results of the estimation with Pooled Ordinary Least Squares (POLS) just to compare the results with these two estimators. However, the POLS often proved to give biased and overestimated results.

4. Empirical data and analysis

The data for the analysis were gathered mainly from secondary sources. Data for supply chain trade, namely domestic value added (DVAFX), which is included in gross foreign exports, and foreign value added (FVA), which is included in gross domestic exports, were obtained from the Eora MRIO (2020) database. Standard gravity variables such as gross domestic product, free trade agreement data, weighted distance, contiguity, and common language are from the CEPII (2019) database. Our key variable of interest, ICT technology, is constructed using factor analysis (following the approach of Portugal-Perez and Wilson, 2012) based on the World Economic Forum (2019) three indicators: Availability of Latest Technologies, Technology Absorption at the Enterprise Level, and Government Procurement of Advanced Technology. The loading factors of the ICT technology variable are shown in Table 2.

Table 2: ICT technology variable – loading factors

ICT technology Cumulative variance				
	Reporter country		Partner country	
Factor	Variance	Proportion	Variance	Proportion
ICT technology	1.88978	1.0187	1.90422	1.0576
Factor loadings				
Variable	Factor1	Uniqueness	Factor1	Uniqueness
Availability of latest technologies	0.8083	0.2639	0.8140	0.2704
Firm-level technology absorption	0.7457	0.1580	0.7715	0.1741
Government procurement of advanced technology	0.3724	0.5784	0.4061	0.6092

Source: Author's calculation

Because values were missing in some years, data for the ICT technology variables were extrapolated by simple linear extrapolation for 2000-2006 and 2018-2019. We use the Harvard Growth Lab's Economic Complexity Index (ECI) for the technology (tech) variable. The ECI assigns countries a score based on the diversity and complexity of their export goods. Because of their specialized and developed capabilities, countries that rank high on the complexity index produce complex products with higher value added (Harvard's Growth Lab, 2021). The variable position is calculated using the approach of Koopman et al. (2010).

Supply chain position is calculated based on DVAFX and FVA, our dependent variables. The first step is to calculate the forward (FP) and backward (BP) participation of countries as follows:

- $FP = (DVAFX_{ijt}/grossexports_{it}) * 100$
- $BP = (FVA_{ijt}/grossexports_{it}) * 100$.

After calculating the forward and backward participation, the next step is to calculate the position. The log ratio of forward and backward participation is then used to calculate the position of countries in the supply chain. A higher ratio means a higher position in the supply chain. To obtain the position in the supply chain, the following formula was used:

- $position_{ijt} = \ln((1+FP)/100) - \ln((1+BP)/100)$.

Table 3 presents summary statistics for all variables in our model. Our dataset includes 130 reporting countries and 131 partner countries over the period 2000-2019.

Table 3: Summary statistics

VarName	Obs	Mean	SD	Min	Median	Max
FVA	145,023	24,7641.08	2.02e+06	0	1,537.425	1.14e+08
DVAFX	145,023	27,5057.96	2.29e+06	0	1,392.731	1.10e+08
gdp_*i*	292,523	5.28e+08	1.75e+09	860,550.3	6.67e+07	2.14e+10
gdp_*j*	290,997	4.79e+08	1.66e+09	409,000	5.69e+07	2.14e+10
rta	293,405	0.20	0.399	0	0	1
distw	293,405	7,241.68	4,336.073	14.136	6,891.347	19,650.13
contig	290,026	0.03	0.156	0	0	1
comlang	290,026	0.11	0.309	0	0	1
ict_*i*	218,096	-0.01	1.236	-4.322591	-.0052789	2.419836
ict_*j*	213,029	0.04	1.208	-5.144729	.0435262	2.636351
tech_*i*	293,538	0.16	0.974	-2.7013	.0559	2.8242
tech_*j*	293,421	0.04	0.996	-2.7989	-.0746	2.8242
position	145,023	0.00	0.000	-.0009062	-3.69e-10	.0041776

Source: Author's calculation

Table 4 presents the results of the supply chain trade estimation in four columns, where the first two columns contain the results of estimating supply chain exports (DVAFX) and supply chain imports (FVA) with the POLS -estimator, while the third and fourth columns contain the results of estimating supply chain exports (DVAFX) and supply chain imports (FVA) with the PPML-estimator. In the case of the POLS estimator, the dependent variables are log-transformed, while they are not in the case of the PPML estimator, as suggested in the gravity estimation literature (Yotov et al., 2016).

Table 4: Results of the POLS vs. PPML regression

VARIABLES	(1) POLS lnDVAFX	(2) POLS lnFVA	(3) PPML DVAFX	(4) PPML FVA
lngdp_*i*	0.497*** (0.0191)	-0.459*** (0.0229)	0.502*** (0.0605)	0.0327 (0.0331)
ln gdp_*j*	-0.236*** (0.0197)	0.587*** (0.0173)	0.0279 (0.0377)	0.484*** (0.0310)
1.rta	0.228*** (0.0269)	0.260*** (0.0271)	0.0333 (0.0534)	0.0300 (0.0221)
lndistw	-0.714*** (0.0218)	-0.717*** (0.0214)		
contig	0.911*** (0.0964)	0.738*** (0.0987)		
comlang	0.336*** (0.0421)	0.297*** (0.0384)		
ict_*i*	0.00208 (0.00547)	-0.0211*** (0.00433)	0.0230* (0.0138)	0.0334** (0.0141)
ict_*j*	-0.0109** (0.00554)	0.0276*** (0.00533)	-0.00587 (0.0153)	-0.0288*** (0.0110)
tech_*i*	0.0372*** (0.0132)	0.266*** (0.0182)	0.0622*** (0.0194)	-0.0847** (0.0355)
tech_*j*	0.0614*** (0.0116)	0.0160 (0.0100)	0.0467 (0.0696)	0.0136 (0.0211)
position	58,434*** (6,632)	-37,277*** (8,156)	13,648*** (3,099)	-30,562*** (2,443)
Yearly FE	Yes	Yes	Yes	Yes
Reporter FE	Yes	Yes	Yes	Yes
Partner FE	Yes	Yes	Yes	Yes
Country-pair FE	No	No	Yes	Yes
Constant	5.840*** (0.503)	9.539*** (0.549)	4.341*** (1.433)	4.763*** (0.872)
Observations	98,459	98,459	98,459	98,459
R-squared	0.931	0.933		

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Source: Author's calculation

5. Results and discussion

The GDP variables of the reported country and the partner country have statistically significant positive effects on supply chain exports, while the effects are statistically significant but negative in the case of supply chain imports with POLS, and not significant in the case of PPML. These results suggest that larger and developed economies are usually able to produce higher value-added products because they attract more foreign investment, technology, and knowledge, and thus have higher value-added production, which naturally leads to higher value-added exports. On the other hand, economic size is not significant in the best case for supply chain imports, as more developed economies are more forward oriented in the supply chain of higher value added products, rather than having more foreign content in their exports. The *RTA* (free trade agreement) variable has statistically significant effects in the case of the POLS estimation, while it is not significant in the case of the PPML estimation. However, the majority of trading partners signed RTAs throughout the observed period, with only 0.96% of RTAs entering into force during the observed period. Consistent with our expectations, the dummy variables contiguity and common official language have statistically significant effects on supply chain trade, as most supply chain trade is regional rather than global. In the case of the PPML estimation, these variables were omitted from the estimation because of the included country pair fixed effects.

As for our main variables of interest, ICT and technological development, ambiguous results emerge. In some cases, the reporting country's ICT quality has statistically significant and positive effects on supply chain trade, both exports and imports; in the case of the partner country's ICT, the results are statistically significant and negative. One would expect ICT to have only positive effects on trade because it speeds up trade processes, documentation, and communication, thus reducing trade costs, but on the other hand, it can also have some negative effects. For example, Antràs (2020) claims that new ICT technologies can affect the relative bargaining strength of different partners in the supply chain. Large buyers in wealthy countries can use ICT infrastructure to obtain information about a larger number of potential suppliers, which enables them to put these suppliers in competition with each other. As a result, the largest companies in wealthier countries can benefit from better trade conditions, while producers in developing countries receive a smaller share of the supply chain's trade profits. Finally, supply chain position, i.e., relative upstreamness, shows statistically significant and positive effects on supply chain exports, i.e., the higher the country's position in the supply chain, the more domestic value added goes into their exports. On the other hand, a higher position in the supply chain also means less foreign value added in exports, which is logical as countries strive to participate more in the supply chain and take an upstream position in the supply chain, which is associated with higher value added production and thus higher exports.

In general, the results suggest that ICT and technological development are important factors in value-added trade, and economic policymakers should focus on trade facilitation measures related to technological adaptation and implementation to increase domestic value-added exports. The findings also highlight the importance of supply chain position and show that countries should strive to take an upstream position in the supply chain and participate more forward in it. This study contributes to the current, mainly empirical literature on value chain trade and the role of ICT and technology in this context.

6. Conclusions

The aim of this paper was to examine the role that ICT and technology play in supply chain trade. Supply chain trade is measured by the domestic and foreign value-added share of exports. The analysis was based on the structural gravity model of international trade. In addition to the "standard" gravity variables, the estimation also controlled for relative bilateral position in supply chain trade. The technology variable used was the economic complexity index, a relatively new measure that indicates countries' technological capabilities to produce more complex and sophisticated products, and thus to attach a higher domestic value to the product, corresponding to the higher share of domestic value added in exports. Although most variables show the expected results, the results for ICT are ambiguous and indicate some negative effects of ICT that could be due to the misuse of the technology. However, the study should be seen as only a first step in understanding the role of ICT in supply chain trade. Its broader goal is to stimulate both theoretical and empirical research in this area. The analysis conducted at the country level somewhat limits the research scope, as supply chains differ across industries, and it would be interesting to examine how ICT affects supply chain trade across industries.Future research could focus on this area to analyse the impact of ICT at the industry level.

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IKT i tehnološki razvoj zemalja – olakšavaju li trgovinu lancem opskrbe?

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Sažetak

Cilj ovog rada jest procijeniti učinke IKT-a i tehnološkog razvoja zemalja na trgovinu u opskrbnom lancu. Kao zavisne varijable koje predstavljaju trgovinu lancem opskrbe su koriste se domaća dodana vrijednost (DVAFX) uključena u bruto inozemni izvoz i strana dodana vrijednost uključena u domaći izvoz (FVA). IKT varijabla je dobivena pomoću potvrdne faktorske analize, dok se za varijablu tehnološki razvoj zemlje koristi Indeks ekonomske složenosti, razvijen od strane Harvard's Growth Lab. Analiza se temelji na strukturnom gravitacijskom modelu, a model se procjenjuje Poissonovim procjeniteljem pseudo-maksimalne vjerodostojnosti (PPML). Uz standardni set gravitacijskih varijabli, model uključuje bilateralni položaj zemalja u opskrbnom lancu. Panel podaci obuhvaćaju razdoblje od 2000. do 2019. i uključuju 130 zemalja svijeta. Kako bi se kontrolirao potencijalni izvor endogenosti, u model se uključuju fiksni učinci zemalja izvoznica i partnera, fiksni učinci trgovinskih parova i godišnji fiksni učinci. Rezultati regresijske analize potvrđuju statistički značajnu vezu između tehnološkog razvoja zemlje i trgovine u opskrbnom lancu. Tehnološki razvoj omogućuje zemlji proizvodnju složenijih proizvoda s većom dodanom vrijednošću i time višu poziciju u opskrbnom lancu. Što je zemlja uzvodnije u opskrbnom lancu, to je više domaće dodane vrijednosti sadržano u njezinom izvozu.

Ključne riječi: *IKT, tehnologija, trgovina opskrbnim lancem, trgovina u dodanoj vrijednosti, PPML*

JEL klasifikacija: *C23, F14, O33*

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