ECONOMIC COMPLEXITY AND TRADE: NEW EVIDENCES ON THE TECHNOLOGICAL GAP

Paulo Ricardo da Silva Oliveira*
University of Campinas, Brazil

Abstract

Within modern evolutionary economics, the nexus of innovation and trade relationship is commonly regarded as a technological gap favoring the most technologically advanced countries. The multilateral gap is a measure of relative technological disadvantage of a country in relation to the most advanced countries. Many empirical and theoretical works have been done in the field of the technology-gap theory of trade, making use of common proxies for the gap – e.g. patents or R&D investments. However, these proxies are limited in terms of data availability and covers only a restrict number of countries. In this paper, the Economic Complexity Index (ECI) is accepted as an appropriate proxy for countries' technological capabilities and used to built a measure of bilateral technology-gap. Further, the technology-gap elasticity of trade is empirically estimated by means of a gravity equation, over a panel of 90 countries covering the years from 1995-2012. Results indicate that the bilateral gap demonstrates important impacts on bilateral trade. Better understanding of the technology and trade relationship is important for the economic development debate, especially for developing and underdeveloped countries. Industrial policy can be a determinant of structural trade imbalances leading to asymmetrical share of the gains of trade.

*Corresponding author: oliveira.prs@gmail.com

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1. Introduction

The idea of technology changes positively impacting exports via improvements on production efficiency or creation of temporary monopolies is broadly accepted, especially among theorists of the technological gap (Posner, 1961; Soete, 1981; Fagerberg, 1987; Maggi, 1993; Dosi et al., 2015; Verspagen, 1993) [1]. For these authors, technology gaps represent the level of technology advancement achieved by some countries – or, likewise, firms within these countries – compared to cutting-edge technologies available worldwide.

Technological differences across countries are seen as the major source of trade, and they turn out to be strongly related to the patterns of specialization. As the economic system is marked by intense and continued technology change, the technology-gap is dynamic, i.e. it changes over time.

This general idea of technological dynamic determing trade is present in many works, including those related to ”product-cycle” hypothesis, such as the North-South models of trade – see Krugman (1979). These models hold that technology innovation comprises several phases, from innovation to imitation, guarantying temporary monopolies to innovative countries. Technology-based advantages in international marketplaces depend on the capabilities of innovation of other countries, which is assymetric, as pointed out by Vernon (1966) and others.

Dosi et al. (2015), and Hufbauer (1970) before them, hold that trade flows are primarily driven by sector-specific absolute advantages, a result from strong asymmetries in countries capabilities to innovate and/or imitate. Importantly, advantages related to non-technological factors, such as land costs, human capital, among others, can potentially offset the benefits of technological leadership (Dosi et al., 1990, 2015; Dosi and Soete, 1988; Posner, 1961; Maggi, 1993).

Besides, a set of limitations including fully employment of all resources in every country, absence of dynamic increasing returns, perfect capital and labor mobility across sectors, among others, the Ricardian model holds that technology differences across countries is a source of Comparative Advantage (CA). In other words, perfect competition, absence of trade barriers, homothetic preferences and, in some cases, geography, will necessarily create an world with certain degrees of specialization and trade of goods and services. In the most recent versions of the model, firms can differ in terms of technology, but perfect competition wipes out variety – see Dornbusch et al. (1977); Eaton and Kortum (2002).

Although the ”neotechnology hypothesis” has been accepted and empirically tested in several studies, economists have struggled with the lack of adequate proxies for technology-gap. One of the major limitation is the existence of data covering a reasonable number of countries. Most studies rely on patent or R&D data, which is notably restrictive in terms of longitudinal extended availability, besides other

[1] Technology-gap theories are also known as the ”neotechnology” hypothesis. This jargon was mostly adopted during the 1980s.

flaws commonly related in terms of these proxies adequacy.

More recently, Hausmann et al. (2011) proposed an innovative measure of the complexity of domestic productive structures, the *economic complexity index* - ECI [2]. By economic complexity, the authors mean the amount of productive knowledge a country has, expressed in the diversity and ubiquity of the products it manufacturers (Hausmann et al., 2011). Noteworthy, author's description of knowledge, and how it is expressed in assymmetric innovative capacity around the globe, are notably analagous to ideas presented in many studies within evolutionary economics strand - see Dosi and Nelson (2010) for example. Moreover, the idea of differences in *economic complexity* as a source of notable asymmetries in the levels of economic development is consistent with both structuralist and evolutionary economics views (Raúl, 1959; Prebisch, 1950; Gala et al., 2016; Fagerberg, 1987).

As ECI is built upon the evaluation of diversity and ubiquity of products supplied by a particular economy, it can be interpreted as a technology-output measure. Knowledge directly affects innovation and imitation capabilities, which are reflected at the type of products a country produces - more accurately, exports. The ECI index is calculated from trade data and covers a large range of countries. Yet, as ubiquity and diversification are calculated from a multilateral binary matrix, based on high level of desegregation, it isn't directly correlated with the matrix volumes of bilateral trade, aggregated by products. In words, as knowledge embedded in complexes products are not ubiquitous and more knowledge enables the production of more diverse products, countries producing a variety of goods and a set of exclusive goods are more economically complex.

Bilateral trade dispersion and attraction have been treated by estimation of gravity equations for a long – see Anderson and Wincoop (2003) for a broadly accepted theory and estimation of gravity equation. However, estimatations of technology elasticity of trade, based on the building blocks of technology-gap approach, are rare. Soete (1981), however, by including size and trade costs effects into her analysis of technology-gap impacts on trade – proxied by GDPs and distance – , were somehow close to modern specifications of gravity. As gravity equations are structured to analyze trade between trade partners, one can estimate the impact of the technology-gap between a pair of countries on their bilateral trade. Interesting, the bilateral approach open a room for a slight and equally important evaluation of the technology-gap. Pioneers of the gap focused on a strictly multilateral approach, considering that leading countries trade more, no matter the destination of their exports. Although multilateral technology gap is important and its existence and impacts are corroborated by several empirical studies, including this one, the investigation of the relation of technology-gap and bilateral-trade is important. Let's use the terminology "bilateral gap" and "multilateral gap" to differentiate both types of gaps.

[2] Further information, datasets and publications are available at http://atlas.cid.harvard.edu

Hence, the aim of this paper is to estimate the trade elasticity of the bilateral technology-gap. In doing so, a standard gravity model for panel data is extended by a proxy of bilateral gap based on the ECI. Bilateral gap is expected to increase trade in favor of the most technology advanced economy, revealing a structural dimension of trade imbalances.

This study mainly contributes to literature by corroborating the existence of effects of technical progress in trade. It advances by considering a new proxy for the technology-gap, based on ECI, and by creating a measure of bilateral gap. A greater understanding of how technology-gaps and trade relates is paramount to economic development issues. If a reasonable proportion of trade imbalances is due to technology differences among countries, continued trade deficit treatment should include well designed industrial and innovation policies. This paper is divided into three remaining sections besides this introduction. Section 2 brings the methodology. Section 3 presents the estimated results. Finally, section 4 concludes the paper and set down policy implications.

2. Methodology

This is an empirical paper and formal theory of technology-gap generating gravity is not fully delivered [3]. Major methodological challenge, at this point, is to structure a gravity equation extended by an adequate proxy for bilateral technology-gaps.

In doing so, I explicitly departed from the most generally accepted specifications of gravity for panel data – see Egger and Pfaffermayr (2003); Baltagi et al. (2014) for details. Some of major concerns about misspecification of gravity equations amount to sample selection bias and estimation of linear models in the presence of high levels of heteroskedasticity. Also important, multilateral resistance to trade (MRT) and other non-observed countries' characteristics, and analysis of longitudinal data requires appropriate procedures to obtain unbiased estimates.

Taking these issues into account, country and year fixed effects were employed and a Poisson pseudo-maximum-likelihhod model was estimated in adittion to the usual Ordinary Least Square (OLS), as suggested by Silva and Tenreyro (2006) [4]. A model comprising such characteristics, i.e country and year fixed effects, are usually referred to as *three way model*. The linear form of the final equation to be estimated can be written as follows:

$$m_{ijt} = \beta_0 + \varphi y_{it} + \alpha y_{jt} + \gamma_{ij} + \omega_j + \lambda_j + \delta_t + \sigma T_{ij} + u_{ijt} \tag{1}$$

[3] Theory has been developed and will be published in the future.

[4] Two-stage estimations *a la* Heckman are also employed by trade economists, especially in the presence of strong evidences of sample selection bias. Helpman et al. (2008) developed a complete framework for a two-stage analysis, which treats for sample selection and firm heterogeneity biases.

where, lower cases represent the logarithm of corresponding variables, and y_{it} is country i's income, y_{jt} country j's income, γ_{ij} is a vector of time-invariant bilateral costs, commonly proxied by great-circle distances and a set of dummies capturing cultural proximity, such as colonial ties, common language, contiguity, among others. ω_j, λ_j and $delta_t$ are, respectively, fixed effects for country j, country i and time t. Finally, $sigmaT_{ij}$ is the bilateral technology-gap between country i and country j. Note that $sigmaT_{ij}$ is not linearized in the final equation. Estimates were also performed with the natural logarithm of $sigmaT_{ij}$, returning similar results in terms of statistic significance and signals. However, R^2 for both models revealed that the variable is preferred in its non-linear form.

Fixed effect interaction between countries and time are not included. But incomes of country i and j have been considered an adequate control for time variant effects Egger and Pfaffermayr (2003). Also, interactions between countries and year would turn the estimation of bilateral-gap elasticity inappropriate based on theory considered. In words, if technology catch-ups are considered, at best, rare, the bilateral-gap will be mostly time invariant. Interaction between fixed time and country effects disable estimation of time invariant effects. All tests and models were run in the Comprehensive R Archive Network (R Cran) making use of several packages, including *gravity*, *plm*, *glm*, *sandwich*, *lmtest*, *car* and *tseries* packages.

2.1. Data

Data on bilateral trade derives from BACI database, which was developed by CEPII at a high level of product disaggregation (for detailed information see Guillaume and Zignago (2010)). Data was aggregated to obtain total trade value in USD by partner and year. Traditional gravity data, such as distance, colonial ties, common language, contiguity, among others, come from the GeoDist database also by CEPII (for detailed information see Mayer and Zignago (2011)). Gross Domestic Product (GDP) at current prices comes from the International Monetary Fund (IMF) database. Finally, ECI were obtained directly from the data set made available by The Atlas of Economic Complexity team.

Final database comprises 145,440 observations for 18 years, 36 variables, and 90 different countries. From this sample, 130,662 observations returned positive bilateral trade values. In the Box 2, appendix A, all (7) variables actually entering the final estimations are described.

2.2. Bilateral technology-gap proxy

ECI index varies from -2.20800 to 3.25200 in the sample. Looking to create a measure of bilateral gap, one could simply create any relation between trade partners to capture their differences in terms of innovative/imitative performance. Let T_{it} be the technology status in country i for year t and T_{jt} the same for country

j. Thus, T_{it}/T_{jt} is the ratio of country i' technology in relation to technology in country j, T_{ij}. If ECI were strictly positive, one could assume $ECI = T_{ij}$, thus $T_{ij} > 1$ would signify country i has superior innovative capacity when compared to country j, and, analogously, $T_{ij} < 1$ the other way around. However, ECI is not strictly positive. Thus, it needed to be re-scaled to comprise strictly positive values ranging from 1 to 6.460. It was carried out by simply summing up a constant of value 3.20800 to all values within the time series [5].

3. Results and Discussion

Results are presented in Table1. As above mentioned, although being the most common econometric procedure, estimation via OLS may return biased coefficients in presence of heteroskedasticity, and it requires the drop out of non-positive trade volumes. Poisson pseudo-maximum-likelihood (PPML), however, is robust in presence of heteroskesdasticity and can be estimated over the entire sample regardless non-positive trade. As there is no consensus about the best procedure to estimate gravity, results from both models are presented for the sake of robustness. Remarkably, results are consistent within and between both models.

[5] Another way to calculate technology gap is to simply subtract original ECI of country i from ECI index of country j. Estimations were also employed to this alternative measure, but model significance is better with the ratio of re-scaled ECI. Nonetheless, both measures of bilateral technology-gap returned positive and significant values for all models.

Table 1. Estimates Results – Dependent Variable Bilateral Trade

	OLS (1)	*PPML* (2)
Distance	-1.451 ***	-0.911 ***
	(0.008)	(0.012)
Income $_i$	0.553 ***	0.796 ***
	(0.029)	(0.055)
Income $_j$	0.757 ***	0.937 ***
	(0.028)	(0.048)
Colony	1.064 ***	0.356 ***
	(0.023)	(0.026)
Language (ethno)	0.684 ***	0.065 **
	(0.017)	(0.021)
Land Border	0.460 ***	0.363 ***
	(0.033)	(0.022)
Tech Gap	0.302 ***	0.120 **
	(0.021)	(0.046)
(Intercept)	-17.416 ***	-27.650 ***
	(0.932)	(1.434)
Observations	130,662	145,440
R^2	0.8034	
Adjusted R^2	0.8031	
Resid. Std. Error	1.579 (df=130459)	
F Statistic	2797***	
	(df = 202; 130459)	

Note: * p<0.05; ** p<0.01; *** p<0.001
Robust Standard Errors for both models.
Year and country fixed effects omitted.

Time-invariant bilateral effects γ_{ij} - distance, colonial ties, common language and contiguity - returned expected coefficient values in terms of signal and magnitude, based on empirical and theoretical literature. Distance are expected to increase bilateral trade costs, as stated by the hypothesis of iceberg costs (Samuelson, 1952). Cultural ties, measured by colony and language, are expected to increase bilateral trade. Lastly, sharing a land border has also a positive effect in bilateral trade. Noteworthy, as reported in the seminal paper by Silva and Tenreyro (2006), colony and common language returns considerable smaller coefficients when PPML estimation is performed.

Let us focus on the estimated bilateral gap elasticity obtained from both models. First, bilateral gap elasticity is statistically and economically significant in both models, confirming the impact of bilateral technology-gap on bilateral trade in favor of most technologically advanced countries. Importantly, estimates using the same sample reveals that those countries with higher ECI indexes, without any transformation, export significantly more to any destination – 0.232 with $p < 0.0001$ in the PPML model, which consistently returns smaller coefficients values for all estimates. It suggests the multilateral gap is more important than the bilateral gap in determining trade – coefficient value 0.120 in PPML.

However, the bilateral gap is also important and brings out different information about bilateral trade. A positive trade elasticity of the bilateral-gap means that most technologically advanced countries trade more with with less advanced ones. In other words, countries with reduced innovative/imitative capabilities will face structural trade imbalances. It reveals the asymmetric nature of trade in presence of technology-gaps and corroborate dynamics of North-South models of trade. Moreover, the ”North” - or simply most innovative countries - relies on its innovative capacity to keep their commercial advantages, making technology spillovers or trade a rare phenomenon. As innovative capabilities is asymmetrically distributed around the globe, and they impact trade significantly, world trade network is not expected to qualitatively change over time. This ”stability” of world trade network is corroborated by empirical works Fagiolo (2009). Asymmetric distribution of innovation/imitation capabilities were not reduced by fragmentation of production around the globe. It means that international labor division, led by the interest of large corporations operating globally, can reinforce technology-gaps – see (Sarti and Hiratuka, 2017). It is possible that imitation is becoming more and more costly, given the complexity of modern technologies which requires coordination of vast ”pieces” of knowledge. As imitation is one of the counter-force closing the gaps, one can expect increases in technology gap in the future if domestic policies fail in improving innovation and/or imitation capabilities.

The results have important implications to theory and policy design. In terms of theory, although certain degree of specialization can be a natural outcome when economies goes from autarky to trade, qualitative aspects of such a specialization can generate very asymmetrical sharing of the gains of trade. This is because specializing in certain products – or production stages – will directly impact not only the exporting capabilities of a specific country, in terms of dollars per product, but also it development opportunities. As an illustration, some studies found a negative correlation between ECI and income inequality Hartmann et al. (2017).

Classical and neoclassical models of trade, usually ignore qualitative aspects of productive specialization as a source of trade asymmetry. Factor proportions models usually assume technology as a free good, making countries endowment the reasonable explanation for countries different capabilities of production and exportation. However, technology gaps matter to explain bilateral trade. In addition, the ECI itself, reveals that diversity of products is an important factor to measure complexity. More important, the capability of innovation/imitation is directly related to the type of specialization, since most complex products can be only produced in countries performing well in the ECI. This relation can been seen from the studies exploring the product space to identify possible reasonable ways a country could increase complexity by advancing in manufacturing goods that requires large amount of acquired knowledge – see (Hausmann et al., 2011).

In terms of policy design, macro-policies alone cannot solve trade imbalances if structural factors play an important role in explaining these imbalances. In this context, industrial and technology policies are required to close the bilateral gaps and improve countries' relative position in the global production chains. Current trade policies should include identifying acquired capabilities to qualitatively improve the export basket and revert negative impacts of specialization.

4. Conclusions

In this paper, the impacts of technological gap on bilateral trade were evaluated through a new proxy based on the Economic Complexity Index (ECI). In doing so, a model in which bilateral trade is a function of sizes, variable and fixed costs, and bilateral gap, were structured. More generally, this model can been see as an extension of a traditional gravity equation, broadly employed in the study of bilateral trade elasticities. Results shown that bilateral gaps significantly impacts bilateral trade in favor of most technologically advanced country. This has important theory and policies implications. In terms of theory, results suggest that specialization matters for explaining trade (im)balances and development opportunities, contrary to some of the general assumptions commonly found in classical and neoclassical models of trade. In terms of policy, findings suggest that besides macroeconomic policies, oriented industrial policies focused on innovation or imitation capacity are important to deal with trade imbalances. Future research on sector data can reveal interesting results about bilateral-gap and trade dynamics.

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A Appendix A

Table 2. Variables Description

Variable Name	Description	Source
Bilateral Trade	USD value of annual exports by year and partner - original variable v.	BACI-CEPII
Income $_i$ and Income $_j$	Gross Domestic GDP in current dollars - original variable Y_USD_crt.	IMF
Distance	Geodesic distances between most populated cities.Distance (or $distw$ in original database) was calculated following the great circle formula.	GeoDist -CEPII
Land Border	Dummy variable assuming value 1 if i and j are contiguous, 0 otherwise.	GeoDist -CEPII
Language (ethno)	Dummy variable assuming value 1 if i and j share a common language spoken at least by 20% of the population, 0 otherwise.	GeoDist -CEPII
Colony	Dummy variable assuming value 1 if i and j had/have a colonial tie, 0 otherwise.	GeoDist -CEPII
Tech. Gap	Ratio of re-scaled ECI index of country $_i$ over re-scaled ECI index of country $_j$	Atlas of Eco. Complexity

Table 3. Descriptive statistics

Statistic	N	Mean	St. Dev.	Min	Max
Distance	145,440	7,420.5	4,469.2	114.6	19,539.5
Income $_i$	145,440	467,522,145,902.0	1,396,413,284,828.0	1,370,000,000	13,600,000,000,000
Income $_j$	145,440	467,522,145,902.0	1,396,413,284,828.0	1,370,000,000	13,600,000,000,000
Tech. Gap $_ij$	145,440	1.1	0.6	0.2	6.4
Colony	145,440	0.03	0.2	0	1
Language (ethno)	145,440	0.1	0.3	0	1
Land Border	145,440	0.03	0.2	0	1