Cadeias Globais de Valor e Sistema de Inovação: uma Análise para a Indústria Aeroespacial[1]

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Resumo: Este artigo analisa a indústria aeroespacial através da teoria de cadeia global de valor (CGV), ligando a posição de um país na cadeia de suprimentos à força de seu sistema de inovação. A análise abrange o período 2007-2018 e inclui informações de 38 países. A participação dos países nas diferentes etapas da CGV é medida usando dados de exportação no nível do produto fornecidos pelo UN Comtrade, enquanto os indicadores do sistema de inovação são derivados de patentes depositadas no *United States Patent and Trademark Office* (USPTO). Os resultados apontam para a existência de uma relação entre capacidades de inovação e participação em diferentes estágios da cadeia de valor global aeroespacial: sistemas de inovação variados e abrangentes (qualidade) ao invés de mais intensivos (quantidade) parecem favorecer a participação de um país em projetos de maior valor agregado nas etapas da cadeia de valor. Essa evidência destaca a importância de desenvolver uma estratégia nacional de inovação visando o desenvolvimento de uma base de conhecimento diferenciada e a integração de diferentes atores para sustentar a indústria aeroespacial e aproveitar a fragmentação produtiva que caracteriza essa cadeia global de valor.

Palavras-chave: indústria aeroespacial, sistema de inovação, cadeia global de valor, competitividade comercial.

Código JEL: D4, O3, L62

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Global Value Chains and Innovation Systems: an Analysis of the Aerospace Industry

Abstract: This paper analyses the aerospace industry through the lens of global value chains linking a country position in the supply chain to the strength of its innovation system. The analysis covers the 2007-2018 period and includes information for 38 countries. The participation of countries to different stages of the GVC is proxied using export data at the product level as provided by UN Comtrade, while innovation system indicators are derived from patents filed at the United States Patent and Trademark Office (USPTO). The results point to the existence of a relationship between innovation capabilities and

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participation to different stages of the aerospace global value chain: varied and pervasive (quality) rather than more intensive (quantity) innovation systems seem to favour a country's participation in higher value-added stages of the value chain. This evidence highlights the importance of developing a national innovation strategy targeting the development of a differentiated knowledge base, and of the integration of different actors to sustain the aerospace industry and take advantage of the productive fragmentation characterizing this global value chain.

Keywords: aerospace industry, innovation system, GVC, trade competitiveness.

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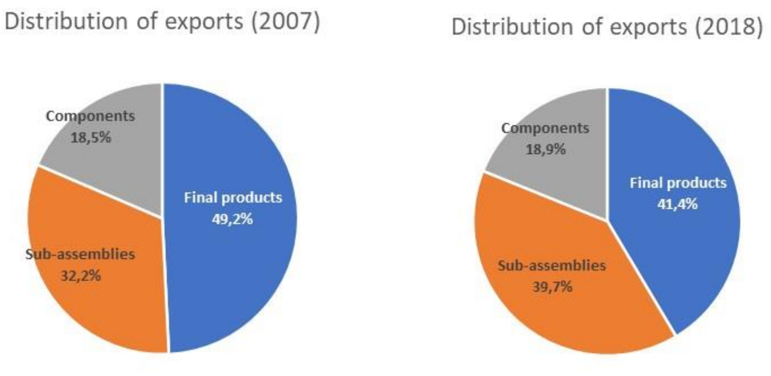
Introduction

The aerospace industry is a case of a high-technology industry that involves strong inter-company collaboration among firms operating at different levels of the value chain (HICKIE, 2006). The collaboration among firms has grown globally as a way to respond to market pressures and to strengthen their competitive capabilities (GEREFFI, 2014; MONROY; RAMÓ; ARTO, 2010). Nowadays, international partnerships are an important factor for large aerospace manufacturing companies (the Prime Contractors) to reduce production costs, to take advantage of the technological expertise of specialized suppliers, and to free resources allowing to focus on higher value-added production segments such as aircraft design, assembly, and marketing (BAMBER et al., 2013; BAMBER; GEREFFI; FREDERICK, 2016; NIOSI; ZHEGU, 2005, 2010; STURGEON *et al.*, 2013).

The growing importance of Global Value Chains (GVC) in the aerospace industry is reflected in the growth of exports in intermediate goods. Between 2007 and 2018 the value of exports of intermediate goods has grown at a rate of about 6% a year, increasing from 272$ billion to about 536$ billion.[2] At the same time, the composition of goods exported has also changed. Figure 1 shows that between 2007 and 2018 the share of sub-assembly goods (in the central stages of the value chain) has grown from 32% to about 40% with a correspondent decrease of the share of final products in total exports.

Figure 1: Distribution of exports across different stages of the aerospace value chain



Source: Authors' elaboration on Comtrade data.

These figures implicitly reveal that countries other than the traditional leaders are increasing their importance in the manufacturing of aerospace products. At the same time, the increasing relevance of the

[2] The classification of intermediate goods is the one used in the article, explained in the methodology section, and presented in the Annex (table A.3).

intermediate phases of production in GVCs suggests that countries may leverage their innovative capacities to move downward, or closer to the final markets, in the value chain.

Indeed, the aerospace industry is very R&D intensive and strongly relies on science and technology to sustain innovation and technological change (GOLDSTEIN, 2002; HARTLEY, 2014; MAZZUCATO; ROBINSON, 2018); in a word, it is a science-based industry (PAVITT, 1984). As a result, patents, know-how, and dynamic learning processes are typical means of technological change, appropriation and competitiveness.

Between 2007 and 2018, the raising importance of developing new solutions in the aerospace industry is reflected by the increasing number of patents filed. At the USPTO patents related to the aerospace industry have quadrupled growing from 2,225 to 9,494 (against an overall increase of patent filings of about 20%) and involving an increasing number of companies from different countries (from 36 to 63).[3]

This paper analyzes the aerospace industry through the lens of global value chains (GEREFFI; HUMPHREY; STURGEON, 2005; HUMPHREY; SCHMITZ, 2002) linking a country position in the supply chain to the strength of its innovation system (IS) (FREEMAN, 1995; LUNDVALL, 1992). We posit that the country context is important to improve productive, scientific, and technological capabilities, and thus to move towards stages of the GVC dealing with products with a higher technological content. This mechanism coexists with the pressure for cost reduction, which acts as a centrifugal force for offshoring or outsourcing the less complex parts of production within the hierarchical governance structure characterizing the aerospace GVC.

In particular, following the theoretical importance of forward-feeding and feedback flows linking ISs and GVCs (LEMA; PIETROBELLI; RABELLOTTI, 2019; LEMA; RABELLOTTI; GEHL SAMPATH, 2018), this study analyses the linkages between countries' foreign competitiveness and IS features in order to answer the following question: *to what extent does the innovation system of a country affect its competitiveness in different stages of the aerospace GVC?*

The paper is organized as follows. In section two, we present the theoretical framework with a focus on the specificities of the aerospace industry both with respect to the GVC and to its technological development and IS. In section three we present the data and the methodological framework. In section four we report and discuss the results of our analyses. Finally, in section 5 we conclude drawing some policy implications especially with respect to less advanced countries.

2. Theoretical framework

2.1. Global Value Chain (GVC)

The GVC approach considers the value chain structure of an industry from a global perspective to derive industry specific evidence (FREDERICK, 2019). A value chain is the full range of activities required to complete a product, including activities such as design, production, marketing, distribution, support, and after-sales services to the final consumer. When these activities are divided among companies located in different countries, the value chain is analysed in the global context giving rise to the concept of GVC (GEREFFI; HUMPHREY; STURGEON, 2005; HUMPHREY; SCHMITZ, 2002).

Studies on GVC have evolved since the early 2000s moving from a theoretical characterization based on governance issues to include an increasing recourse to data analysis thanks to the widening of information on international transactions (PONTE; GEREFFI; RAJ-REICHERT, 2019). In general, GVC studies aims at answering three main questions: how is value added along the chain? How is the distribution of the value-added defined and who coordinates it? How can firms/countries improve their participation in GVC and enter into more complex segments?

[3] The technological classes considered will be discussed more in detail in the methodology section and presented in the Annex.

As we said, initially studies on GVC mainly used case studies, exploring the governance relationship between lead firms and their suppliers, based on the observation that specific actors are more important than market exchange in coordinating activities (GEREFFI; HUMPHREY; STURGEON, 2005; GEREFFI; KORZENIEWICZ, 1994; GIBBON; BAIR; PONTE, 2008). Over time, the focus moved to more quantitative analyses to identify the value-added in each stage (ATHUKORALA, 2010), and trade-in-value-added indicators based on input-output datasets were developed (TIMMER et al., 2014; STURGEON, 2019). Common to the different approaches is the recognition of strong industrial specificities and the need to integrate qualitative and quantitative analysis on specific industries (UNCTAD, 2020; LEMA et al., 2021).

2.2. Aerospace industry specificities

The aerospace industry is a high value-added sector characterized by a strong role of national governments related to issues of sovereignty and the efforts to implement strategies to foster competitive industrial and technological capabilities. This is made more complex because many different technologies contribute to the final products (HAYWARD, 1994; LANDONI; OGILVIE, 2019; MCGUIRE, 2014). The industry is also characterized by strong global trade linkages coordinated by few aircraft producers. These firms largely rely on scale economies to sustain their leadership, and invest remarkable sums in learning and R&D to compete in the global market (NIOSI; ZHEGU, 2010).

Many national case studies on the aerospace industry have been realized by experts and/or academic centres commissioned by professional associations or government agencies. These studies are frequently based on a GVC approach (BAMBER *et al*. 2013; BAMBER, GEREFFI, AND FREDERICK 2016; MCGUIRE 2014; STURGEON *et al*. 2013), on cluster theory (KETELS *et al*., 2015; PORTER *et al*., 2011) or on descriptive sectoral analyses (ECORYS, 2009; HAYWARD, 2013; TAXOVA, 2014).

Also the academic research has followed a similar pattern and focused on various approaches: GVCs (ELOLA; VALDALISO; LÓPEZ, 2013; MONROY; ARTO, 2010; NIOSI; ZHEGU, 2010), clusters/regional innovation systems (BIGGIERO; SAMMARRA, 2010; COOKE; EHRET, 2009; HICKIE, 2006; LUCENA-PIQUERO; VICENTE, 2019), and mixed approaches (NIOSI; ZHEGU, 2005; ROMERO, 2011; TURKINA; ASSCHE; KALI, 2016).

Many authors have highlighted how the national innovation environment is an important asset in the evolution of productive capacities in this industry (ALBERTI; PIZZURNO, 2015; MANI, 2013). Improving national capabilities is frequently conceived as a government-centred strategy, with governments committed to science and innovation (ALTENBURG; SCHMITZ; STAMM, 2008; LEE; YOON 2015; WINTHROP; DECKRO; KLOEBER, 2002) and employing industrial policies based on subsidies, public procurement and special regulations (BRADDORN; HARTLEY, 2007; MCGUIRE, 2014; WTO, 2010).

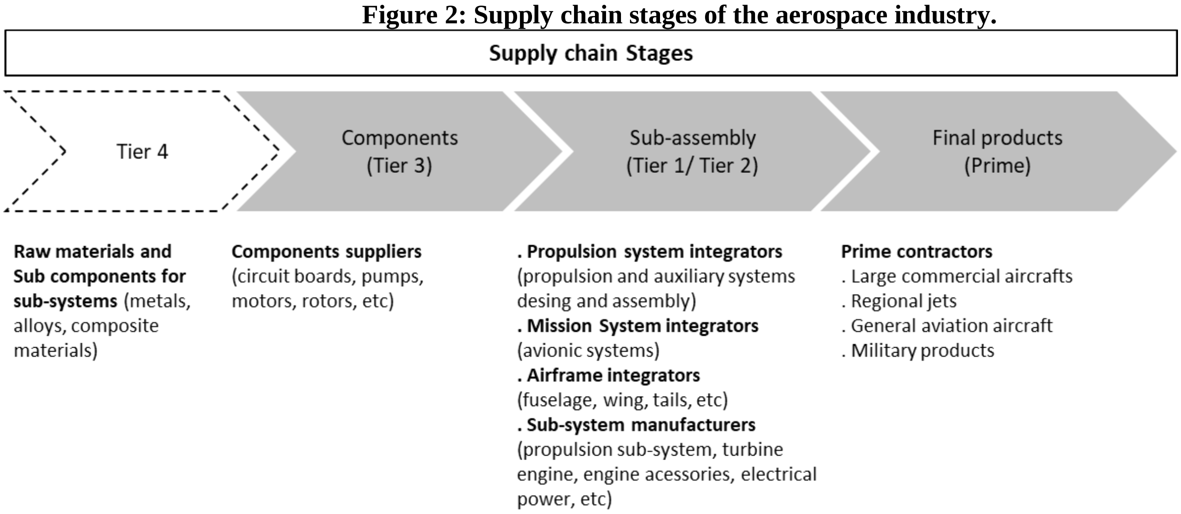
The relevance of the IS for the aerospace GVC is widely acknowledged because the national context is perceived as a key factor shaping productive, scientific, and technological capabilities. However, the GVC analysis of specific industries has often suffered from the unavailability of inter-firm transactions to provide information on the value-added. Input-output (IO) tables have helped to remedy this drawback and measure value-added in GVC (AHMAD et al. 2017; JOHNSON, 2018). However, despite their usefulness in explaining value-added and compare it across countries (BORIN; MANCINI, 2019), they pose serious limits for the analysis of specific sectors. Indeed, IO tables are generally available at a rather aggregate level (e.g., 2-digit industry level), while the analysis of GVCs within a specific industry requires a much more detailed classification. This is why in this paper we choose to use data on products to measure different stages of the aerospace GVC.

The structure and stability of GVC governance and the distribution of power is a relevant dimension of GVCs in different industries (GEREFFI; HUMPHREY; STURGEON, 2005). The aerospace GVC is characterized by a hierarchical structure, dominated by leading companies (Prime Contractors) that keep a stable control over the supply chain and the related knowledge flows (MCGUIRE, 2014; MONROY; ARTO, 2010; NIOSI; ZHEGU, 2005). The governance mode is almost the same with respect to technological and productive capabilities, and the upgrading toward value-added segments is frequently treated as intrinsically connected to the improvement in downstream supply chain capabilities (BAMBER et al. 2013; BAMBER; GEREFFI; FREDERICK 2016; TURKINA; ASSCHE; KALI, 2016).

The relationship between countries' competitiveness and innovation systems is largely product specific, but usually innovation capabilities are increasingly important when moving down the value chain from basic components to final products embodying different technologies. In other words, we expect countries' competitiveness in stages of the supply chain producing higher value-added products to be more tied to the strength of the innovation system.

To highlight the different stages of production in the aerospace industry a tiered supply structure has been commonly adopted (BAMBER *et al.* 2013; BAMBER; GEREFFI; FREDERICK 2016; NIOSI; ZHEGU, 2005, 2010; STURGEON *et al.*, 2013). Figure 2 illustrates the tiered structure of the aeronautics value chain. The upstream stage (Tier 4) mainly involves raw materials and components which can meet multiple purposes, or feed into other value chains: for which it is difficult to derive measures specific to the aerospace industry; therefore, we will not include this stage in our analysis. Moving down in the value chain, products show a higher degree of technological content, become more specific to the industry, require higher innovation capabilities and a closer relationship with lead/firms. In tier 3 suppliers manufacture specific components such as rotors or pumps, that have a lower level of complexity. In tiers 1 and 2 suppliers produce goods of an intermediate level of complexity, integrating different components into part of the systems, so/called Sub-assemblies, that are used by the prime contractors to manufacture final products.

Figure 2: Supply chain stages of the aerospace industry.



Source: Own elaboration based on Bamber *et al.* (2016) and Sturgeon *et al.* (2013).

The value chain is governed by the prime contractors, that produce final products and are responsible for project management, airframe assembly, final systems design & integration, marketing, and sales. Prime contractors define distinct modes of relationship considering the capabilities of suppliers, which in turn seek to upgrade their outputs as a mean to move to a tier closer to the final product. This process of competitive upgrading has generated upstream and downstream pressures on Tier 2 companies, mainly those located in developing countries (BAMBER; GEREFFI; FREDERICK, 2016). We will use this tiered structure to measure the countries' participation to the GVC and assess the role of its innovation system.

In the Innovation System literature, the process of generating innovations is seen as the outcome of a complex and dynamic social system, involving networks of different agents and institutions that interact, promote, modify and disseminate new knowledge and technologies (FREEMAN, 1995; LUNDVALL, 1992). When looking at the innovation system from a sector perspective, these are defined as '*a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production, and sale of those products*' (MALERBA, 2002, p.250). The assumption is that a series of factors impact innovation, like market features, innovation networks, and the regulatory regime (MAZZUCATO; ROBINSON, 2018). Following Lee and Lee (2019), we will thus consider a specific approach to measure and proxy the strength and depth of the IS in the aerospace industry and analyse its role in GVC participation.

3. Data and methods

The empirical analysis covers the 2007-2018 period and includes information on 38 countries (see table A.1).[4] The information is derived from different sources of data. The main set of indicators is derived from the UN Comtrade database (GVC indicators) and from the USPTO (Innovation System indicators); in the regression analysis we will control for a set of variables from other data sources.

3.1. Linking trade data to the stages of the aerospace value chain

As we said, we measure a country participation to the aerospace GVC by unpacking its manufacturing exports across different stages of the value chain. To identify products from the aerospace industry we rely on the 6-digit level of the Harmonized System (HS), the international nomenclature for product classification that defines standards for about 5,300 different product classes. Previous studies analyse the aerospace industry conceptualizing its value chain, and identifying the types of goods that correspond to different stages of the value chain and the relative HS product classes (BAMBER; GEREFFI, 2013; BAMBER et al., 2016). We build on and elaborate their findings and list of products. The interaction with aerospace engineers at the Aeronautics Institute of Technology (ITA) allowed us to integrate the initial list of 6-digit HS products with additional entries,[5] and at the same time highlighted the need to slightly modify the product-tier (stages) correspondence to better represent the aerospace industry.

We use a classification of aerospace products into Final Products (Prime contractors), Sub-assemblies (Tiers 1/2), and Components (Tier 3) to proxy different stages of the value chain (table A.2). As we said, we do not consider tier 4 because it is principally made of horizontal suppliers that provide a large range of durables and capital goods that, while can be used by, are not specific to the aerospace industry.

3.2. Identifying the core technologies for the aerospace industry

We rely on USPTO patent applications to proxy a country IS in the aerospace industry. We acknowledge that proxying the IS by means of patents allows to capture the technological dimension but is unsuited to measure organizational and economic competencies (Dosi & Teece, 1998). We are also aware that the choice of using patents from USPTO may introduce a home bias due to the fact that, even with similar levels of inventive activity, US applicants may tend to file more patents at the USPTO than foreigners (Dernis & Khan, 2004). Therefore, we have also ran robustness checks excluding the USA from the regression analysis; results, not reported but available upon request show that the exclusion of the USA from the analysis does not change the results significantly.

To identify patents related to the aerospace industry we have performed a search into the International Patent Classification (IPC) because available concordances between patents and industrial sectors do not detail industries enough for our purpose (e.g., LOOY et al., 2015). The initial list of IPC codes has been discussed with specialists – academic engineers, employees of the Brazilian Air Force and of firms in the Brazilian Aeronautical industry – and refined accordingly. The guiding principle of the exercise was to identify the core technologies related to the aerospace industry; otherwise said, we opted to

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[4] Following recent literature (BAMBER et al., 2013; BAMBER; GEREFFI; FREDERICK, 2016; STURGEON et al., 2013), the analysis is performed on top exporters and relevant emerging countries. Countries were ranked according to the value of export in aereonautics for 2018 and the sample was cut to include the last emergent country quoted in the literature; the approach resultef in the selection of 38 countries that are responsible for about 80% of world sector exports.

[5] For example, we have added the following codes not considered previously: 880100 – Balloons and dirigibles; gliders, hang gliders and other non-powered aircraft, 880260 – Spacecraft; (including satellites) and suborbital and spacecraft launch vehicles analysis, 840890 – Engines; compression-ignition internal combustion piston engines (diesel or semi-diesel engines), of a kind used for other than marine propulsion or the vehicles of chapter 87; 880521 – Ground flying trainers and parts thereof; air combat simulators and parts thereof.

minimize the risk to include patents not really related to the aerospace industry. The list of codes used to retrieve patents data can be found in the annex (Table A.3).

3.3. Measuring the IS of the aerospace industry

We rely on two main variables to proxy the aeronautics innovation system of the countries included in the analysis. First, we consider the number of aeronautic-related patents filed by firms of a given country; this provides a measure of the overall streght of the innovative capacities of the aeronautics sector. Second, we build an indicator to capture more qualitative features of innovation systsms considering three dimensions: *i)* the extent at which knowledge production is diffused across the economy (*diffusion*); *ii)* the technological diversification of aeronautics patents (*diversification*), and *iii)* the extent to which knowledge production in aeronautics relies on a diversified set of technologies (*originality*).

To capture the first dimension, *diffusion*, we rely on Lee and Lee (2019) and, for each country *c*, consider the complement to one of the Herfindahl–Hirschman Index, a widely used concentration index:

$$diffusion_c = 1 - HHI_c = 1 - \sum_{i \in I_x} \left(\frac{n_{it}}{n^*_{xt}} \right)^2$$

where I_x is the set of patent applicants, n_{it} is the number of patents an applicant *i* files in year *t*, and n^*_{xt} is the total number of patents applied by country *x* in year *t*. Countries with higher values of *diffusion* show a less concentrated production of knowledge across actors.

Technological *diversification* is the number of IPC 4-digit clasess[6] in which a country has patents normalized by the total number of possible IPC classes in a given year:

$$diversification_c = N_{ct}/N_t$$

Finally, to measure *originality* we rely on Trajtenberg et al. (1997) that stressed the importance of knowledge diversification for innovation suggesting that by relying on a large number of diverse knowledge sources of R&D a country may have higher chances of obtaining original results:

$$originality_c = \left(1 - \sum_{k=1}^{N_i} \left(\frac{Ncited_{ik}}{Ncited_i} \right)^2 \right)_{xt}$$

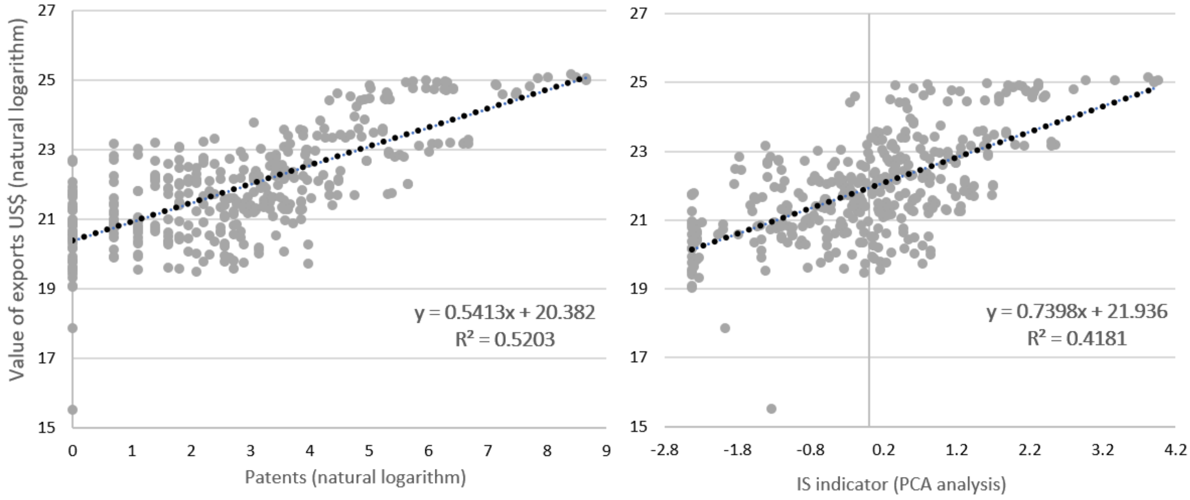
where k is the technological sector (WIPO classification) or scientific area, $Ncited_{ik}$ is the number of citations made by patent *i* to patents that belong to patent class *k* (scientific area *k*), and $Ncited_i$ is the total number of citations made by patent (paper) *i*.

A principal component analysis (PCA) was performed considering these three indicators to extract a variable capturing qualitative aspects of the aeronautic innovation system. The results of the PCA are reported in the appendix (table A.4), and according to the eigenvalue criteria we retain the first component, which captures about 56% of the total variance, in the regression analysis. The component is positively related to the three variables considered, but especially with *Diversification* and *Diffusion;* the variable *Originality* is particularly relevant for the second component, which we will include in the supplementary regressions as a robustness check (table A.7).

In figure 3, we plot the value of total exports against the two innovation system variables: patents (in logarithms) on the left, and the IS qualitative indicator on the right. The two variables are highly correlated (see table A.6), revealing a strong and positive association between the number of patents developed in a country and the diversity and pervasiveness of its innovation system. The figure highlights a positive relationship between exports and both patents and the IS indicator.

[6] At the 4-digit level, the IPC classification defines about 625 technical classes to which a patented technology may be assigned.

Figure 3: Aeronautic exports and IS variables: patents and IS qualitative indicator



Source: Own elaboration.

In the econometric analysis, we will test whether specific relationships arise along different stages of the value chain in a multivariate framework (i.e., controlling for a series of other factors).

3.4. Econometric framework

We measure countries' competitiveness in different stages of the value chain considering two different approaches. First, we look at the absolute advantages of countries measured as the value of *exports* of final goods, sub-assemblies and components. Second, we consider the countries' revealed comparative advantage (*RCA*)[7] looking at the relative export specialization in each stage of the value chain. The aim is to assess whether IS can have a different role in determining the countries' (absolute and relative) competitiveness across the GVC.

We test the above relationships using two-way fixed effects models with the following specification:

$$y_{it} = \beta_0 + \beta_1 IS_{it} + \sum_{k=1}^{N} \vartheta_k X_{it} + \theta T_t + \alpha_i + \varepsilon_{it}$$

where y_{it} stands for the total value of exports or RCA for each stage of the GVC; β_0 is the constant term; IS_{it} are the variables measuring the strength of the innovation system of a country *i* (*patents* and *IS quality* indicator); X_{it} is the matrix of control variables; T_t are year dummies; α_i denotes a vector of country-specific non-observed characteristics; ε_{it} is the idiosyncratic error and β_1, ϑ_k and θ are the parameters to be estimated. The two-way fixed effect approach allows us to control both for country specific time-invariant determinants of competitiveness and for unobserved determinants that vary commonly across countries during the period of observation, as well as for possible macroeconomic shocks.

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[7] Revealed Comparative Advantage (RCA) is measured by the following equation:

$$RCA_{p,c} = \frac{\frac{Exp_{c,p}}{\sum Exp_c}}{\frac{\sum_{p=1}^{N} Exp_p}{\sum_{c=1}^{N} Exp_c}}$$

where $Exp_{c,p}$ is the amount of exports of country *c* of product *p*, $\sum Exp_c$ is the sum of exports of country *c*, $\sum_{p=1}^{N} Exp_p$ is the sum of exports of product *p* over the world and $\sum_{c=1}^{N} Exp_c$ is the sum of exports of the whole world. This index measures whether a product's share in a country's export basket is larger or smaller than the product's share in world trade, revealing its comparative advantage in exporting it. The index was first proposed by Balassa (1965).

The first control variable is *GDP per capita*, meant to capture the fact that with economic development countries tend to move toward more knowledge intensive and complex stages of the GVC (GEREFFI, 2018); the variable is taken from the World Bank Development Indicators dataset.[8] We also control for the country *export diversification* of aeronautic products considering the inverse of the concentration index of exports (1-HHI_{exp}). This variable is meant to capture the fact that in aeronautics artifacts integrate a series of different complex products, and therefore a broader diversification may facilitate the integration of different competencies leading to the production of more complex artifacts (VÉRTESY, 2017). Trade diversity is calculated at the 6-digit level of the HS classification. Finally, we control for the *military expenditures* of governments. The aeronautic industry is strictly tied with the military one with many players developing products both for civilian and military purposes (e.g., Airbus or Boeing). On the one hand, military spending may have demand-pull effects for the whole industry and thus provide support also to organizations that develop civilian innovation both through knowledge spillovers and sub-contracting (MOWERY, 2009; RUTTAN, 2006). On the other hand, the development of cutting-edge military technologies may lead to secrecy for national security reasons and trade restrictions on specific products due to geopolitical considerations (HARTLEY; SANDLER, 1995). Overall, even though we deem necessary to control for *military expenditures*, we do not have a clear expectation on the sign of the coefficient; the variable is obtained from the Stockholm International Peace Research Institute (SIPRI) database.[9]

All monetary variables are taken in logarithms (*exports diversification, GDP per capita, military expenditures*). In all models we tested for possible multicollinearity and for heteroskedasticity in the residuals. The variance inflation factor takes values smaller than 3 in all the regressions, suggesting that multicollinearity is not a major issues. Given that the modified Wald statistic highlighted the presence of heteroskedasticity in the residuals, all regressions use robust standard errors.

4. Results

4.1. Descriptive statistics and regression analysis

Descriptive statistics of the variables used in the analysis are reported in table A.5, while the correlation matrix is reported in table A.6 (see the appendix).

The values of participation in different stages of the value chains are positively correlated among them: countries with high values of exports in final products have, on average, high values of exports also in the other stages of the value chain. The measure of revealed comparative advantage in final products is also positively correlated with participation in all the stages of the values chain. However, this does not hold true for sub-assembly and components. In particular, countries with a higher RCA in sub-assembly show, on average, lower values of exports in the same stage of the value chain. This preliminary evidence already highlights that looking at absolute values (scale) and relative specialization may provide different insights on the patterns of countries' GVC participation.

Both the total number of patents and the IS indicator are positively correlated with exports (in all stages of the value chain) but show a negative correlation with the RCA in sub-assembly and components. All-in-all, this evidence points to different relationships between the strength of the innovation system, and absolute and relative advantages in GVC. The regressions will test these preliminary observations in a multivariate framework.

In table 2 we report the regression results for absolute participation i.e. export values. First, we include only patents, then only the IS quality index and finally both regressors together; this approach allows us to obtain a first insight on the stability of the relationships at stake.

Unexpectedly, when controlling for other factors and country unobservable' features, the coefficient of the *patents* variable is never statistically significant. On the contrary, the coefficients of the *IS quality* indicator are statistically significant (and do not vary with the inclusion of *patents* in the regression): while

[8] Available at: https://data.worldbank.org/indicator.
[9] Available at: https://www.sipri.org/databases.

we find a positive relationship with absolute participation in final products and sub-assembly, this turns out to be negative for components. This finding suggests that countries with well developed IS tend to participate in more complex segments of the value chain.

Table 2: Absolute advantages (exports) in different stages of the GVC: two-way fixed effect regression

	Final Products			Sub-assembly			Components		
IS variables									
Patents	0.137		0.0653	0.0126		-0.0196	0.0046		0.0240
	(0.145)		*(0.158)*	*(0.048)*		*(0.053)*	*(0.059)*		*(0.066)*
IS quality		0.184*	0.161**		0.0652*	0.0722**		-0.0300**	-0.0396**
		(0.090)	*(0.071)*		*(0.036)*	*(0.037)*		*(0.013)*	*(0.020)*
Controls									
Military expenditure	-1.371**	-1.330**	-1.324**	0.764***	0.789***	0.786***	0.615**	0.602**	0.604**
	(0.625)	*(0.625)*	*(0.626)*	*(0.204)*	*(0.204)*	*(0.204)*	*(0.258)*	*(0.258)*	*(0.259)*
GDP per capita	1.805**	1.781**	1.748**	-0.482	-0.522	-0.511	-0.181	-0.154	-0.166
	(0.719)	*(0.715)*	*(0.720)*	*(0.337)*	*(0.335)*	*(0.337)*	*(0.301)*	*(0.300)*	*(0.302)*
Export diversification	1.360**	1.309**	1.321**	0.566***	0.550**	0.547**	-0.313*	-0.302*	-0.296*
	(0.648)	*(0.647)*	*(0.649)*	*(0.214)*	*(0.214)*	*(0.214)*	*(0.148)*	*(0.148)*	*(0.149)*
Country fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Constant	12.29***	12.64***	12.75***	18.11***	18.38***	18.35***	16.10***	15.93***	15.97***
	(4.673)	*(4.673)*	*(4.688)*	*(1.548)*	*(1.548)*	*(1.552)*	*(1.985)*	*(1.991)*	*(1.997)*
Observations	359	359	359	366	366	366	373	373	373
N. countries	38	38	38	38	38	38	38	38	38
R-squared	0.212	0.215	0.215	0.406	0.410	0.410	0.196	0.197	0.197

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10

A look at the control variables provides additional interesting insights. The *export diversification* is significant and positive for final products and sub-assembly but negative for components, suggesting that countries do not simply move within the value chain, but most probably add new and more complex products to their export basket. Similarly, economic development is positively related to final product exports but not significantly related with exports in the other stages of the GVC. Finally, the results on *military expenditure* reveal an interesting pattern, which can at first seems counterintuitive. Military spending is positively related to absolute participation in the complex stages of the GVC, but negatively related to final products exports, possibly due to sovereignty and production of strategic final products for internal military purposes.

In table 3 we report the regression results for relative specialization, i.e. RCA. Again, the variable on patents does not show statistically significant coefficients, while the IS quality indicator shows a pattern similar to that obtained in the previous analysis. The quality of the sectoral IS is positively related to the relative specialization in final products and negatively to the specialization in components, but we do not find a statistically significant relationship for sub-assembly. All-in-all, our results point to the existence of different relationships between the quality and strenght of the sectoral IS and a country's specialization in different segments of the GVC: a country's specialization in more complex stages of the value chain seems to be explained by the higher quality of national innovation systems rather than by a larger number of patents (quantity).

The relationship between economic development and participation (specialization) in more complex stages of the GVC is confirmed, as well as the positive association with export diversification. Military spending has a positive effect on the specialization in components, but negative in sub-assembly and not significant for final products. Taken together with the previous results, military spending may be functional to enter the GVC, but does not seem to help in moving up towards high value-added stages.

Table 3: RCA into different stages of the supply chain: two-way fixed effect regression

	Final Products			Sub-assembly			Components		
IS variables									
Patents	0.0248		0.0045	-0.0546		-0.0772	0.0444		0.136
	(0.031)		*(0.034)*	*(0.045)*		*(0.051)*	*(0.078)*		*(0.087)*
IS quality		0.0433*	0.0415**		0.0154	0.0463		-0.133*	-0.187**
		(0.025)	*(0.021)*		*(0.042)*	*(0.046)*		*(0.070)*	*(0.078)*
Controls									
Military expenditure	-0.201	-0.190	-0.189	-0.357*	-0.338*	-0.344*	0.819**	0.755**	0.765**
	(0.135)	*(0.135)*	*(0.135)*	*(0.198)*	*(0.199)*	*(0.198)*	*(0.341)*	*(0.340)*	*(0.339)*
GDP per capita	0.409***	0.396**	0.394**	-0.0960	-0.151	-0.113	-0.638**	-0.502*	-0.568*
	(0.158)	*(0.157)*	*(0.158)*	*(0.231)*	*(0.231)*	*(0.232)*	*(0.299)*	*(0.315)*	*(0.297)*
Export diversification	0.332**	0.312**	0.313**	0.903***	0.902***	0.882***	-2.639***	-2.591***	-2.557***
	(0.130)	*(0.130)*	*(0.130)*	*(0.190)*	*(0.191)*	*(0.191)*	*(0.328)*	*(0.327)*	*(0.327)*
Country fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Year fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Constant	-2.086**	-1.955*	-1.947*	5.502***	5.784***	5.657***	1.817	0.966	1.189
	(1.038)	*(1.039)*	*(1.042)*	*(1.525)*	*(1.533)*	*(1.532)*	*(2.626)*	*(2.622)*	*(2.620)*
Observations	373	373	373	373	373	373	373	373	373
N. countries	38	38	38	38	38	38	38	38	38
R-squared	0.099	0.104	0.104	0.197	0.194	0.200	0.213	0.221	0.227

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10

4.2. Reading the results from a country perspective

The results point out the importance of considering the different nuances of countries' IS besides simply measuring "technological strength" as the number of patents. Countries better placed in the export of downstream products in the supply chain are also those with the more developed and higher quality IS.

Two main features emerge in the innovation-GVC relationship in the aerospace industry: *(i)* the importance of the scale and scope of the IS (the diversification of patents among actors and technologies), and *(ii)* the importance of Prime Contractors (NIOSI; ZHEGU, 2010).

Most successful countries tend to conjugate both attributes, as the three most competitive countries show. USA, France, and Germany benefit both from having main Prime Contractors (e.g., Boeing and Airbus) and a large number of companies operating in Tier 1 and 2 within a strong innovation system. A counterexample is represented by the Brazilian case which, despite having a world-level Prime Contractor (Embraer), is not able to exploit scale and scope economies to develop differentiated exports and to benefit from its innovation system.

For countries specialized in sub-assemblies, the options to improve competitiveness and enter in more complex segments of the GVC may be different. When the development of the innovation system is too challenging, the suppliers' learning opportunities from buyers from GVC relationships may be more important (BIGGIERO; SAMMARRA, 2010; COOKE; EHRET, 2009; REBOLLEDO; NOLLET, 2011; SAMMARRA; BIGGIERO, 2008). However, the risk of lock-in in lower stages of the GVC must be seriously considered.

Cooke and Ehret (2009) highlighted the importance of technological capabilities and competencies in the Welsh aerospace industry for the Airbus decision to outsource part of the production there, *"...the availability of well-developed skills is crucial to the success of the Airbus supply chain and other aerospace firms"* (COOKE; EHRET, 2009, p.549). In Mexico, on the contrary, Romero (2011) observes that Mexican advantages are mainly related to manufacturing, and "*...policy measures seem insufficient to encourage firms to undertake more complex activities*" (ROMERO, 2011, p.303). It seems that the real challenge for developing countries that have developed a production of low complex products thanks to the fragmentation of the aerospace GVC, is to increase their technological capabilities to enter more complex stages of the value chain. Government policies would need to ensure access to the potential offered by GVC participation to improve local capabilities. In turn, this is expected to have an effect on the IS through the enhanced demand of a better system from local suppliers (Lema et al., 2019) and should be coupled with a simultaneous strategy to strengthen the sectoral IS with appropriate policies.

5. Conclusions

In this study we have analysed the relationship between a country innovation system and its competitiveness in different stages of the GVC with a specific focus on the aerospace industry.

To quantify and qualify a country participation in the GVC we followed previous evidence pointing to the hierarchical governance structure of the aeronautics industry, dominated by leading companies that maintain a stable control over the value chain and the knowledge flows. The process of industry upgrading in the GVC has been measured through a country participation to and the relative specialization in the different stages of the value chain, where downstream stages (closer to the market) are intrinsically related to increasing technological complexity.

Our econometric results corroborate our initial conjectures: the relationship between countries' competitiveness and innovation system in the aerospace industry is stage dependent. The quality of the IS plays a stronger role for countries' competitiveness in the downstream stages of the value chain.

Reinforcing the integration of local IS will provide firms with the necessary knowledge to improve their capabilities and enter higher value-added stages of the value chain. As the link between GVC participation and innovation capacities is not necessarily positive (LEMA et al., 2021), countries should pursue innovation policies to leverage the possible benefits deriving from the internationalization of their companies and not taking them for granted.

The hard task for those countries specialized in components and sub-assemblies – mainly developing countries with weak IS – is to strengthen their national systems to boost local firms' learning from the interaction with foreign suppliers and buyers. The risk of lock-in in low value stages of production may be moderated by appropriate policies to strengthen the innovation system. In this framework, government policies may have a crucial role in supporting riskier and more uncertain activities (e.g., through technology transfer, R&D subsidies and support, or public procurement) to increase the technological content of products, besides strengthening the overall innovative environment (e.g. learning access to specialized skills, extension and incubation services, financial resources and local research inputs).

A limitation of our study derive from the assumption of a positive relationship between GVC stages, proxied with export data, and value-added among countries (BAMBER; GEREFFI, 2013; BAMBER et al., 2016). We are aware that the association may be heterogeneous across countries, depending on the specific components (and the relative technology) produced and exported. Our findings would need to be complemented with the analysis of firm-level production and transaction data, which are unfortunately very difficult to be accessed.

Despite that, the evidence presented points to a positive relationship between the strength and quality of an innovation system and the comparative advantages in the downstream phases of the aeronautics value chain. This in turn suggests that government policies sustaining innovation and knowledge spillovers in the aerospace industry may help taking advantage of the international fragmentation of production that increasingly characterize this sector.

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ANNEX

Table A.1 – List of countries included in the regression analysis

Australia	Germany	Netherlands	South Africa
Austria	Hungary	Norway	Spain
Belgium	India	Philippines	Sweden
Brazil	Ireland	Poland	Switzerland
Canada	Israel	Portugal	Thailand
China	Italy	Rep. of Korea	Turkey
Czechia	Japan	Romania	Ukraine
Denmark	Malaysia	Russian Federation	United Kingdom
Finland	Mexico	Saudi Arabia	USA
France	Morocco	Singapore	

Table A.2 - Classification of products in the stages of the Aerospace industry value chain

VC stage	HS Product category	HS code	Description
Final products	Balloons	880100	Balloons and dirigibles; gliders, hang gliders and other non-powered aircraft.
	Helicopters	880211	Helicopters; of an unladen weight not exceeding 2000kg
		880212	Helicopters; of an unladen weight exceeding 2000kg
	Airplanes	880220	Aeroplanes and other aircraft; of an unladen weight not exceeding 2000kg
		880230	Aeroplanes and other aircraft; of an unladen weight exceeding 2000kg but not exceeding 15,000kg
		880240	Aeroplanes and other aircraft; of an unladen weight exceeding 15,000kg
	Spacecraft	880260	Spacecraft; (including satellites) and suborbital and spacecraft launch vehicles
Sub-assemblies	Landing gear	880320	Aircraft and spacecraft; under-carriages and parts thereof
	Aircraft parts & assemblies (generic)	880330	Aircraft and spacecraft; parts of aeroplanes or helicopters n.e.c. in heading no. 8803
	Propellers & rotors	880310	Aircraft and spacecraft; propellers and rotors and parts thereof
	Other parts	880390	Aircraft and spacecraft; parts thereof n.e.c. in chapter 88
	Main engine (propulsion)	840890	Engines; compression-ignition internal combustion piston engines (diesel or semi-diesel engines), of a kind used for other than marine propulsion or the vehicles of chapter 87
		841111	Turbo-jets; of a thrust not exceeding 25kN
		841112	Turbo-jets; of a thrust exceeding 25kN
		841121	Turbo-propellers; of a power not exceeding 1100kW
		841122	Turbo-propellers; of a power exceeding 1100kW
		841181	Turbines; gas-turbines (excluding turbo-jets and turbo-propellers), of a power not exceeding 5000kW
		841182	Turbines; gas-turbines (excluding turbo-jets and turbo-propellers), of a power exceeding 5000kW
	Other engines (other on-board engines)	840710	Engines; for aircraft, spark-ignition reciprocating or rotary internal combustion piston engines
		841210	Engines; reaction engines, other than turbo-jets
	Launching gear	880510	Aircraft launching gear, deck-arrestor or similar gear and parts thereof
	Ground trainers	880521	Ground flying trainers and parts thereof; air combat simulators and parts thereof
		880529	Ground flying trainers and parts thereof; other than air combat simulators and parts thereof
	Interior	940110	Seats; of a kind used for aircraft
Components	Main engine	841191	Turbines; parts of turbo-jets and turbo-propellers
		841199	Turbines; parts of gas turbines (excluding turbo-jets and turbo-propellers)
	Other engines	840910	Engines; parts of aircraft engines (spark-ignition reciprocating or rotary internal combustion piston engines)
	Landing gear	401130	Rubber; new pneumatic tyres, of a kind used on aircraft
		401213	Retreaded tyres; of a kind used on aircraft
	Electronic instruments	901420	Navigational instruments and appliances; for aeronautical or space navigation (excluding compasses)

Source: authors' elaboration based on Bamber and Gereffi (2013) and Bamber et al. (2016).

Table A.3 - IPC classes related to the aerospace industry included in this study

IPC code	Description
B64B	Lighter-than-air aircraft
B64C	Aeroplanes; helicopters
B64D	Equipment for fitting in or to aircraft; flying suits; parachutes; arrangements or mounting of power plants or propulsion transmissions in aircraft
B64F	Ground or aircraft-carrier-deck installations specially adapted for use in connection with aircraft; designing, manufacturing, assembling, cleaning, maintaining or repairing aircraft, not otherwise provided for; handling, transporting, testing or inspecting aircraft components, not otherwise provided for
B64G	Cosmonautics; vehicles or equipment therefor
G01W 1/08	Aircraft for meteorological use
G05D 1/00	Control of position, course or attitude of aircraft
A62C 3/08	Fire prevention, containment or extinguishing specially adapted for particular objects or places in aircraft
G01C	Measuring course or position of aircraft
A47C	Seats for aircraft
G09B	Teaching the control of aircraft
E06B	Windows for aircraft
G01C 21/24	Measuring course or position for cosmonautics
F02K	Jet-propulsion plants

Source: authors' elaboration

Table A.4. results of the principal component analysis

Principal components/correlation		Number of obs		373
		Number of components		3
		Trace		3
Rotation: (unrotated = principal)		Rho		1
Component	*Eigenvalue*	*Difference*	*Proportion*	*Cumulative*
Comp1	1.675	0.780	0.558	0.558
Comp2	0.895	0.465	0.298	0.857
Comp3	0.430	.	0.143	1.000
Principal components (eigenvectors)				
Variables	*Comp1*	*Comp2*	*Comp3*	*Unexplained*
Diversification	0.668	-0.177	-0.723	0.000
1-HHIp	0.640	-0.358	0.680	0.000
Originality	0.379	0.917	0.126	0.000

Table A.5. Descriptive statistics of the variables included in the regression analysis

	Mean	**Median**	**S.D.**	**Min**	**Max**
Dependent variables					
Exports of final products (log)	19.38	19.22	2.69	4.96	24.90
Exports of sub-assembly (log)	20.87	20.84	1.52	15.31	24.25
Exports of components (log)	19.69	19.70	2.07	11.76	23.23
RCA in final products	0.50	0.32	0.51	0.00	2.04
RCA in sub-assembly	1.44	1.50	0.66	0.00	2.99
RCA in components	1.37	0.92	1.23	0.00	6.64
Independent variables					
IS quality indicator	0.00	0.11	1.29	-2.43	3.96
Patents (log)	2.87	2.77	1.97	0.00	8.66
Military expenditures (log)	9.34	9.06	1.38	6.90	13.53
GDP per capita (log)	9.93	10.29	1.06	6.91	11.54
Export diversification	0.67	0.71	0.16	0.05	0.97

Table A.6. Correlation matrix: variables used in the regression analysis

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Exports of final products (log)	1									
2. Exports of sub-assembly (log)	0.517	1								
3. Exports of components (log)	0.420	0.807	1				← Dependent variables			
4. RCA in final products	0.805	0.145	0.064	1						
5. RCA in sub-assembly	-0.666	-0.181	-0.454	-0.747	1					
6. RCA in components	-0.327	0.001	0.494	-0.485	-0.200	1				
7. IS quality indicator	0.463	0.252	0.137	0.226	-0.270	-0.217	1			
8. Patents (log)	0.307	0.112	0.295	0.141	-0.306	-0.039	0.908	1		
9. Military expenditures (log)	0.372	0.671	0.517	0.173	-0.127	0.097	0.548	0.659	1	
10. GDP per capita (log)	0.342	0.130	0.161	0.110	-0.252	-0.159	0.413	0.392	-0.115	1
11. Export diversification	0.268	0.439	0.053	0.108	-0.242	-0.163	0.280	0.311	0.243	0.012

Table A.7: Absolute and relative participation: two-way fixed effect regression including the second component from the PCA

	Final Products		Sub-assembly		Components	
IS variables	Absolute Value	RCA	Absolute Value	RCA	Absolute Value	RCA
Patents	0.0389	-0.0218	-0.0359	-0.0321	0.0248	0.104
	(0.166)	*(0.036)*	*(0.055)*	*(0.053)*	*(0.070)*	*(0.091)*
IS quality	0.206*	0.0826**	0.0997*	-0.0242	-0.0408*	-0.138*
	(0.115)	*(0.036)*	*(0.0547)*	*(0.0528)*	*(0.0235)*	*(0.081)*
PCA component 2	-0.0476	-0.0437**	-0.0288	0.0749***	0.001	-0.0521
	(0.0905)	*(0.0196)*	*(0.0296)*	*(0.0287)*	*(0.0378)*	*(0.0495)*
Controls						
Military expenditure	-1.326**	-0.204	0.782***	-0.339	0.604**	0.748**
	(0.627)	*(0.134)*	*(0.205)*	*(0.197)*	*(0.259)*	*(0.340)*
GDP per capita	1.710**	0.372**	-0.530**	-0.0765	-0.165	-0.594
	(0.724)	*(0.157)*	*(0.238)*	*(0.230)*	*(0.303)*	*(0.397)*
Exports diversification	1.283*	0.284**	0.522**	0.932***	-0.295	-2.591***
	(0.653)	*(0.130)*	*(0.216)*	*(0.191)*	*(0.251)*	*(0.329)*
Country fixed effects	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
Year fixed effects	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
Constant	13.25***	-1.508	18.64***	4.905***	15.96***	1.712
	(4.788)	*(1.054)*	*(1.581)*	*(1.546)*	*(2.035)*	*(2.666)*
Observations	359	373	366	373	373	373
No. of countries	38	38	38	38	38	38
R-squared	0.216	0.118	0.412	0.217	0.197	0.230